Evaluation of an Animal Warning System Effectiveness Phase Two - Final Report

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Phase Two - Final Report

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ABSTRACT

The problem of vehicle/animal crashes is one of the few areas in which the number of incidents is climbing steadily in recent years. This issue is addressed in this research. There have been a few new technologies, all with their own strengths and shortcomings that claim to accurately detect the large animals that cross our roadways. No single technology is suited for every site, and close attention must be given to any selected site based on its weather, vegetation, topography, and local animal types and sizes. In the first phase of this project, we selected a test site in Northern California along State Route 3 near the city of Fort Jones, and installed an animal detection system that deploys microwave break-a-beam technology to detect objects crossing the roadside, including the local deer. 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 phase two, we collected 10 months of baseline and actual data to analyze the effectiveness of our PATH Animal Warning System (PAWS). In addition, we analyzed test results for reliability of the selected animal detection system at a controlled access facility (in Lewiston Montana) and at our California test-bed (SR3). We also conducted an online survey to learn about drivers' experiences with the system as well their opinions of the system.

Key Words: **ITS, Intelligent Transportation Systems, Vehicle Animal Crashes, Animal Wildlife Detection Systems, Animal Warning Systems, Human Factors, Driving Behavior, Public Opinion**

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EXECUTIVE SUMMARY

This report is for Phase Two of "Evaluation of an Animal Warning System Effectiveness" project that was done under an agreement between Caltrans and California PATH Program with Award Number of 65A0349. Western Transportation Institute of Montana State University was the subcontractor to this project. This report represents the data analysis to determine the effectiveness of PATH Animal Warning System (PAWS)and the reliability of the selected animal detection system. The number of animal-vehicle collisions is one of the few areas of surface transportation that safety is not improving. As more developments require more roads to be built, the areas that animals inhabit are shrinking and thus causing more crashes between vehicles and animals. The increases in human and animal fatalities and injuries as well as material costs of these crashes necessitate 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 to bad detection. The communication of the threat to the driver involves the amount of information that can be delivered about a threat in a timely manner and how easily it can be understood.

The eventual goal of this project was 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 animal warnings signs. During this first phase, we have selected a site that covers roughly 5/8 of a mile of a section of State Route 3, on both sides of the road, near the town of Fort Jones in Northern California. Based on the characteristics of the chosen site, an animal detection system using break-a-beam microwave system was selected to provide input for our PAWS animal warning system. Then, the test-bed was constructed and the system was installed. Furthermore, we developed PAWS Monitoring system and PAWS Data Acquisition System (DAS). The PAWS Monitoring System provides a quick and easy way to see at a glance how all the System components are functioning. In addition, it allows researchers to quickly see if the PAWS animal warning system has detected any recent events. The PAWS Data Acquisition System (DAS) collects and archives the data that combines the triggers received from animal detectors to the animal warning signs with the data collected from the vehicular radars and videos to measure the driver's response to these warning signs.

As the first task for Phase Two, we had to repair the system that was left unattended for a period of almost 9 months between the end of Phase One and start of Phase Two. This unavoidable and unaccounted time gap was due to contractual delays between our university and Caltrans. Then, we had to deal with the problems that were caused when a vehicle crashed with one of the poles on the test site, causing major damage. We also improved the PAWS monitoring system and PAWS Data Acquisition System (DAS).

The main goal of PATH's part of this study was to try to understand whether or not the dynamic animal warning signs triggered by the PAWS system influenced the behavior of the drivers in the test site. In general, an experimental design must designate some conditions as baseline driver behavior and some conditions as the treatment for comparison. This study employed two different and complementary experimental designs to try to understand whether or not the dynamic animal warning signs influenced driver behavior.

The research team collected about 10 months of data. In the first analysis, the baseline conditions consisted of PAWS events or warning signs activations over the first 2.5 months of the study. During this time period (baseline study), the dynamic animal warning signs were covered so that drivers could not see them, even though the PAWS system was fully operational. The treatment conditions consisted of PAWS events or warning signs activations over the remaining 7.5 months of the study after the dynamic animal warning signs were uncovered, allowing drivers to see them.

One hypothesis proposed by this study was that the dynamic animal warning signs might reduce the traffic speeds when illumined, and this was confirmed. Mean traffic speeds were reduced from 56.2 mph during PAWS events when the warning signs were covered to 53.1 mph during PAWS events when the warning signs were illuminated. The dynamic animal warning signs appeared to be even more effective in the evening and overnight hours with an average mean speed reduction of 4.9 mph. Using this same methodology, mean and peak vehicle deceleration rates were also examined, but the interpretation of this data was less clear.

While the first experimental design provided for the most direct comparison between like conditions, there is always a possibility for driver adaption over time or other time-based effects to influence data when the baseline conditions occur early in the course of a long study. In order to mitigate these, a second analysis was conducted using a different experimental design. In this design, the time segment just prior to a PAWS event was used as a measure of the baseline conditions. By comparing traffic speeds just prior to an event with the traffic speeds during a PAWS event, a baseline that is not limited to the beginning of the 10-month study could be established. However, this second experimental design is not without criticism. During the pre-event baseline conditions, no wildlife was presumably detected, while during the event warning conditions, wildlife was presumably detected. Thus, using this methodology, the differences in mean speeds might be due either to drivers reducing their speed to be more cautious or drivers reducing their speed because they have actually spotted wildlife in the roadway.

Using this second experimental design, the analysis concluded once again that the illumination of the dynamic animal warning signs was associated with a reduction in the mean vehicle speeds through the test site. The mean pre-event speed was 58.3 mph while the mean speed while the animal warning signs were illuminated was 53.1 mph, resulting in a 5.1 mph speed reduction. Furthermore, the speed reduction remained relatively constant, ranging from 4.5 to 5.8 mph throughout the 7.5 months of the study following the uncovering of the dynamic animal warning signs. Also, similar to what was seen using the first experimental design, the mean speed reductions tended to be greater in the evenings and overnight.

Overall, the results of the two different experimental methodologies agreed that there was some reduction in the mean speeds of the drivers when the dynamic animal warning signs were illuminated, and those speed reductions were greater during the evening, overnight, and early morning hours when deer and other wildlife tend to be more active. There was also some hint of evidence that the declaration rates required when drivers spotted animals on the roadway may also have been reduced, but this conclusion was less strong and would require a more detailed analysis to further understand. Finally, it can also be concluded that there was no evident driver adaptation over time to the warnings provided by the PAWS system. The reductions in mean speed continued throughout the 7.5 months of the study when the dynamic animal warning signs were uncovered.

There were two separate evaluations of the reliability of animal detection systems: one off-site at Lewistown, Montana, and one at the test site along California State Route 3. The system that was selected is a microwave break-the-beam system manufactured by ICx Radar Systems (Scottsdale, AZ). The off-site reliability test took place at a test-bed specifically constructed to investigate the reliability of animal detection systems. The test-bed consisted of an animal enclosure, space for multiple animal detection systems, and six infrared cameras with continuous recording capabilities. 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 number of false positives was relatively low but the number of false negatives was relatively high. The percentage of all intrusions in the detection area that was detected was relatively low. Based on the values for the reliability parameters, the system does not meet the recommended minimum norms for the reliability of animal detection systems. Specifically, the percentage of false negatives is too high, and the percentage of intrusions detected is too low. However, when the downtime of the system was excluded, the percentage of false negatives dropped to about 4%. This suggests that the system can meet the suggested norms for reliability if the beam remains operational. In conclusion, the substantial downtime of the system (7.67%) during the tests with animals is a major concern, suggesting that the system may not be operational for substantial lengths of time.

Further analysis of the data revealed more about the reliability of this animal detection system. Wind conditions play an important role in the ability of the system to correctly detect the presence of large mammals. Perhaps stronger winds caused the sensors to get slightly out of alignment. When the receiver does not receive a signal for a longer time period, the beam goes out of operation, allowing false negatives to occur. Higher temperatures were associated with an increase in false negatives. However, it is not clear how an increase in temperature would cause the radar detection system to generate more false negatives. There were relatively few false negatives during the night. This suggests that daylight is somehow associated with false negatives, but it is also possible that daylight is generally associated with stronger winds during the day at our test-bed site. Also, an increase in humidity was associated with an increase in false negatives. Interestingly, the animal species did not matter enough to be included in the top model. This suggests that the system detects species that resemble sheep, llamas, or horses in body size similarly. The results of this analysis suggest that it is very important that the poles and the sensors are firm and do not move in the wind.

For the test site, along State Route 3 in California, a human triggered the system at about 66 ft (20 m) intervals. The results indicated that the system is capable of detecting a human and therefore is likely to also be able to detect large ungulates such as black-tailed deer. While the system did not have any blind spots, three of the beams did show evidence of desensitizing during testing, even with at least three minutes between consecutive triggers. This means that while the system is likely to detect deer as they approach and leave the road, the system may not be triggered another time if an animal continuously blocks the beam or if multiple animals cross the beam. Since the warning signs are programmed to remain on for three minutes after the last detection, the desensitizing of the beams is likely to only affect a relatively small number of the deer crossings. Nonetheless, it is possible that deer could be on or near the road without the animal warning signs being activated. While this can be considered a problem, this phenomenon is also possible if the beams would not desensitize at all. For example, if an animal crosses a beam but then stays in the right-of-way (having fully passed the beam) or on the road for more than three minutes, the animal warning signs would also turn off with a deer still present.

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

The number of reported black-tailed deer carcasses along SR 3 in California appears to have declined from 2009 onwards. This decline occurred both in the control sections and the road section with the system. Assuming that the search and reporting effort for the carcasses indeed remained constant, this suggests that the black-tailed deer population in the area has declined in the last years. This is consistent with some of the remarks of the public. Given the relatively low number of large mammal carcasses, especially from 2009 onwards, the relatively short road section that has the system installed, and the relatively short time period during which the system was present with the warning signs attached, it is not really possible to conclude whether the animal detection system may have reduced the number of large mammal-vehicle collisions.

The researchers conducted a survey with regard to people's experiences with and opinions on our animal warning system. The survey targeted people who drove that particular road section when the animal detection system was installed and functioning. While the survey was linked to from a website that provided basic information about animal detection systems in general and about some of the characteristics of the specific system installed along SR 3, the survey was not preceded by an outreach campaign that provided information on the reliability and effectiveness of the system. The reliability and effectiveness data were not available until June 2012, at the end of the research project.

The results of the survey among drivers of the road section with the system along SR 3 in California indicated that most respondents want the system removed. The most common concerns relate to the cost of the system, the perception that the system is in the wrong location, the brightness of the warning signs at night, and the perception that the system is not reliable.

The system along SR 3 may well become more reliable, perhaps "sufficiently reliable," if certain modifications are made to the system. Since it is rare to have a reliable system with associated research equipment in place, the researchers suggest continuing the research into the reliability and effectiveness of the system after potential system modifications have been implemented. Only then can we, as a society, make progress with the design and implementation of these systems and learn whether they indeed have a future as an alternative to wildlife fencing in combination with wildlife

The current project was primarily a design, implementation, and research project. Most research projects take place outside of the view of the public, and the products are only shown to the public after extensive testing. Unfortunately, animal detection systems need to be installed along a real road to investigate their effectiveness, and not everyone may understand or accept that these systems may still have problems when they are first installed. In general, it is a good idea to investigate the reliability of a system at a closed-access facility before installing it along a real roadside. In addition, it is a good idea to investigate the reliability along a real roadside before attaching the warning signs, if the constraints of the project allow for this. This reduces both the likelihood of reliability issues and possible misunderstanding and annoyance by the public.

While this project did include a website with general information about animal detection systems and the system that was installed along SR 3, the current project was not a public education project. This project was mostly aimed at designing and installing the system and investigating its reliability and effectiveness in the time period that was available. The current project was not aimed at providing the public with information about the results of the study, as those results only became available towards the end of the project. If the system is to stay in place, and if system modifications are to be implemented, the researchers suggest a communication program that includes information on the system and the results of the study. Communication through a website and local and regional media are unlikely to be sufficient; it is desirable to have multiple public presentations in the area that allow for questions and discussion on relevant topics. Given the results of the survey it is especially important that the public is informed about funds associated with the research and development of animal detection systems vs. the actual costs of implementations if and when these systems are mass produced. It is also important to inform the public about the various parameters besides the number of large mammal-vehicle crashes that need to be considered when selecting a road section for an animal detection system.

Many respondents complained about perceived unreliability of the system, including false positives caused by vehicles turning on and off the road. The vast majority (93%) of all correct detections for which the cause was identified related to vehicles turning on and off the road. Before the project was initiated it was known that the system reports vehicles that break the beam as a detection. Therefore this is a design issue that may need to be revisited rather than a failure of the detection technology. The number of these "false positives" can be greatly reduced if vehicles turning on and off the road no longer result in activated warning signs. The researchers suggest installing a detection loop at the side roads. If a vehicle is detected, then the detection by the animal detection system can be declared "invalid" and the warning lights will not turn on. While there are two access roads in the road section with the system (in beam 3 and 4) one may choose to only install a loop at the access road that receives the highest use (Air Force Way in beam 3). Note that large wildlife species, including black-tailed deer, and humans will still trigger the system when they break the beam at the access road(s).

The researchers are of the opinion that the current project was able to measure the reliability of the animal detection system fairly well. Additional reliability research may be advisable after potential system modifications have been implemented. Without such data one cannot be sure if thresholds for reliability have been met and one cannot inform the public about the reliability of the system. The researchers are of the opinion that the current project did not allow sufficient time to investigate the effectiveness of the system with regard to large mammal-vehicle collisions. The researchers suggest monitoring large mammal carcasses in the control sections and in the road section with the animal detection system for multiple years (e.g., at least 3-5 more years) and then analyzing the data once again.

Finally, the research team suggests the success parameters and threshold values for an animal detection system project must be carefully defined. Being able to answer the research questions is obviously among the parameters. Other parameters can include thresholds for the reliability and effectiveness. While the experience and opinions of the public are very valuable in deciding on location, minimum performance criteria for reliability and effectiveness, and potential modifications to an animal detection system, public acceptance of or opinion on the long term future for animal detection systems should probably not be based on a system that may have design or reliability issues after its initial installation. It should probably be based on a strategic plan. The public can and probably should have a role in such a strategic plan but only if it is based on multiple systems that have been in place for considerable time in different regions where potential design and reliability issues have been corrected and where a public outreach communication plan has been executed to communicate about the purpose, reliability, and effectiveness of the system.

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1 INTRODUCTION

Project Background

According to one study, vehicular collisions with wildlife are the origin of 29,000 human injuries, 211 fatalities, and over one billion dollars in property damage every year (Conover et al. 1995). More recent data shows that there are more than 300,000 reported vehicle collisions with large animals each year. 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 either infrared camera or beam (laser or infrared) 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. As detailed above, the quality of the detection is the ratio of good detection to 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 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 in 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 to learn about near misses and not just concentrate on crashes that are in small numbers on any stretch of the road and are random in nature.

[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.

A 16-month project was conducted in order to achieve two objectives: i) study the effectiveness of animal warning systems to detect wildlife on the roadside, ii) measure driver's response to these systems. During the first phase, we installed a commercial product in order to detect deer in a section of California State Route 3 (SR3) near Fort Jones. We also developed a data collection system in order to evaluate the effectiveness of the system and study driver behavior. During the second phase, we evaluated the effectiveness of this system in terms of deer detection and driver response to our animal warning system. This final report is an evaluation of the overall effectiveness and benefit of the system.

Review of Wildlife-Vehicle Crash Mitigation Solutions

In the United States, it is widely agreed that the number of vehicle-animal crashes is on the rise. As more and more animal habitats are invaded by human development, the probability of vehicle-animal collisions is increasing. A crash involving a large animal like elk, moose, deer, cows, or the like can cause fatality, serious injury, and property damage. If a solution can be found that prevents or reduces this type of crash, then society can benefit both financially and in terms of human and animal lives saved.

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 at eliminating entire animal populations, so wildlife-vehicle collisions might occur less frequently but nevertheless still occur. 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 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 also wards off animals by producing ultrasonic waves. The Maxsa can be reactivated & deactivated from inside a vehicle.[3] 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.[4]

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

[3] http://www.autoanything.com/products/product_sp.aspx?p_id=1578&se=car_safety_deer_alert
[4] http://www.usroads.com/journals/rmj/9705/rm970503.htm

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 built tunnels or "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.[5] 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 animals can cross the road. Although controversial, expanded hunting seasons are also used to reduce the number of animal-vehicle collisions.

Yet another method is to detect the animal and use a trigger to dynamically activate warning signs to alert the driver to the presence of a large animal nearby. 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.[6] When animals are detected, flashing beacons on roadway signs are triggered and warn drivers to anticipate animals in the roadway.[7] 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.[8] Roadway signage and roadside light reflectors seem to help in the short term, but in the long term their effects seem to diminish.[9] Less is known about camera-based dynamic warning signs or other similar systems.

Review of the Use of Warning Signs for Wildlife Crossing

The Manual on Uniform Traffic Control Devices (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."[10] 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."[11]

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[5] http://www.usroads.com/journals/rmj/9705/rm970503.htm
[6] 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.
[7] Ibid
[8] Hedlund, 2004 (see lit review folder)
[9] Hedlund (see lit review)
[10] in MUTCD 2003 edition, p. 2C-1 http://mutcd.fhwa.dot.gov/pdfs/2003r1/Ch2C.pdf
[11] Ibid

A recent solution for keeping the use of warning signs at a minimum is to use variable message signs that can be triggered when the hazard is present. The use of these signs opens the range of possibilities to warn drivers, allowing for longer texts to be displayed, alternate between sign and text. Recent research in this domain showed that drivers tend to adapt their behavior in response to these signs. Rama and Kulmala (2000)[12], on a before/after study, noticed that the mean speed was reduced by 1 to 2 km/h in response to an iconic sign indicating a slippery road due to snow. The use of another sign specifying the gap to maintain with the lead vehicle also leads to a decrease of short gap. Luoma et al. (2000)[13] interviewed drivers who had encountered these signs and found out that the variable message signs had other benefits, such as refocusing drivers' attention to seek cues on potential hazard or more careful passing behavior.

Knapp et al. (2004)[14] 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 warning signs 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 "Deer on the road when flashing" signs.

Research Goals

This study addresses two transportation issues. First, the cost of wildlife collisions in terms of lost lives and material damage needs to be addressed. Second, the successful application of technology for solving this problem can potentially be transferred to other problems where an infrastructure-based solution can be applied.

This project aims at improving transportation safety by assessing the effectiveness of a wildlife warning system. In that sense, the first and most direct improvement will be in finding out if such a system is efficient for reducing crashes, which in turn will lead to a reduction of crashes state wide. A second and important outcome is the lesson learned through the evaluation of the system that could be transferred to the evaluation of other infrastructure-based systems providing dynamic information to drivers. Dynamic information can be a way to improve communication with drivers about road hazards and has the potential of a much higher effectiveness than any current permanent system in catching drivers' attention.

If this opportunity to address the evaluation of the system is not taken, the two main consequences are the lack of a possible solution for reducing wildlife crashes and installing a

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[12] Rama p. Kulmala R. (2000) Effects of variable message signs for slippery road conditions on driving speed and headways Transportation Research Part F 3 85-94
[13] Luoma J. Rama P. Penttinen, M. Anttila V. (2000), Effects of variable message signs for slippery road conditions on reported driver behaviour Transportation Research Part F 3 75-84
[14] 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

system without knowing firsthand what the benefit of that system is relative to its cost. For example, a very expensive solution such as fencing could be used while a cheaper and more efficient alternative could be available.

2 PROJECT TASKS

Task 1: Deer-Vehicle Collisions

A carcass gathering reporting system was established by which the carcass would be collected by Caltrans D2 crew and the data sent to WTI. While monitoring data does not require the report of all road-killed deer, they do provide a consistent search and reporting effort. We analyzed the deer road-kill data for a potential decrease after the installation of the system (comparison in time). We also analyzed deer road-kill data for the road sections with the system and adjacent road sections (comparison in space). The comparison in time is sensitive to potential fluctuations in deer herd size and other factors that may change over time. The comparison in space is sensitive to potential changes in local conditions between the road sections with the system and the road sections that serve as a control. We acknowledge that depending on the number and variability of the deer-vehicle collisions in the road section with the system it may take many years before conclusive evidence of a potential reduction in deer-vehicle collisions can be presented. The proposed length of the project (16 months) was too short to gather data that would allow for conclusive results.

Task 2: Driver Behavior Observation

Once the system met the minimum criteria for reliability and once the baseline data on driver behavior had been gathered, the animal warning signs were turned on. Two or three months after the animal warning signs had been turned on, we investigated the effect of activated warning signs on vehicle speed and driver behavior under any road and weather conditions. The three-month delay allowed local drivers to become familiar with the purpose and function of the system. Once local drivers learn to trust the system, their response may be stronger and more consistent.

Subtask 2a: Observation of Driver Behavior Prior to the Activation of the Warning Signs

<u>Treatment 1: Baseline Driver Behavior</u>: Before the animal warning signs were turned on, we monitored driver behavior. For this setting, we used the operational animal detection part of the system only, but not the activated animal warning signs. The current conventional warning signs remained in place. We used video images in combination with the radar data to monitor the behavior of the driver. Hence, we will be able to measure the following:

- Treatment 1a: Driver behavior when deer are absent
- Treatment 1b: Driver behavior when deer are present

Treatment 1 data collection ran from August 3, 2011 to October 16, 2012.

Subtask 2b: Observation of Driver Behavior after the Activation of the Animal Warning Signs

<u>Treatment 2: Activated Animal Warning Signs:</u> The animal detection and driver warning part of the system were both installed and operational. However, for this setting we selected vehicles that entered the road section when there were deer present and when the warning signals were activated. The warning signs were initially activated for 3 minutes with reactivation for an added

3 minutes if the animal detection system is retriggered by animals within the original 3 minutes. As part of the analysis, a comparison between the data collected on driver's behavior for the first few months and the last few months of this subtask were done to look at possible diminishing effects after novelty of the system wore off.

Treatment 2 data collection ran from October 17, 2011 to May 30, 2012.

A huge amount of data from STS animal detectors, Omcon videos, SMS radars, and Animal Warning Signs were collected for this task. All of these data needed to be checked first for integrity and then synchronized. Due to the lack of sufficient funding and time allocation for the research team, not all of the collected data were used in our final analysis. Every effort was made to make sure that a representative sub-sample of collected data (more than half) was included in the final analysis.

If any component of our animal detection system and/or data collection system including radars, sensors, videos, data storage devices, wires, and so on was either stolen or broken throughout this project, the replacement equipment would be bought from the equipment budget in the budget sheet. If there was no need to purchase new or replace existing computers, the funding came from the "Computer" line item of the budget.

3 PATH ANIMAL WARNING SYSTEM (PAWS) DESIGN

Overview

The scope of this project is to assess the effectiveness of a wildlife detection system that can provide dynamic information to the driver. By dynamic, we mean that instead of providing a permanent warning, whether a threat is present or not, this system will allow warning drivers only when a threat is present. The intent of this approach will be to increase the likelihood to influence driver behavior. Current permanent warnings often become part of the landscape and hence are ignored by drivers, while messages that can be associated with an immediate threat will increase drivers' confidence in the system and awareness of the threat. Therefore, our three objectives are to:

- Evaluate the effectiveness of a commercially available system at detecting wildlife.
- Deploy a warning sign that will convey to the driver that a specific threat (deer) is present and what behavior to adopt.
- Evaluate the effectiveness of the system on influencing driver behavior.

This research project involves the selection of two specific technologies: one for the animal warning system and one for the data collection system.

Prevention of wildlife-vehicle collisions: The range of solutions for avoiding wildlife-vehicle collisions may include whistles, fencing, under/overpasses, and driver warning systems. As specified in the request for proposal, a special interest should be given to driver warning systems. Two technologies are currently used in this domain: "break the beam" systems and video-based systems. For this project we chose a break-the-beam system from *ICx Radar Systems* called STS Animal detection System.

Data recording system: The goal of the data recording system is to monitor driver behavior. We used a combination of video and radars for this purpose to provide inputs for our Sensor Input Coordination and Reporting System. Here, we planned on being able to associate presence of an animal with driver behavioral changes. The video images support the identification of vehicles and vehicle movement and sometimes the presence of the animals, while the radar data provide accurate continuous speed measurements. The video system selected for this project is from OMCON, and the vehicular radars are from SmartMicro Systems. The animal warning sign is an LED sign depicting a deer that was made by ElectroTech.

PAWS Data Monitoring and Recording System

PAWS data monitoring and recording system was designed to collect the data from our sensors, review the data for their fidelity and robustness, and then archive the data for future processing.

3.1.1 System and Equipment Design

The installed system has seven radars, six camera, four animal warning signs, a PAWS computer, and 6 pairs of animal detection heads that results in 6 invisible beams, three on each side of the road. The length of the test-bed is 1070 meters or roughly 2/3 of a mile. Below, there is a brief explanation about each system component followed by a schematic of a typical pole installation.

3.1.2 SMS Radars

The SMS radar system was installed and calibrated in September of 2009 with the help of a SMS support engineer. There are seven SMS radars with three one side of the road and four on the other. This configuration was used to maximize the coverage of theses radars given the number of available poles as well topography and geometry of the study site. Figure 3.1 shows a diagram of the SMS radar layout.

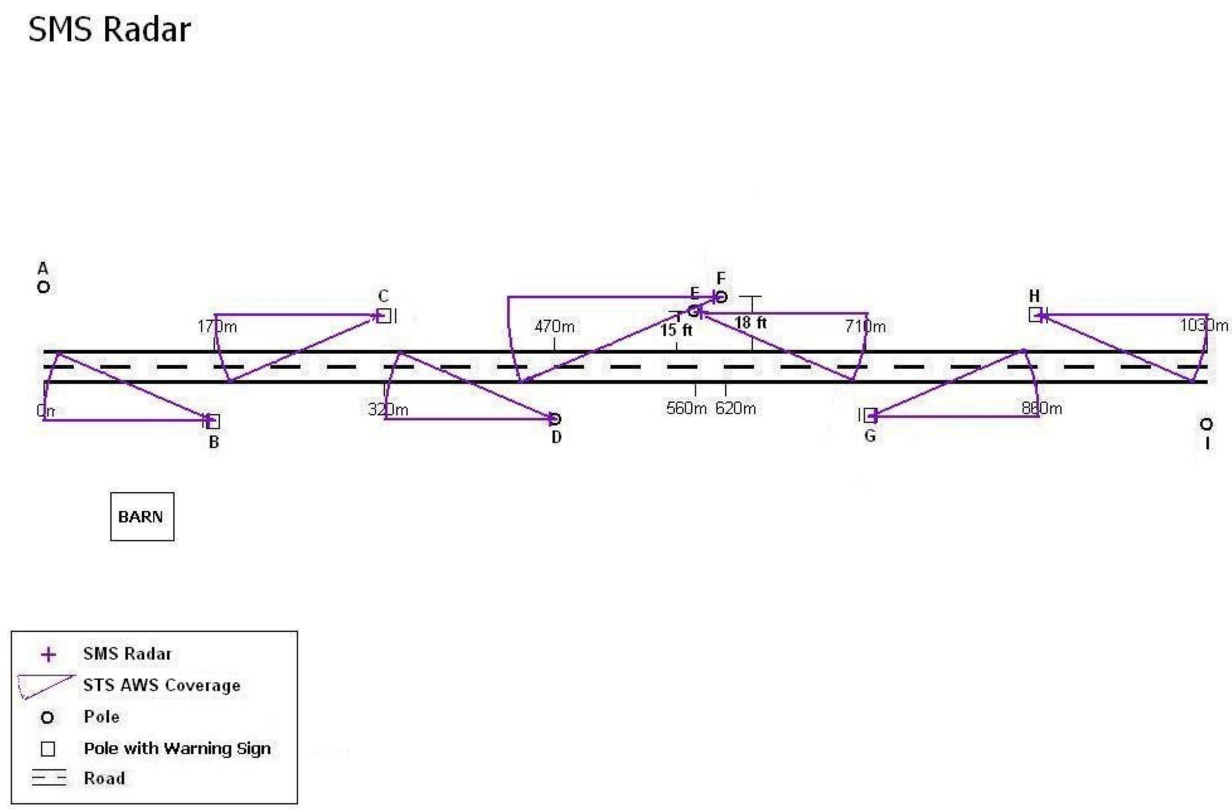


Figure 3.1: A Diagram of SMS Radar Layout.

3.1.3 Omcon Video Cameras

The Omcon video cameras were installed and calibrated in September of 2009. There are six Omcon videos, with three on each side of the road. This configuration was used to maximize the coverage of these videos given the number of available poles as well topography and geometry of the study site. Figure 3.2 shows a diagram of the Omcon video camera layout.

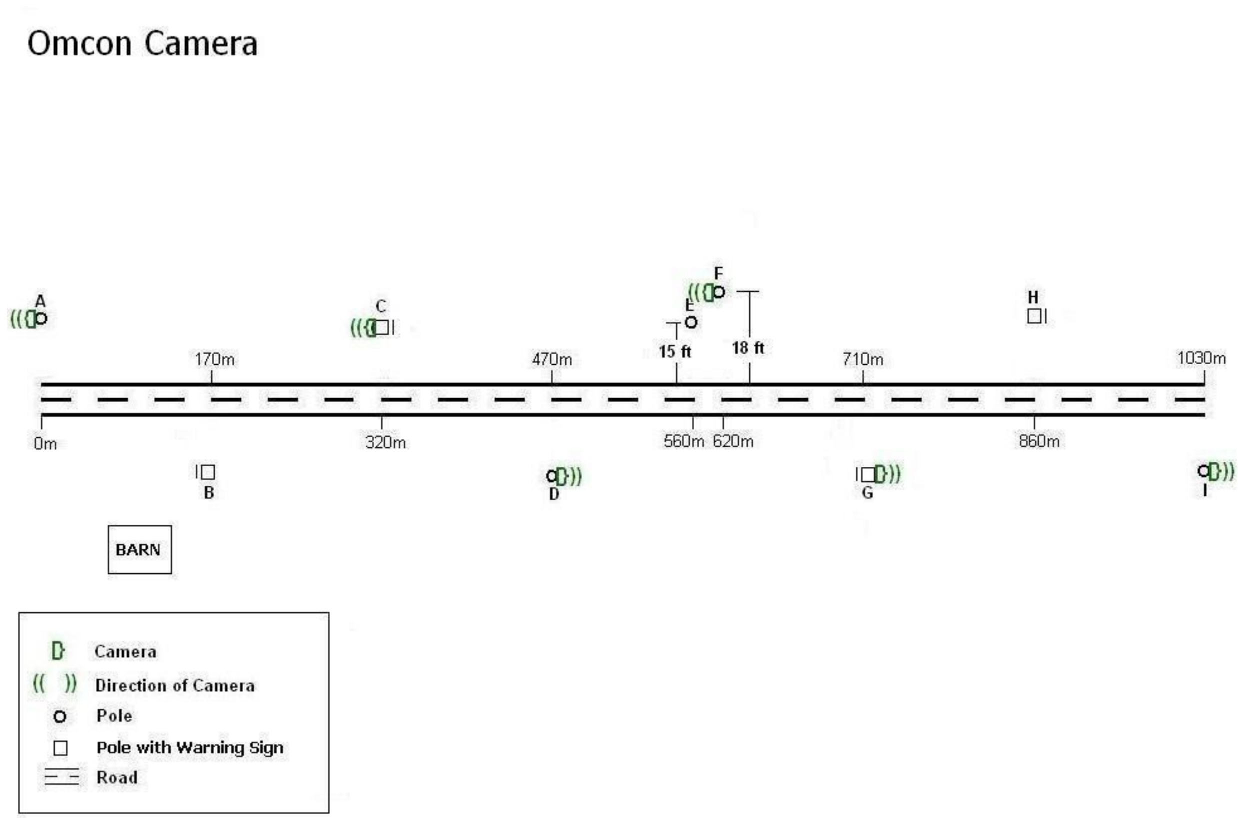


Figure 3.2: A Diagram of Omcon Video Cameras Layout.

3.1.4 *Animal Warning Signs*

The four animal warning signs were designed and manufactured by Electro-Tech. Two animal warning signs (see Figure 3.3) 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.

Figure 3.3: Installation of an Animal Warning Sign.

3.1.5 *PAWS Computer*

PAWS computer was built to PATH's specifications by Advanced Digital Logic Inc. and was installed in the road side NEMA cabinet.

3.1.6 *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. Figure 3.4 shows a diagram of the RADS, and Figure 3.5 shows a typical side view of the pole installations.

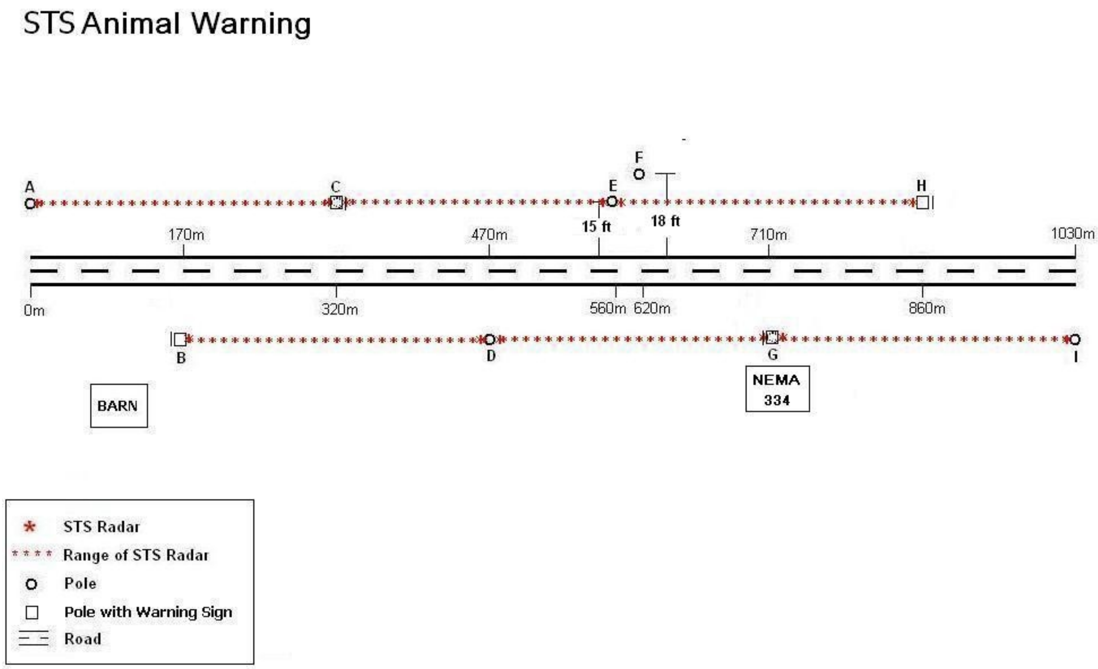
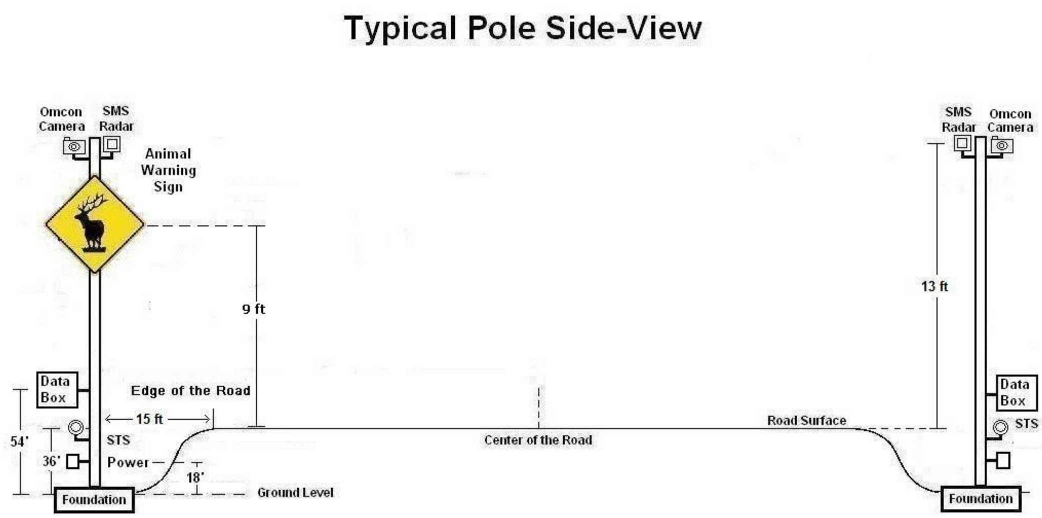


Figure 3.4: A Diagram of RADS System Layout.



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 3.5: Typical Pole Installation Side-View.

Fallen Pole H

On July 16, 2011, Pole H was hit by a car and fell on the ground. The equipment on Pole H included one SMS radar head, one animal warning sign, one STS animal detection transmitter, one NEMA box, one network switch, one power supply, and one circuit breaker that controls the power to Poles H and I. With the support from Caltrans D2, Pole H was re-installed, and broken parts including the power supply, the network switch, and the circuit breaker were replaced. However, a new STS transmitter could not be procured. The original inventor of the device and the company that currently owns it are in an intellectual property conflict, and a replacement could not be procured.

Figure 3.6: Pole H after Being Struck and Removed.

System Functional Description

Figure 3.4 depicts the layout of the installed animal detection system. Simply put any deer or object crossing through the detection lines will trigger the animal warning signs, causing them to flash a warning sign to the drivers for three minutes.

Since the detection system cannot track whether deer that passed the lines of detection have crossed the road, the animal warning signs have been designed to flash for three minutes in the event of beam breakage. If any beams were to be broken again within that time, the warning signs will flash for an additional three minutes from the time of the subsequent detection. The signs will stop flashing after three minutes even if the deer has crossed the line of detection but has not left the road.

The STS animal detection system cannot identify the object that is in the line of detection, so other animals of at least 3 feet in height besides deer, as well as tall brush, cars, and also humans, can break the beam and trigger the driver warning signs. This may surprise drivers when they see the warning signs are on but no deer in the vicinity of the roadway.

The layout of the animal detection system is designed for deer that are breaking detection beams by walking between poles and entering the road from either side. Sometimes, deer will walk along the road and enter our test-bed. In this scenario, the deer do not cross detection beams and drivers may see deer on the road even though the animal warning signs are not flashing. Deer could also enter the road where there are no beams on that side of the road, but there is one on the opposite side. This would also surprise drivers when they see deer on the road without activated warning signs. The situation was exacerbated by the loss of Pole H.

If an obstruction such as a car breaks and lingers in the detection zone, the broken beam would become desensitized and stop making attempts to reestablish itself after a few tries. Once the car moves out of the detection zone, the sensors need three minutes to re-sensitize before they can reestablish the beam.

Harsh weather conditions may have an impact on the reliability of the system. The reliability test conducted by WTI revealed that the substantial downtime of the system (40%) was due to a snowstorm that caused snow and ice to build up on the sensors, causing the beam to go out of operation. Once the snow and ice melted, the sensors resumed operation. Fortunately, we did not have the same snow accumulation at our test-bed, so our system was up nearly 100 percent.

4 PAWS MONITORING SYSTEM AND WEBSITE

Overview

The PAWS monitoring system provides a quick and easy way to see at a glance how all the System components are functioning. It also allows researchers to quickly see if the PAWS animal warning 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.

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 4.1.

Figure 4.1: Switch Management Menu.

Other components used by PAWS such as the SMS vehicular radars, the flashing driver 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 4.2 is a screen shot of the navigation bar of the monitoring system. Figure 4.3 is a screen shot of a Nagios webpage that provides an overview of the health of each individual component in its component group. The components are the cameras, the Linux Servers, the Animal Warning Signs, the SMS vehicle radars, the STS animal detection system, and the Network Switches. The checks that were added for each system component were as follows:

STS animal detection system:

- Checks messages to see if there is a fault indicated.
- Checks to make sure the monitoring system has received a message from the component within the last 120 seconds. (The component emits a heartbeat signal every 60s).
- Checks to make sure the system indicate its beam is online.
- Notifies when a beam break occurs.
- Notifies if data is received with an incorrect checksum.

Animal Warning Signs:

- If the sign is off, make sure there hasn't been a beam break in the last 3 minutes.
- If the sign is on, make sure there was a beam break in the last 3 minutes.

Cameras:

- Make sure the recording process is running.
- Make sure that the video file from the cameras is growing in size.

SMS Radars:

- Make sure that the smsparse daemon is running.

In Nagios, the status of each component is updated every 90 seconds, and the results are indicated as "OK" or "DOWN." The User can select each host to view detailed information for that component. Figure 4.4 is a screen shot of a Nagios webpage that provides detailed host information of PAWS computer. The information includes the status of each service, the time and date of the last check that was performed, the duration for which the service has been at its current status, the attempts, and a detailed status description.

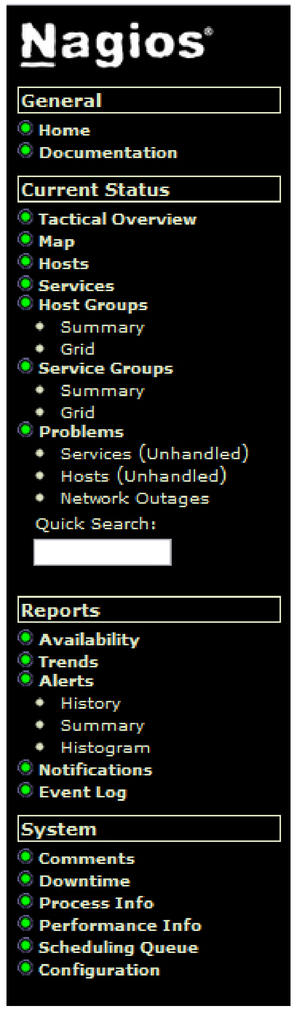


Figure 4.2: Nagios Navigation Bar.

Figure 4.3: Nagios Overview by Component Group.

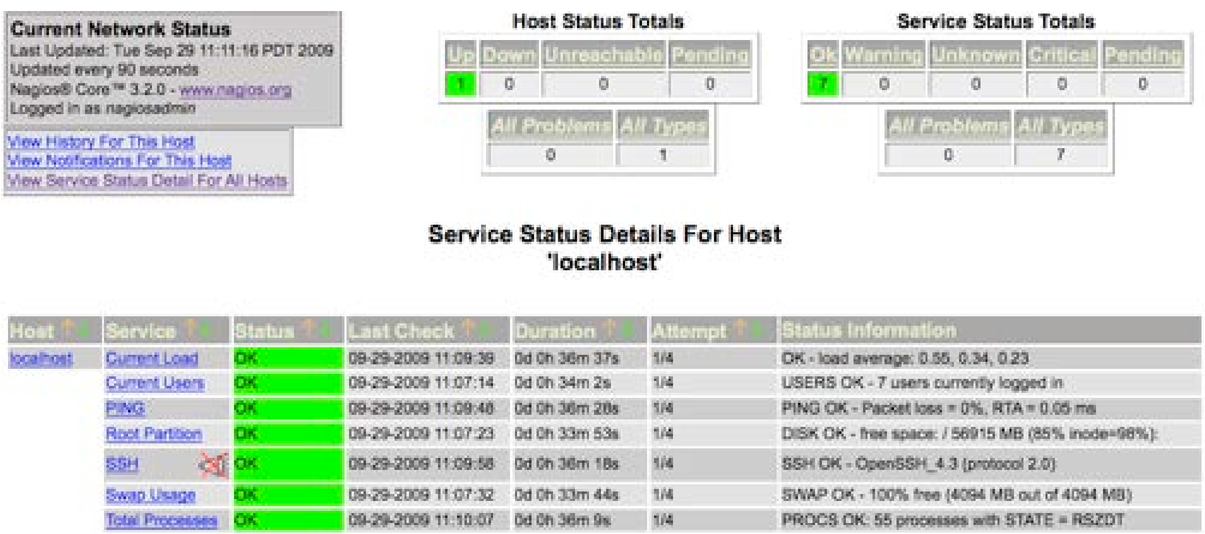


Figure 4.4: Nagios Detailed Host Information.

Figure 4.5 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".

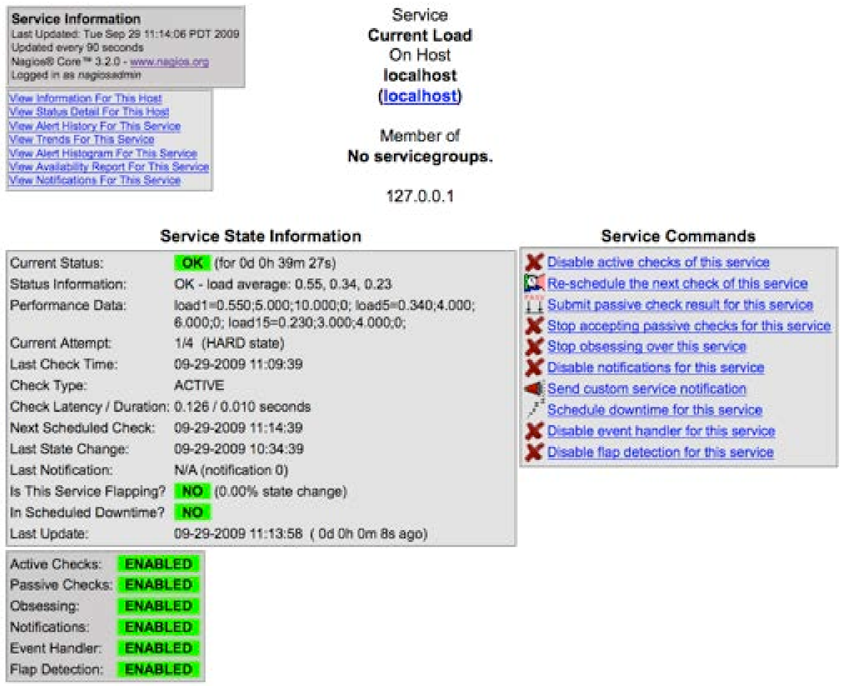


Figure 4.5: Nagios Detailed Service View.

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 4.6 provides a sample of still images.

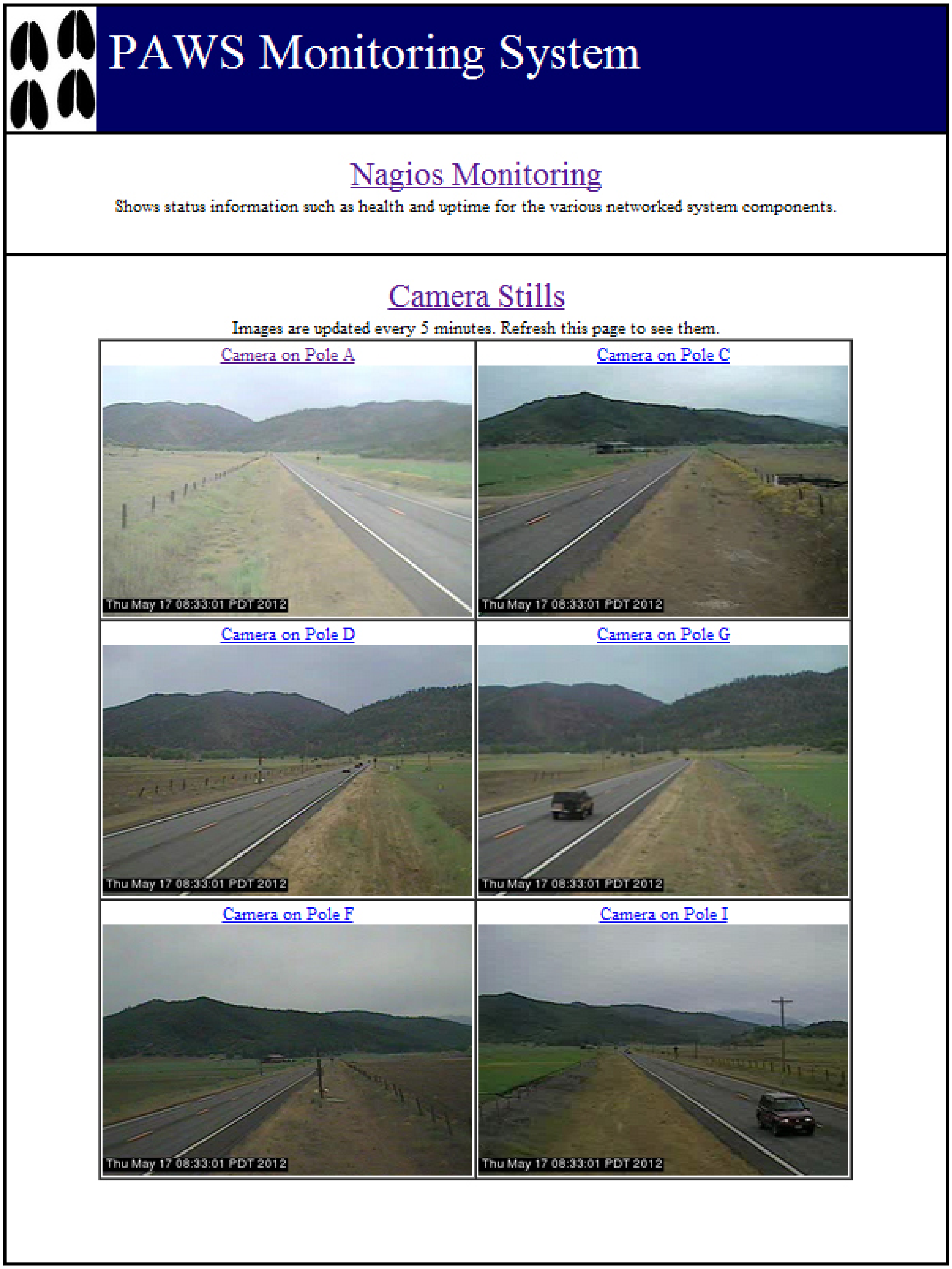


Figure 4.6: Nagios Camera Monitoring.

The Nagios monitoring system regularly checks the services of each host component and updates their status on the website. Below is a list of hosts and their services, including figures of how they appear on the website and their descriptions.

Host	Service	Status
camera-pole-a	ASF	OK
	PAWSRECORD	OK
	PING	OK

Host: Camera

Services:

ASF: A script that looks at temp video files and checks that they are growing

PAWSRECORD: A program that Nagios uses to send packets of information to and from the cameras to check that the cameras are still running.

PING: A signal to detect the reachability of the host and determines the round-trip time for messages sent from the originating host to the destination computer

localhost	AWSRCV	OK
	Current Load	OK
	Current Users	OK
	DB_SLV	OK
	EVENT_TOTAL	OK
	External Partition	CRITICAL
	PAWS_CREATE	OK
	PING	OK
	Root Partition	OK
	Swap Usage	OK
	Total Processes	OK
	WRFILES	OK

Host: localhost, which is the LAN server for the monitoring system. It runs DB_SLV and other programs that are acquiring data.

Services:

AWSRCV: Stands for Animal Warning System Receive, a database client that acquires data from the animal warning system and puts it in the data pool.

Current Load: Checks the CPU load and ensures that there is no particular process loading it down.

Current Users: [to be completed]

DB_SLV: A program used to allocate memory.

EVENT_TOTAL: [to be completed]

External Partition: Checks the amount free space on the external USB drive that stores data.

PAWS_CREATE: Creates database variables. It is the first database client that is started. It requests memory allocation from DB_SLV.

PING: A signal to detect the reachability of the host and determines the round-trip time for messages sent from the originating host to the destination computer

Root Partition: Where the operating system is started up and maintained.

Swap Usage: Checks for unusual changes in the usage of swap space.

Total Processes: Monitors unusual changes in the number of programs that are running.

WRFILES: Reads data from input and writes specified files

sign-pole-b	PING	OK
	SIGN	OK
	SIGNRCV	OK

Host: Signs, the animal warning signs installed on Poles C, H, B, and G

Services:

PING: A signal to detect the reachability of the host and determines the round-trip time for messages sent from the originating host to the destination computer.

SIGN: The heartbeat message coming from the sign.

SIGNRCV: A database client that waits for the animal detection signal to turn on.

sms3	SMSPARSE	OK
	SMS_CANSTAT	OK
	SMS_COUNTER	OK
	SMS_OBJECTS	OK
	SMS_RADAR_HEAD_ID_0_POLE_H	OK
	SMS_RADAR_HEAD_ID_1_POLE_F	OK
	SMS_RADAR_HEAD_ID_2_POLE_E	OK
	SMS_RADAR_HEAD_ID_3_POLE_C	OK
	SMS_RADAR_HEAD_ID_4_POLE_G	OK
	SMS_RADAR_HEAD_ID_5_POLE_D	OK
	SMS_RADAR_HEAD_ID_6_POLE_B	OK
	SMS_TSCAN	OK

Host: SMS Radar head

Services:

SMSPARSE: A database client that receives data transmitted by the SMS radar controller (bumper box). If this process crashes, an error is generated and Nagios attempts to restart it.

SMS_CANSTAT: The controller area network which the radar heads are connected to. The monitoring system checks the status of the intranet.

SMS_COUNTER: The message counter those increments by one count for each object control message. If the counter increments by more than one count, a message has been lost; this is an error and is indicated as such.

SMS_OBJECTS: Number of radar targets (objects) saved to file.

Radar Heads: The service that collects information and detects heartbeat signals from the radar heads installed on each pole.

SMS_TSCAN: The servo loop time (should be around 50 ms, error if 200 ms)

sts-pole-o-to-a	BADCHECKSUM	OK
	BADEVENT	OK
	BADSTATUS	OK
	EVENT	OK
	FAULT	OK
	MESSAGE	OK
	OFFLINE	OK
	PING	OK
	SEQNUM	OK

STS: STS Animal Detection Transmitter

Services:

BADCHECKSUM: A process that detects errors that may have occurred during the transmission or storage of data.

BADEVENT: Indicates that there was an event but that the animal radar beam was not broken.

BADSTATUS: Indicates a heartbeat message that also carries a "beam broken" indication.

EVENT: Checks whether or not the beam is broken and if the system has responded to an external stimulus.

FAULT: Checks to see if the system has decided it is in a fault condition and the sensor is broken

MESSAGE: A heartbeat message is transmitted from each receiver every 60 seconds. If more than one message is missed, an error is generated indicating that the heartbeat message is not being transmitted regularly.

OFFLINE: Error message indicating that an STS receiver is out-of-service

SEQNUM: A sequence number 1-9999 is transmitted with each STS message. If this number is out-of-range or greater than one count higher than the last sequence number, an error is generated.

switch-pole-a	PING	OK

Host: Switch, the switching hub that connects the network devices of the monitoring systems.

Services:

PING: A signal to detect the reachability of the host and determines the round-trip time for messages sent from the originating host to the destination computer.

5 DATA COLLECTION, PROCESSING, AND REDUCTION

5.1 Data Collection

5.1.1 Overview

The California PATH Animal Warning System (PAWS) data collection, as analyzed in this report, officially began on August 3, 2011 and officially ended on May 30, 2012, resulting in approximately 10 months and 1 TB of engineering and video data. The system was operational 24/7, and in the time period covered by this report, only 11 days of data was discarded due to system failures or work being performed on the test site. Figure 5.1 below depicts a brief timeline of data collection period and system functionality during this phase of the project.

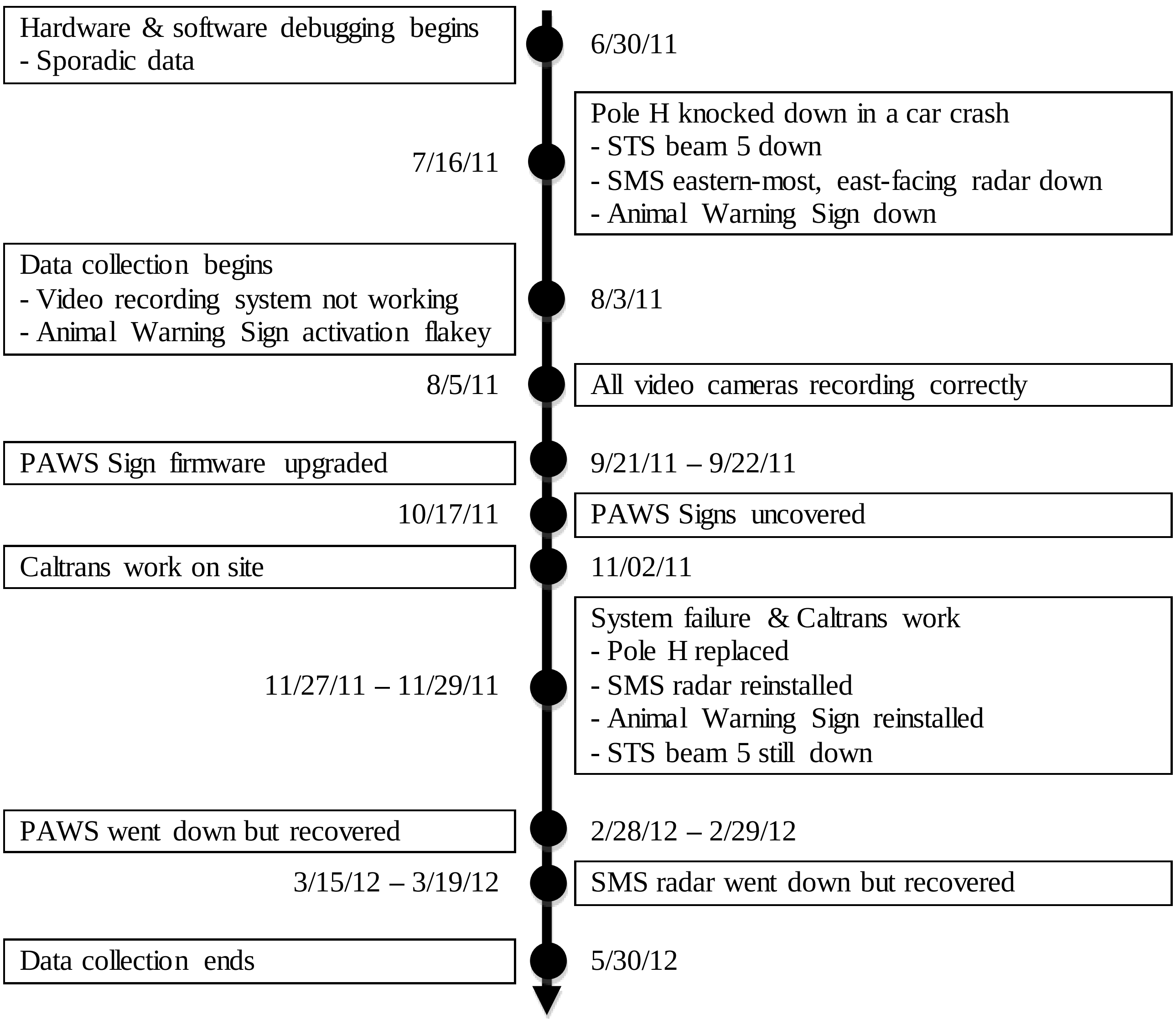


Figure 5.1. Data collection timeline.

During the data collection, there were also about a half-dozen shorter system outages, generally related to power failures or system reboots, which brought the system down for several minutes to several hours, depending on the incident. However, in these cases, data was only discarded for the time period where the system was nonfunctional.

5.1.2 Data Collection and Transfer Process

The PAWS Data Acquisition System (DAS) recorded data continuously, saving the data in roughly 3-minute files stored on the system's local hard drive. Each morning just after midnight, a new date folder was created to store the next day's data. The engineering, or numeric data, gathered from the STS and SMS radar systems were recorded at 20 Hz (every 50 ms), and stored in plain text data files (.dat). The video from each of the 6 cameras came to the DAS in an Advanced Streaming Format (.asf). The incoming video stream was saved directly to the hard drive in 3-minute files, synchronized with the 3-minute data files that were also being recorded.

The engineering data amounted to roughly 900 MB per day, and the video data amounted to 22 MB per minute or roughly 32 GB per day if it was recorded continuously. Unfortunately, recording data and video on a 24/7 basis would have quickly overwhelmed the DAS storage capacity, and thus, the DAS employed a set of rules regarding which video files to keep and which to discard. While all engineering data files were kept, video files were only kept during the PAWS warning events and for the 3-minute time periods both before and after the warning events. For each PAWS warning event, a minimum of 12 minutes of video files were typically saved (6 minutes to cover the 3-minute event, and an additional 3 minutes before and after the event). A typical event contained 265 to 900 MB of video, and a typical day contained about 25 events, averaging about 8 GB of data and video per day. The data files produced by the PAWS DAS were arranged according to the file and naming structure as described below:

[YYMMDD]	(Day Folder)
[YYMMDD][EEE]	(Event Folders)
[Camera IP]-[MMDD][SSSS].asf	(Event Video Files)
e[MMDD][EEE][SSSS].dat	(Event Data Files)
logs	(System Logs Folder)
[Device]-[YYMMDD].log	(System Log Files)
nonevents	(Nonevent Data Folder)
n[MMDD][EEE][SSSS].dat	(Nonevent Data Files)

Where:

- [YYMMDD] is the date with 2 digits representing year, month, and day.
- [EEE] is a 3-digit event number. Event numbering restarts from 001 each day.
- [SSSS] is a 4-digit sequence number staring at 0001 and incrementing every 3 minutes to roughly 0480. Sequence numbering restarts from 001 each day.
- [Camera IP] is the internet protocol address of the camera, e.g., 10.0.0.31
- [Device] is the name of the device creating the log file. Each camera and Animal Warning Sign generated a log file, and logs were also created by the STS receivers, the SMS radar receivers, and the various software processes running on the DAS.

Once a day, the system would attempt to transfer the previous day or days' worth of data from the local hard drive to a USB drive attached to the system. Every 3-4 weeks, as the USB drive became full; a Caltrans maintenance worker would swap the full USB drive for an empty USB drive, and ship the collected data to California PATH. The data was copied from the USB drive to a secured RAID disk array for processing and long term storage. Backups of both the original data and the processed data were also performed in case there was ever a catastrophic failure of the RAID array. The empty USB drives were then reformatted and shipped back to the Caltrans Yreka Maintenance office near the test site.

5.2 Data Pre-Processing

5.2.1 Data Validation

Once the data from the PAWS DAS had been loaded on the RAID array at California PATH's Richmond Field Station facility, several analysis scripts were run to check data validity. All data pre-processing and reduction scripts were written in MatLab and run in the MatLab environment. The data validation scripts created a number of summary files for each 3-minute engineering data file and for each day as a whole. The general goal of the data validation pre-processing was to check for the common anomalies listed in Table 5.1.

Table 5.1. Data Pre-Processing Analysis Common Anomalies.

Checked Parameter	Explanation
File Count	Each day should have 480 files. A few missing files from one day may normally be included in the previous day if a PAWS warning event happened near midnight. However, missing and extra sequence files pointed to a problem with the data quality and triggered the need for an analyst to examine the data further to reconcile the differences.
Duplicate Files	Since the file naming scheme and storage folders for nonevent and event data files differed, there was the potential for duplicate 3-minute sequence files. Duplicates were reconciled manually.
File Duration Warnings	Each sequence file should be approximately 3 minutes, including roughly 3600 lines of data (recorded at 20 Hz). Significantly longer or shorter file sizes tended to indicate a problem with DAS that needed to be investigated further.
File Break Warnings	Since the data was recorded at 20 Hz, the time between subsequent 3-minute files should be roughly 0.050 seconds. Significantly longer file breaks generally indicated that a power loss or system reboot occurred.
STS Receiver Status STS Beam Breaks Number of Events PAWS Sign Status	The STS receiver status, number of beam breaks, number of events, and animal warning sign activations were scrutinized to make sure that the system was functioning normally. There were generally between 10 and 30 events per day, days with significantly more or less events were scrutinized to determine if some sort of work on test site was triggering false alarms.

SMS Health Parameters	There was a number of health parameters associated with the SMS radar. First, the SMS CAN (network) connection should be up. Second, the number of radar heads responding should be 6, and third, the response time from each radar head should be around 50 ms.
SMS Target Count	The SMS radar system could track up to 64 targets at a time. However, the DAS only recorded 10 targets at a time. Most of the time, 10 targets was plenty, but for very short periods of time, the SMS radar targets may have overloaded the DAS (tracking 11-13 targets). This parameter was tracked throughout the study to make sure that adjustments did not need to be made to the DAS to record more targets.
SMS Moving Targets SMS Target Range	For various reasons, as discovered early in the project, the SMS could report that it was tracking targets, but the targets being tracked were not actually moving. The data validation analysis counted the number of moving targets and the range of values traversed by each target. As an example, a typical car traversing the test site was tracked with a distance value ranging from -400 to +600 m.

After running the data validation pre-processing scripts, an analyst examined a summary file that was generated for each new set of processed data and noted days with potential issues. The analyst then examined the summary files generated for each questionable day to determine what happened. Full days, individual PAWS events, or individual 3-minute data files could be marked as bad and excluded from the analysis as needed. Approximately 3 full days were excluded from the analysis due to Caltrans and/or California PATH work being performed on the system and test site. Six full days were excluded from the analysis due to either STS, SMS, or PAWS DAS system failures, and at least five other partial days (more than an hour or two) were excluded for similar reasons. Another half-dozen short (under an hour) system outages occurred, generally related to power failures or system reboots.

5.2.2 *Data and Video Repository File Reorganization*

The second stage of the data pre-processing involved the reorganization of the engineering data and video file and folder naming structure and the conversion of the video files from Advanced Streaming Format (.asf) to H.264/MPEG-4 (.mp4). The reorganization and renaming of the engineering and video files were primarily undertaken in order to simplify the development of the scripting needed to perform further analyses on the data, but as an additional benefit, it was undertaken to reduce the effort required by a human analyst to find specific data and video files when needed. The simplifications included placing all of the engineering data into a single folder, using a more consistent file naming convention, shortening file and folder names when possible, replacing the cryptic IP camera naming scheme with a lettering scheme that matched the system diagrams, and creating file names that could survive catastrophic disk failures that would require professional data recovery. The engineering data and video files were rearranged and renamed according to the file and naming structure described below:

Date[YYMMDD]	(Day Folder)
Analysis	(Analysis Folder)
Date_[YYMMDD]_[Analysis Name].txt	(Analysis Output Files)
Data	(Engineering Data Folder)
[SSS]-[EE]-[YYMMDD].dat	(Engineering Data Files)
index.txt	(Index of Engineering Data Files)
weather.xls	(Weather Data Files)
Event[EE]	(Event Video Folders)
[Camera]-[SSSS]-[EE]-[YYMMDD].mp4	(Event Video Files)
logs	(System Logs Folder)
[Device]-[YYMMDD].log	(System Log Files)

Where:

- [YYMMDD] is the date with 2 digits representing year, month, and day.
- [EE] is a 2-digit event number where 00 indicates nonevents. Event numbering restarts from 01 each day and increments each time the STS animal detection system detected a break in the beams.
- [SSS] is a 3-digit sequence number staring at 001 and incrementing every 3 minutes to roughly 480. Sequence numbering restarts from 001 each day.
- [Camera] is a letter corresponding to the camera location, A, C, D, F, G, or I
- [Device] is the name of the device creating the log file. Each camera and sign generated a log file, and logs were also created by the STS receivers, the SMS radar receivers, and the various software processes running on the DAS.

In addition to reorganizing and renaming the data files, the data reorganization pre-processing scripts created an index file for each day. The index file contained the data file sequence numbers, start and end times of each file, and event number. The index file was used to guide most of the scripts used in the data reduction stage of the analysis.

While the engineering files reorganization and indexing only took about 12 minutes of processing per day of data, the longer task in this stage of the data pre-processing was the conversion of the video files from Advanced Streaming Format (.asf) to H.264/MPEG-4 (.mp4). The ASF video format was recorded by the PAWS DAS because that was the native format broadcast by the IP cameras used to monitor the test site. On the recording end, this reduced the processing power required by the PAWS DAS in the field, but this format had several drawbacks:

1. ASF video is an older format that is not highly compressed, resulting in larger file sizes.
2. ASF video is optimized for streaming, and does not easily allow for non-linear playback. Thus, skipping around in the video or playing the video in slow motion or reverse was poorly supported on all of the video players capable of playing ASF video files.
3. Very few commercially available video players are capable of playing native ASF video.

Because of these issues, all of the videos were converted to H.264 format using HandBrake (http://handbrake.fr/), a commercially available video format conversion program that could be used in conjunction with MatLab scripts. The video conversion process reduced the roughly 11 MB ASF video files to 7 MB MPEG-4 video files that could be played in most commercially available video players. Additionally, the video conversion script renamed the video files according to the new file naming convention described earlier, matched each video file to a specific event, and discarded nonevent video files that were mistakenly saved. The MatLab conversion scripts logged any encountered errors and validated whether or not all expected video files were seen and converted. The video conversion reduced the overall disk space requirements of the data from about 8 GB per day to roughly 3-5 GB per day, but the processing required between 1.5 and 4.5 hours for each day's worth of video files (depending on the speed of the computer doing the conversion and the number of video files recorded that day).

After each new batch of data was processed, an analyst reviewed the logs, investigated any abnormalities noted, and verified that missing data or video files were actually missing from the original data. Backup copies of both the original and reorganized data files were then created on external hard disks.

5.2.3 Weather Data

Weather data was downloaded from MesoWest (http://mesowest.utah.edu/), a cooperative project between the researchers at the University of Utah and the National Weather Service that has been operating since 1996. MesoWest monitors weather from a network of weather stations in real-time but also provides archival weather station data. The nearest weather station to the test site that contained a complete set of data was located at the Montague-Siskiyou County Airport, approximately 25 miles northeast of the test site. This particular station is run by the National Weather Service, and it was chosen based on both reliability and data availability. Although the analysis primarily focused on the overall weather conditions, the weather station provided the following information:

- Hourly Updates
- Temperature (°F)
- Dew Point (°F)
- Wet Bulb (°F)
- Relative Humidity (%)
- Wind Speed (mph)
- Wind Gusts (mph)
- Wind Direction
- Pressure (in)
- Weather Conditions (clear, fog, rain, snow)
- Visibility (mi)

An automated script was written in MatLab to download the weather data for each day, and place a weather.xls file into the data directory. Additional scripts were written to read and parse the weather.xls file, allowing the weather data to be integrated with the PAWS data during the data reduction phase of the project.

5.2.4 Data Parameter Decoding, Scaling, and New Parameter Generation

The engineering data files recorded by the PAWS DAS contained 110 individual data parameters, 40 related to the STS receivers, beams, and animal warning signs and 70 related to the SMS radar. Customarily, the PAWS DAS is designed to record the outputs of the various attached systems in the original format provided by that system. This keeps the processing power required by the DAS to a minimum, and it prevents errors in the DAS development from contaminating the data. Some of the steps undertaken in the data preprocessing phase includes decoding, scaling (or units conversions), and generating new data parameters as needed for the analysis. In this project these preprocessing tasks were fairly limited in scope and able to be accomplished on-the-fly as data was loaded from saved files into memory in MatLab.

Although the PAWS DAS directly recorded almost all of the parameters needed for the analysis, there were three additional parameters that were needed: vehicle speed, acceleration, and heading. The SMS radar was based on a two dimensional XY-coordinate system. Although the X-axis was roughly aligned with the width of the road, and the Y-axis was roughly aligned with the length of the road, the road was not perfectly straight through the test section. Thus, it was determined that a better estimate of the vehicle speed involved combining the X and Y speed components that were reported by the SMS radar. Vehicle acceleration was then computed based on the differentiation of the vehicle speed profile, and vehicle heading was recorded based on the Y-axis track through the test site so that eastbound and westbound cars could be distinguished.

5.2.5 SMS Radar Filtering

The SMS radar system consisted of 7 integrated radar heads, and the system was capable of internally tracking up to 64 targets through the test site. Each new target seen by the radar was given an ID number increasing from 1 to 64, and rolling over back to 1. During a typical 3-minute data file taken at the test site, a mean of 16 targets were detected, although at times, anywhere between 0 and 63 targets were seen. Thus, the target IDs cycled from 1 to 64 about every three to twelve minutes. Unfortunately, even with this sophisticated radar system, the target tracking data was very noisy, and there were a number of different filters required to process the SMS radar data in order to get clean tracking for each vehicle traversing the test site.

One of the first potential problems noted with the system was that the DAS was only programmed to record the first 10 radar targets detected by the SMS radar system during any 50 ms update. This limitation was intentional and had been primarily implemented as a means to reduce the amount of data being generated by the DAS. Most of the time, less than 10 objects were being simultaneously tracked by the SMS radar system. However, for 0.1% of each day (less than 2 minutes per day), the number of moving targets seen by the SMS radar system exceeded the output capacity of data files being saved by the DAS. During this time it was possible for the target tracking on an object to be briefly lost.

Since both targets IDs were repeated and target tracking data could potentially be interrupted, the first step in filtering the SMS radar data was to combine like target IDs and determine whether or not a break in the tracking data indicated a loss of data or the recycling of the target ID, indicating a completely different vehicle. Tracking losses were typically under 5 seconds and easily interpolated across. A change of vehicle due to target ID recycling was fairly obvious based on the 3-12 minute elapsed time.

The second major problem with the SMS radar system came from false targets. For the most part, the system itself handled consolidating targets and tracking targets moving between radar heads, but there were a number of cases, occurring quite frequently, where the radar system reported false targets or ghost targets. Figure 5.2 shows one minute of radar data containing two approaching vehicles, one from the east (target ID 5) and one from the west (target ID 1). However, during this time, the SMS reported seeing 6 targets. Target IDs 3 and 6 were most likely caused by multipath returns and indicate ghost reflections of Target ID 1. For eastbound vehicles, the locations of these ghost targets were fairly consistent, indicating that they were probably generated as the vehicle transitioned between being seen by subsequent radar heads.

Similarly target ID 7 appeared right as the two vehicles passed each other, indicating a ghost reflection generated by the crossing of the vehicles. After some investigation, target 4 was a spurious target generated by a bug in the SMS radar system. It seemed to occur frequently at the same location when tracking some eastbound vehicles. The high frequency of ghost targets was likely due to the fact that there was very little overlap in the coverage of the 7 SMS radar heads. While this allowed the system to cover the entire 1070 m test site, it also degraded the target recognition when transitioning between radar heads. Fortunately, most of the false targets only appeared in the data for about 10 seconds or less, allowing them to be filtered out by a simple time-based filter.

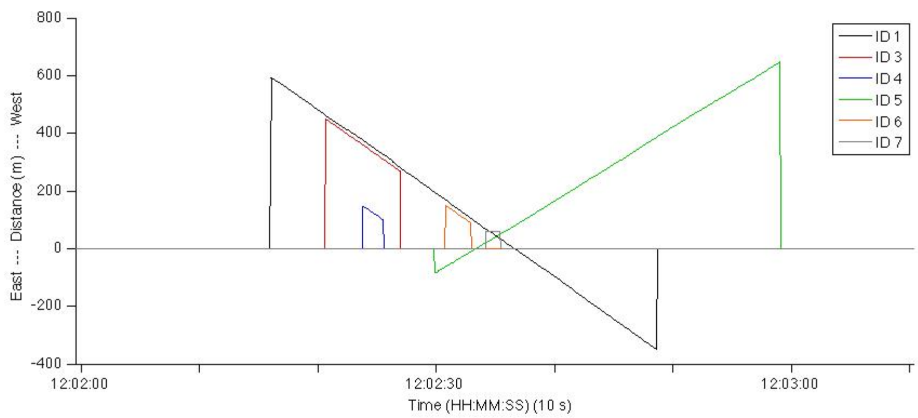


Figure 5.2: SMS radar spurious target filtering.

Unfortunately, one of the side effects of filtering out short duration (under 10 seconds) targets was the loss of data on some vehicles. As shown in Figure 5.3, some westbound vehicles like target ID 43 were briefly seen by the radar on the east edge of the test site's radar detection zone (Y-values between -300 and -200 m). Target tracking on vehicle ID 43 was then lost after a few seconds, and when the vehicle was eventually reacquired, as the vehicle reached a Y-value around -100 m, the vehicle was given a new target ID (45).

A similar pattern was sometimes seen for eastbound vehicles entering the test site at the limits of the radar's detection range on the west side of the test zone (although less frequently than for westbound vehicles). The time-based filter used to reduce the number of false targets also filtered out the first segment of the data in these cases where a target was acquired briefly, lost, and then reacquired with a different target ID. Thus, in the demonstrated case, the data shown for target ID 43 was discarded, and the analysis was only based on the data shown for target ID 45.

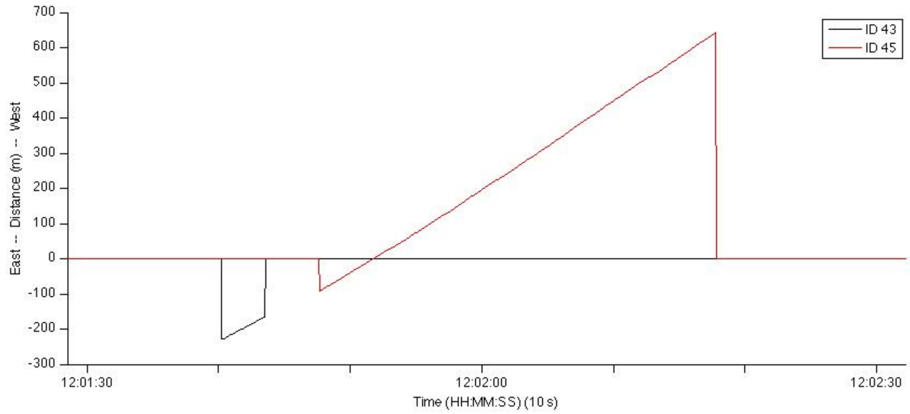


Figure 5.3: Westbound vehicle target loss and reassignment.

The third and final problem with the SMS data for which a filter was derived was localized to eastbound vehicles. As shown in Figure 5.4, target IDs 3 and 7 was actually the same vehicle, verified by video. The SMS radar system, as implemented at the test site, had a tendency to lose the tracking of eastbound vehicles as they transitioned from one radar head to the next, crossing through Y-values between 100 and 50 m. This particular pattern occurred quite frequently, and a filter was written to merge the two tracks and interpolate over the missing data. A similar pattern was not seen with westbound vehicles.

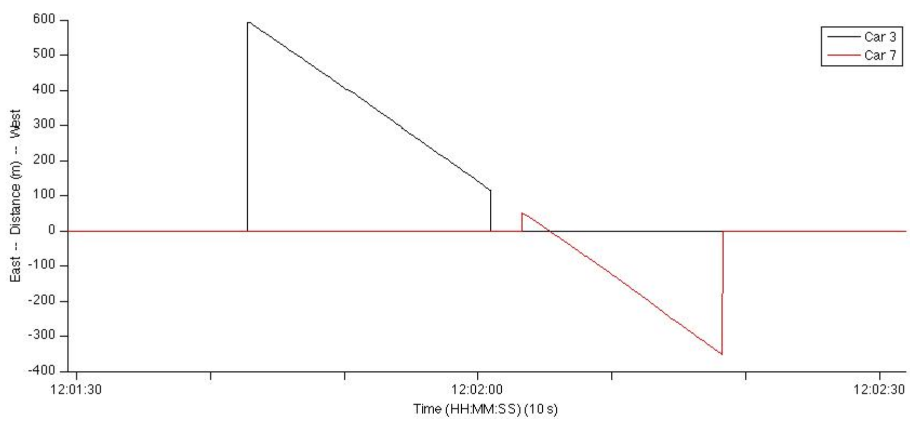


Figure 5.4: Eastbound vehicle target loss and reassignment.

5.2.6 Unresolved Issues with the SMS Radar Filtering

There were some SMS radar issues which could not easily be filtered out within the scope of this project. As shown in Figure 5.5, the SMS radar could track a vehicle through most of the test site, detect what it thinks is a second vehicle, and eventually resolved the two vehicles back into a single target retaining the second target ID instead of the first. In the segment shown, this happened for westbound targets 28 and 29, 32 and 34, and 39 and 40. In each case, there were overlaps in time between the two targets, but the overlaps did not always occur at the same location in respect to the test site. Although it is only shown in the figure for westbound vehicles, the pattern was also seen in eastbound vehicles, and it may occur between 0 and 15 times per hour based on a very small random sample of the data collected.

Unfortunately, the pattern shown in Figure 5.5 was more challenging to filter out than it would appear. Based on an analysis of the video, sometimes, this could be due to a vehicle towing a trailer, but sometimes there really were two vehicles that were very closely spaced. Additionally, there were issues with vehicles turning off or onto the main road, or pulling off to the side of the road. Attempts to handle the case of a target vehicle switching ID with some overlap between the two IDs could not be perfected in the time-frame of this project. For as many of the cases as were handled correctly, a similar amount of cases were generated where vehicle tracks were incorrectly merged.

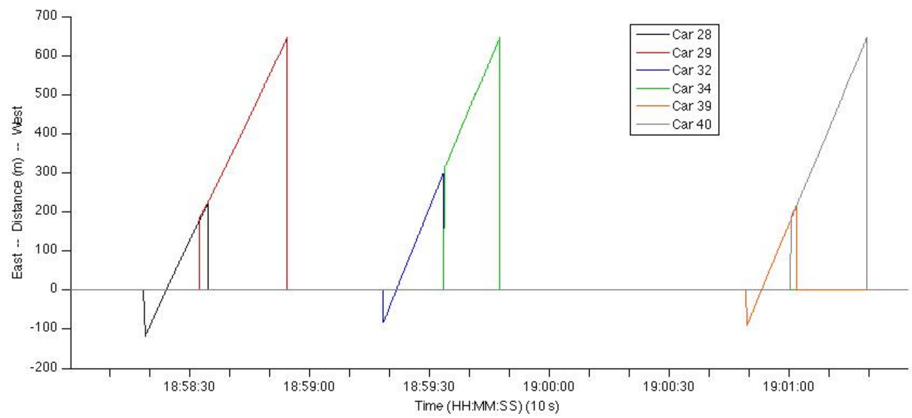


Figure 5.5: SMS radar over-counting the number of vehicles.

Fortunately, the net effect of this issue on the subsequent analyses is actually relatively minor. In essence, the vehicle counts reported in the analysis will be inflated by small percentage. In any analysis looking at mean vehicle activity, some vehicle will be counted twice when this error occurs. However, based on the sheer number of vehicles that have been tracked through the test site for 10 months, a small percentage of cases that get counted twice should not affect an analysis of the mean behavior. In any analysis looking at individual vehicle behavior, such as a deceleration rate for decelerating vehicles, the behavior of interest would typically occur in only one of the two vehicle tracks. In this type of analysis, the second track would have been ignored, and thus, would not affect the analysis.

5.3 Data Reduction and Experimental Design

5.3.1 Overview

The PAWS DAS basically recorded a snapshot of the STS and SMS radar systems every 50 ms for approximately 10 months, resulting in a large amount of raw time series data. The goal of the data reduction process was to mine this time series data creating summaries describing both the PAWS system performance and the resulting driver behavior. The data reduction process consisted of two basic steps: first, selecting time periods to summarize and second, selecting performance metrics to calculate for that time period.

The data reduction process again utilized the MatLab environment and scripting language. For this project, a collection of functions was written to load, filter, visualize, and reduce or summarize the data that was recorded by the PAWS DAS. At the lowest level, functions were written to load individual data files, and then additional functions worked to scale up the loading of individual files into the loading of a series of data files into memory. At the intermediate level, functions were written to filter and visualize various data parameters, such as the filtering of the SMS radar target data which has already been described. Due to limitations in MatLab, and in the interest of optimizing the loading and processing speed, much of the project effort needed to be placed into optimizing these lower and intermediate level functions. Even once optimized, it was determined that an entire day's worth of data could not be efficiently loaded into memory and processed. To optimize for speed of processing, analyses had to be broken into smaller time periods of less than two hours. To some extent, this limitation dictated how the various analyses could be constructed.

At the top level, functions were written to coordinate an automated analysis and save the resulting output files. For each individual analysis, a set of start and end dates needed to be specified, and two scripts needed to be written: a filter script and an analysis script. The filter script specified a list of time segments of data to load and process for each day, while the analysis script specified how to calculate system, environment, and driver performance metrics that could be used to summarize the time segment being processed. Each individual analysis could be easily parsed out by date range to one or more computers that were set up to share the data. Due to the large amounts of data generated in this project, the processing time required to reduce the data was significant. As an example, an analysis that loaded and processed the data associated with each PAWS sign activation could take around 6 hours of processing time to run, while an analysis that examined traffic speeds for each hour of data could take several days of processing time to run. Multiple iterations of each analysis were typically required as software bugs and unanticipated data conditions were encountered.

5.3.2 Selection of Time Segments for Analysis

The analyses conducted in this report used various combinations of three general time segment categories: hourly summaries, baseline conditions, and treatment (warning) conditions. The analysis of overall traffic speeds was based on a simple hourly summary computed for each clock hour in the day. The remainder of the analyses was based on comparing designated baseline conditions to designated treatment conditions. The treatment conditions consisted of time segments containing PAWS warning events. A PAWS warning event was defined as the time segment where the PAWS detected a beam break and illuminated the four warning signs along the test site. The PAWS warning event definition also included an additional 30 seconds both at the beginning and at the end of each sign activation and deactivation. This additional time was added to the event definition to include the full radar tracks of vehicles that were already in the test site at the time that the event occurred.

In this report, two experimental designs were defined and analyzed. The first design used PAWS warning events recorded at the beginning of the study from August 3rd through October 16th as the measure of the baseline conditions. During the first 2.5 months of the study, the PAWS system was activated, but the animal warning signs were covered. This allowed for a direct comparison between providing or not providing PAWS warnings to the drivers traversing the test site.

Unfortunately, due to the length of the study, a number of different factors including seasonal changes and learning effects could have influenced the traffic speeds if the baseline conditions were limited to a short time period at the beginning of the study. In order to mitigate these effects, a second experimental design was proposed using the time segment just prior to a PAWS warning event as a measure of the baseline conditions. In this case, baseline time segments were selected 3 to 6 minutes before an animal warning sign activation and matched in approximate duration to the duration of the subsequent event. If a potential baseline segment was itself part of a previous event (or came shortly after a previous event), then that segment was discarded from the analysis.

5.3.3 Selection of Driver Performance Metrics

The final step of the data reduction phase was to mine the SMS radar data in order to generate a reduced data set describing the driver behavior while traveling through the test site. The first step in this process was the selection of driver performance metrics which might be used to compare the baseline and treatment conditions. As opposed to static animal crossing warning signs, the dynamic animal warning signs only activated when the PAWS system detected objects crossing the roadside right of way. Rather than simply warning drivers to be cautious because animals have been found along this stretch of roadway in the past, the animal warning signs provided drivers with notice of a specific threat, i.e., an animal has recently been detected along the roadside. Just how the drivers would react to that more specific warning was the major question posed in this research project. A number of different driver performance metrics were considered including the following:

- Mean Vehicle Speed
- Number of Vehicle Decelerating
- Mean Deceleration Rate
- Peak Deceleration Rate
- Peak Speed Drop

Upon seeing the illuminated animal warning signs, one hypothesis is that drivers will simply slow down. In this case, the data should show a reduction in the mean vehicle speed between the baseline and treatment conditions. However, there is a strong possibility that drivers will ignore the dynamic signs in the same manner that most ignore the static warning signs. If this turns out to be the case, the system could still be effective if the dynamic warning signs cued the drivers to be more alert while traversing the test site.

Unfortunately, measuring driver alertness directly was not possible, but several surrogate metrics related to alertness are proposed in this report. If the warning signs cued the drivers to be more alert, then the drivers should spot the animals in the roadway sooner. This should result in smoother and more gradual deceleration rates for the vehicles that needed to slow down after spotting wildlife. Higher levels of driver alertness should correlate with fewer panic stops, and subsequently reduced mean and peak deceleration rates. Similarly, there may also be reductions in the amount of speed that drivers needed to slow down when spotting wildlife on the road.

6 RESULTS

6.1 PATH Animal Warning System (PAWS) Events

6.1.1 Overview

The California PATH Animal Warning System (PAWS) was active from August 3, 2011, through May 30, 2012, with the exception of only 11 days where the system was down or work was being performed at the test site. The animal detection system used five 35.5 GHz radars from ICx Radar Systems, formerly Sensor Technologies and Systems (STS), mounted about 15 feet off the edge of the pavement to establish invisible microwave beams. Each radar beam covered about a third of a kilometer of roadway shoulder. Originally there were six radars, three on each side of the road, but one of the radars covering the northeast corner of the test site was damaged after a car accident and unable to be replaced during the experimental testing period. Thus, the experiment was based on the coverage of only five animal detection radars.

PAWS monitored the animal detection radar system for beam breaks. When a beam was broken, the PAWS Data Acquisition System (DAS) generated an event and illuminated the four driver warning signs. However, not all of the PAWS events generated were due to wildlife crossing the roadway. Due to system implementation limitations, beam 3 of the STS animal detection radar system was placed such that the beam crossed a dirt road. Vehicles coming from or turning onto that road triggered a-PAWS event. Additionally, since the test site was adjacent to several farm fields, farm equipment and laborers were also noted to frequently trigger PAWS events during planting and harvesting seasons.

During the roughly ten months (290 days) of data collection, a total of 4882 PAWS events were generated at a rate of approximately 16.8 events per day. A total of 1368 PAWS events occurred during the baseline time period when the animal warning signs were covered, and 3514 PAWS events occurred after the warnings signs had been uncovered. The animal detection radar system was capable of detecting intermittent problems, such as strong winds blowing the sensors out of alignment or grass growing too tall and blocking a receiver. Eventually, a sensor that was not performing adequately would be marked as bad and subsequently ignored, but before the system marked the sensor as being down, there was a potential for false alarms. Of the 4882 PAWS events, only 67 events (1.4 percent) appeared to be animal detection system false alarms occurring when the triggering animal detection sensor appeared to be in an unreliable state.

Based on the observations of the event video files made by the Western Transportation Institute (WTI) partners in this project, several patterns emerged allowing estimates to be made regarding the number of vehicles triggering the system versus the number of deer or other wildlife triggering the system. Most of the vehicles triggering the PAWS system were turning down the road covered by the animal detection system's beam 3. If an event consisted of a single break of beam 3, then the event was labeled as being probably triggered by a turning vehicle. When wildlife was observed to trigger the system, the pattern seen by the system included two beam breaks, one on each side of the road as the animal crossed. If an event consisted of two beam breaks on opposite sides of the road, then the event was labeled as likely being triggered by deer or other wildlife. While 94.8 percent of PAWS events fell into one of these two patterns, there was a small number of events (5.2 percent) that fell into another or unknown category. These events could be wildlife, people, or sometimes even cars pulled off to the side of the road.

6.1.2 PAWS Events by Month

As shown in Figure 6.1, the total number of PAWS events varied from as high as 665 in August to as low as 360 in February. Approximately 67.4 percent or 3292 of the events were labeled as most likely being triggered by turning vehicles, while 27.4 percent or 1335 cases were labeled as probable deer or other wildlife. This averaged to 11.4 car events and 4.6 wildlife events being generated each day. Interestingly, the ratio between the number of car events and the number of wildlife events did not remain constant each month. The highest number of car-generated events occurred in August (516) and September (400). From October to April, the number of car-generated events averaged between 10 and 11 per day, while August and September average 17.8 and 14.2 car-generated events per day. Mostly likely, this activity corresponded to increased farming and harvesting activity.

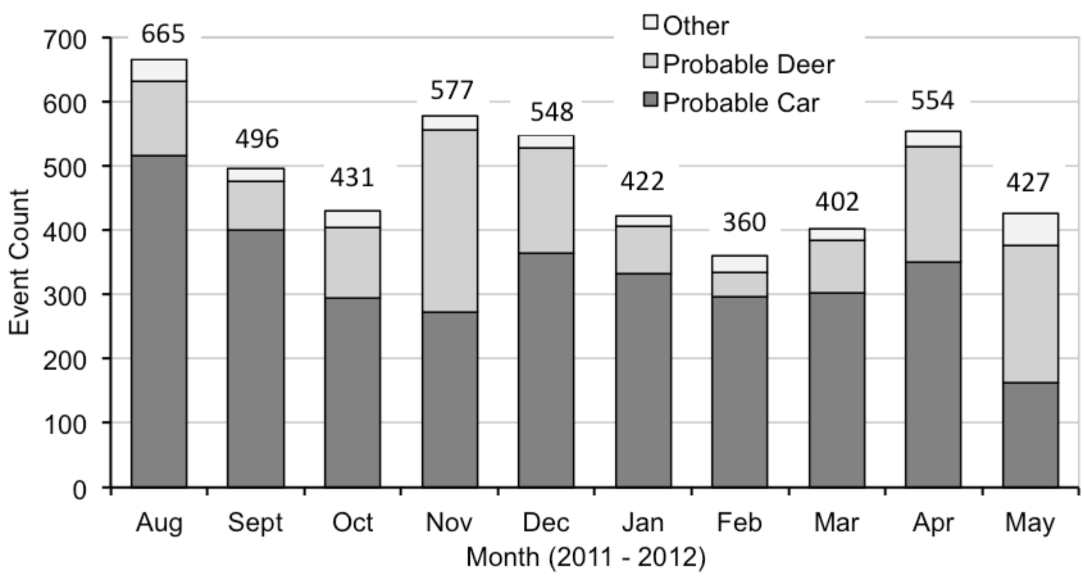


Figure 6.1: PAWS events by month.

As shown in Figure 6.2, the number of wildlife-triggered events also varied by month with increased activity seen in November, December, April, and May. Wildlife related PAWS events peaked at a rate of 10.5 per day in November, and averaged between 5 and 7 per day in November, April and May. The pattern shown in Figure 6.2 actually matches typically described deer activity patterns. Increased deer activity is usually seen during late fall mating season, October through December, and again during the spring, April and May. Overall, the monthly patterns seen for both cars-generated and wildlife-generated events generally match expectations.

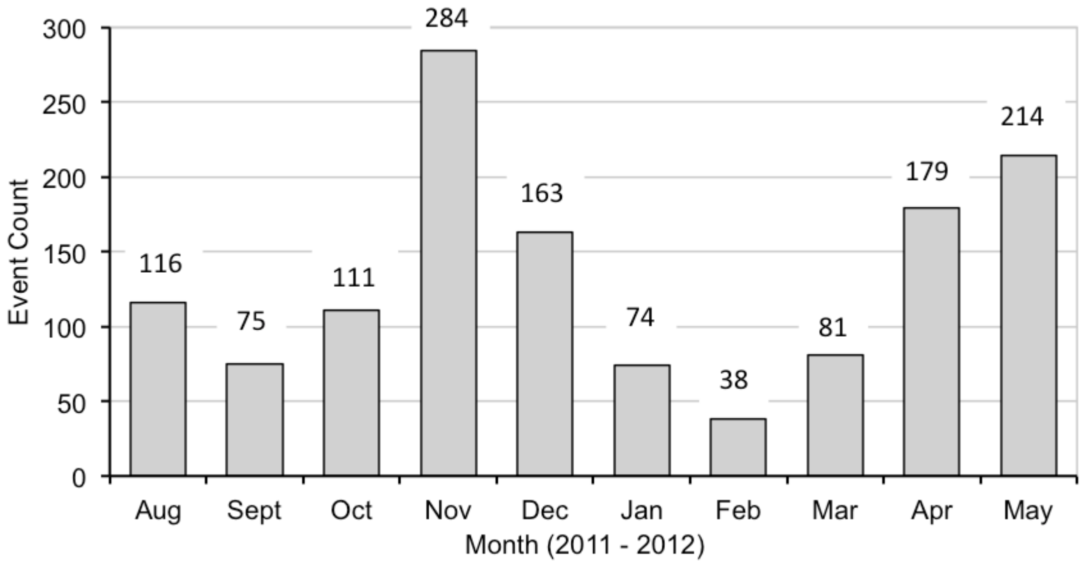


Figure 6.2: PAWS events most probably related to wildlife activity.

6.1.3 PAWS Events by Day-of-the-Week

Figure 6.3 breaks down the overall mean number of events per day across the days of the week.

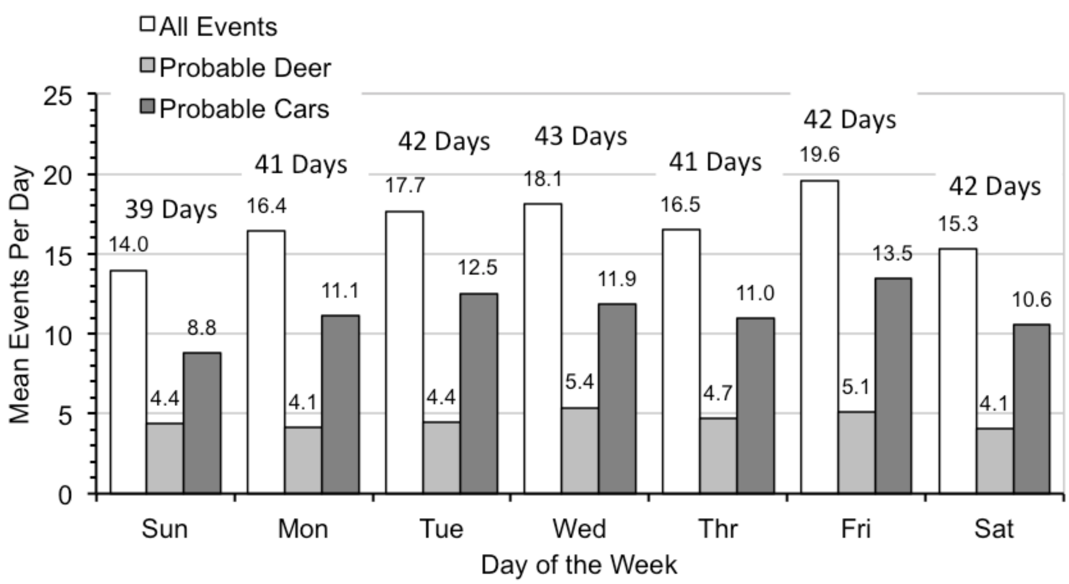


Figure 6.3: PAWS events by day-of-the-week.

During the study period, each weekday occurred anywhere from 39 and 43 times, e.g., there were 43 Wednesdays but only 39 Sundays. However, the number of wildlife-triggered events remained fairly constant at 4.1 to 5.4 events per day. This pattern would be expected given that deer movements would likely not be related to specific weekdays. The number of car-triggered events did vary by day of the week; corresponding to what would be expected for human activity. The number of car-triggered events was generally higher during the weekdays ranging from 16.3 on Mondays to 19.6 on Fridays, but lower on weekends, averaging on 15.3 on Saturdays and 14.0 on Sundays.

6.1.4 PAWS Events by Hour

The pattern of PAWS events per hour, shown in Figure 6.4, also corresponds with expectations. PAWS events that were likely triggered by turning vehicles were mostly clustered during the daytime hours of 6 AM to 8 PM. PAWS events that were suspected of being due to wildlife activity were more frequently noted from about 4 PM until midnight, when animals are known to be most active. From about 10 AM until about 6 PM, there was almost one event per hour per day. Between 10 PM and 6 AM, there was only a mean of 0.33 events per hour per day, or put another way, during any given night, there was only about a 33 percent chance of an event in any given hour.

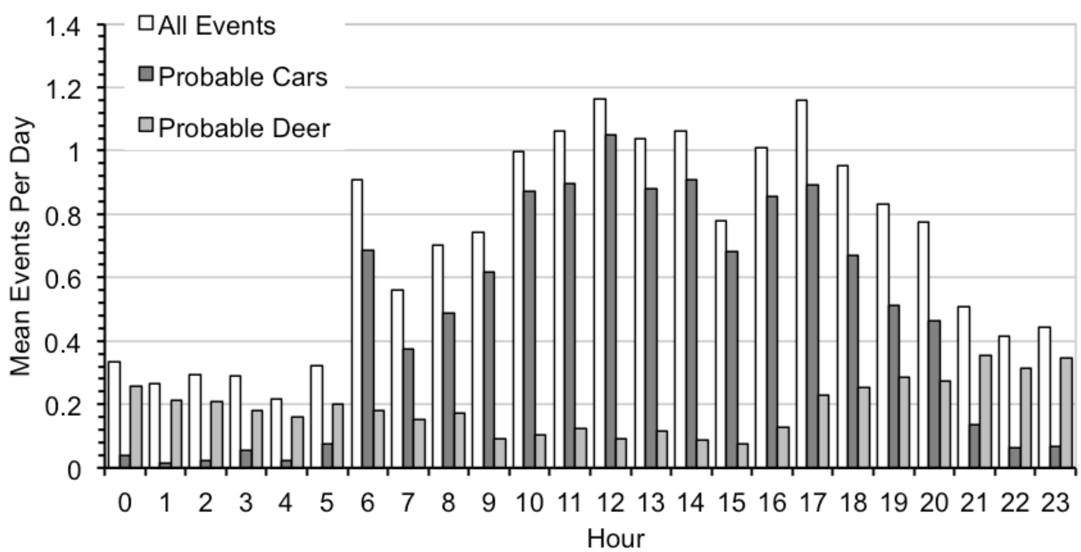


Figure 6.4: PAWS events by hour.

6.1.5 PAWS Events by Weather Conditions

Weather information was available for 99.9 percent of the PAWS events that were recorded. The weather station was reported as down for only 6 of the PAWS events in February. Each event was matched to the hourly reports by the weather station which recorded the overall conditions as being clear, foggy, raining, or snowing. Theoretically, the animal detection radars used by the PAWS should not have been affected much by adverse weather conditions such as fog, rain, or snow, and Figure 6.5 confirms this. Almost 94.3 percent of the PAWS events occurred when conditions were reported as being clear, and only 4.6 percent of the events occurred while it was raining. Less than 1.0 percent of the events occurred in either fog or snow.

If the system were highly susceptible to adverse weather conditions, one of two patterns should have been observed. Either the animal detection radar receivers should have been reporting as offline, or the number of PAWS events should have increased. Looking at the data for the winter months, there did not appear to be an increase in STS sensor malfunctions, and based on Figure 6.5, there did not appear to be an inordinate number of PAWS events recorded during adverse weather conditions.

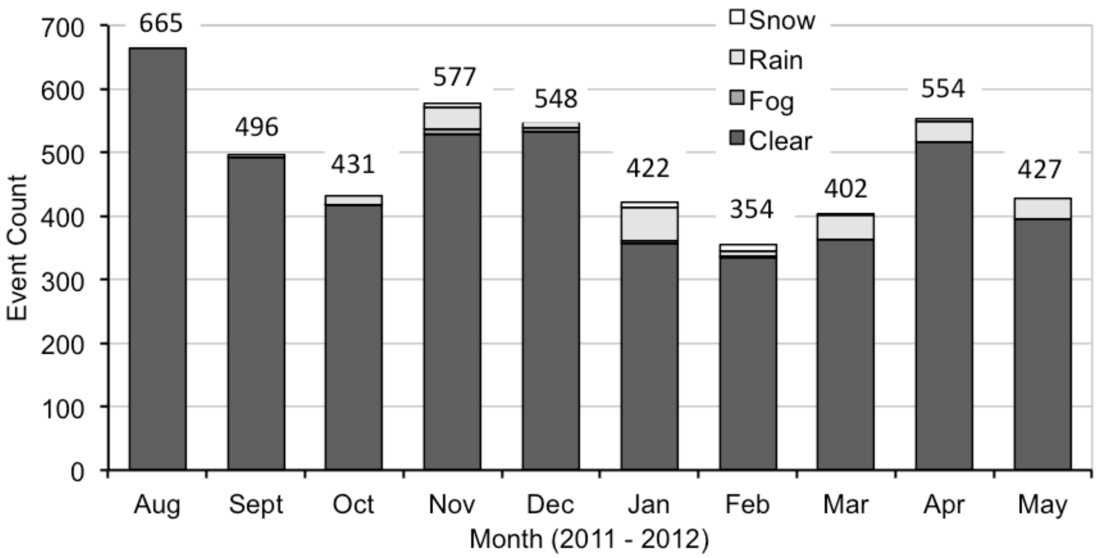


Figure 6.5: PAWS events by weather conditions.

6.1.6 *Performance of PAWS Signs*

Although the animal warning signs used by PAWS generally functioned well during the experiment, there was one issue that should be noted regarding the warning signs. Shortly before the data collection began, Pole H was hit and fell during a car accident. Among other things, Pole H supported the eastern-most animal warning sign. From August 2, 2011 until November 26, 2011, the first animal warning sign for south-westbound traffic (vehicles travelling towards Fort Jones) was missing. The south-westbound traffic only saw one warning sign illuminate during a PAWS event, and that sign was located about two-thirds of the way through the test site. Otherwise, once the warning signs were uncovered on October 17, 2011, all of the installed signs appeared to turn on and turn off simultaneously. No events were recorded where any of the installed warning signs failed to illuminate. Note: The animal warning sign on Pole H was reinstalled on November 26, 2011, and it too functioned correctly until the end of May 2012 when this analysis was concluded.

6.1.7 *PAWS Performance Summary*

Overall, PAWS appeared to function as designed. During the roughly ten months (290 days) of data collection, a total of 4882 PAWS events were generated with 1368 events (28 percent) occurring during the baseline period when the animal warning signs were covered and 3514 events (72 percent) occurring after the warning signs were uncovered. Approximately 3292 events (67.4 percent) were likely triggered by turning vehicles, while 1335 events (27.4 percent) were likely triggered by deer or other wildlife. Only 67 events (1.4 percent) were likely due to animal detection system sensor malfunctions. Finally, neither weather nor any other unexplained systematic bias appeared to influence the number of PAWS events generated.

6.2 Test Site Vehicle Speeds

6.2.1 Vehicle Speed Data Set Overview

The data set used to analyze the vehicle speeds through the test site was generated by averaging vehicle speeds for each hour of recorded data. After the SMS radar data was filtered, each vehicle's mean speed was calculated through the test site, and then an average speed was calculated for all of the vehicles traveling through the test site during that hour. The vehicle direction of travel, eastbound (northbound on State Route 3) or westbound (southbound on State Route 3), was included as a factor.

The data set included 6887 hours spanning over 290 days during the roughly 10 months of data collection. The data were relatively equally distributed by month ranging from 504 to 744 hours gathered each month. The month with the least amount of data, 605 hours, was March (2012), and this was due to a system outage for several days during that month. The data set was also relatively equally distributed by day of the week and by hour of the day, so there were no general biases in the data collection period.

Of the 6887 hours of data collected, the nearby weather station was reportedly down for 24 hours on February 20, 2012. Excluding this day, the weather station reported that conditions were clear during 6463 hours or 94.2 percent of the data set. Fog was relatively rare, only 43 hours or 0.6 percent of the data set. Rain was recorded during 294 hours or 4.3 percent of the data set, and snow was also relatively rare being recorded during 63 hours or 0.9 percent of the data set.

6.2.2 Vehicle Counts

The overall count of vehicles travelling in both directions through the test site ranged from 0 to 421 per hour, with a mean of 128.2 (SD 102.5) and a median of 117 vehicles per hour. (See Table 6.1.) The mean hourly vehicle counts were relatively similar between travel directions with means of 67.7 (SD 61.2) eastbound and 60.5 (SD 53.0) westbound vehicles per hour. However, as cautioned earlier, the vehicle counts reported are likely inflated due to imperfect radar tracking and filtering, and some of those tracking imperfections could have affected one direction more than the other. As an example, radar tracking could be lost on a vehicle, and then when the vehicle was reacquired, it was labeled as a new vehicle, thereby increasing the vehicle count. Additionally, bicycle and farm vehicles were detected by the SMS radar and counted as vehicles.

Table 6.1: Overall mean hourly vehicle counts.

Direction	Min	Max	Median	Mean	Std. Dev.
Eastbound	0	322	53	67.7	61.2
Westbound	0	359	52	60.5	53.0
Total (Both Directions)	0	421	117	128.2	102.5

To examine the vehicle count data set, a generalized linear model was created in the SPSS statistical software package (http://www.spss.com/) assuming a Poisson probability distribution and logarithmic link function. The assumption of an underlying Poisson distribution for the traffic count data should be valid given that the test site was a rural road with free-flowing traffic. The model included month, day of the week, hour of the day, direction of travel, and all of the 2-way interactions with direction of travel. All of the factors were highly significant as shown in Table 6.2.

Table 6.2: Mean hourly vehicle count generalized linear model test results.

Model Parameter	Wald Chi-Square	Degrees of Freedom	Significance
(Intercept)	2338697.46	1	$p < 0.001$
Study Month	7381.47	9	$p < 0.001$
Day of the Week	28692.31	6	$p < 0.001$
Hour of the Day	260432.09	23	$p < 0.001$
Travel Direction	45.30	1	$p < 0.001$
Month * Direction	1027.82	9	$p < 0.001$
Day * Direction	38.13	6	$p < 0.001$
Hour * Direction	70047.62	23	$p < 0.001$

As shown in Figure 6.6, monthly variations in the vehicle counts tracked typical travel patterns, showing decreases in the mean number of vehicles per hour through the winter months as compared to spring and fall. Figure 6.7 depicts the mean hourly vehicle counts by day of the week. The mean hourly vehicle counts were 30 to 53 percent less on weekends as compared to week days, although this is not particularly surprising since in general, weekend travel tends to be lighter. Additionally, the mean hourly vehicle counts did not appear to differ much by direction of travel, either by day of the week or by month.

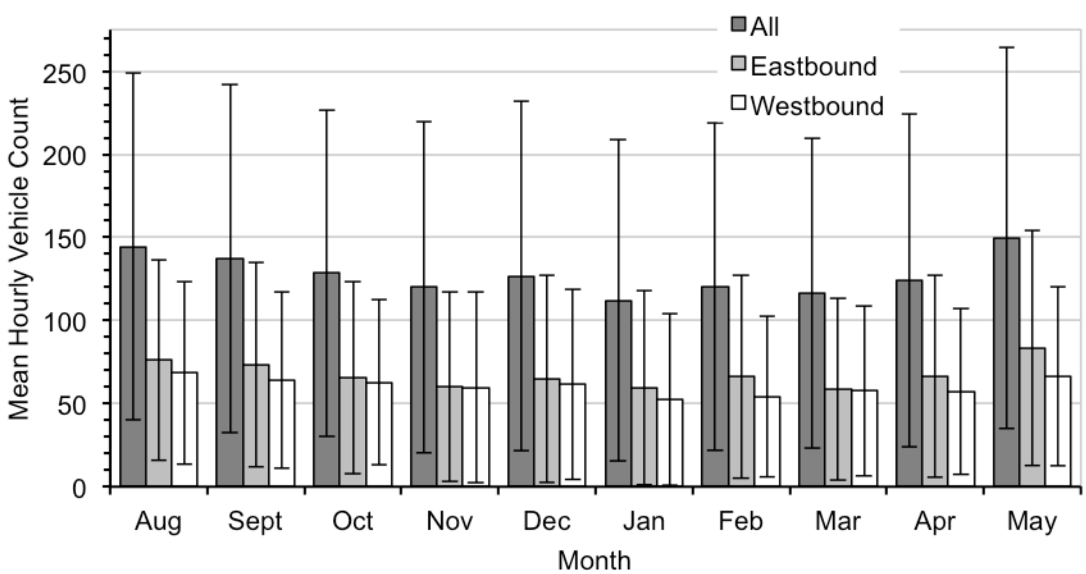


Figure 6.6: Mean hourly vehicle count by month.

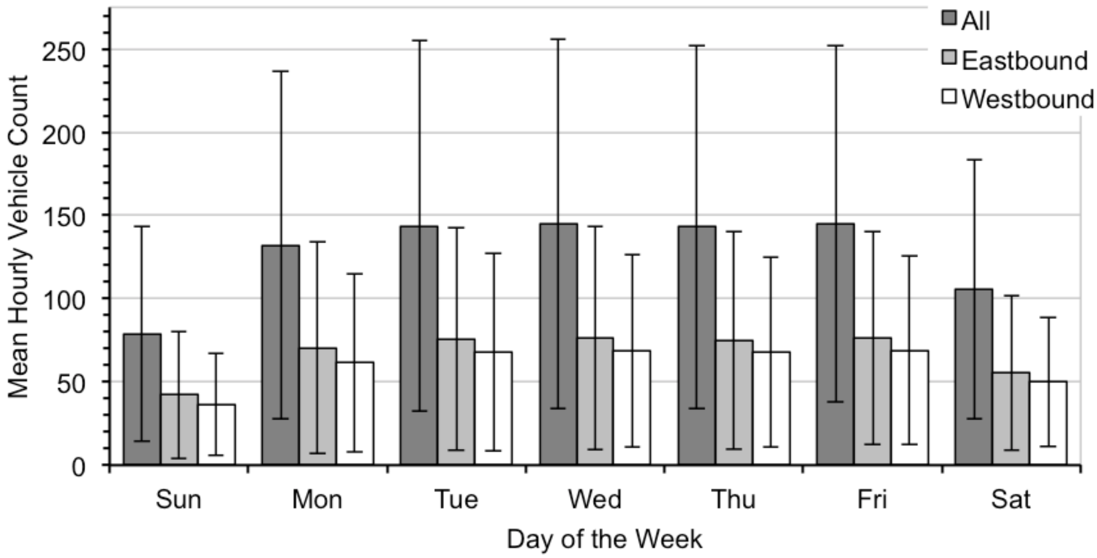


Figure 6.7: Mean hourly vehicle count by day of the week.

Figure 6.8 provides the most descriptive picture of the travel patterns in both directions along the test site. From 11:00 PM to 5:00 AM, the mean hourly traffic ranged from 7 to 18 cars per hour. The peak morning hour from 7:00 AM to 8:00 AM averaged 216 vehicles per hour, and the peak evening hours from 4:00 PM to 6:00 PM averaged about 245 vehicles per hour. Morning and afternoon traffic remained relatively consistent ranging from 195 to 235 vehicles per hour. Traffic fell sharply after 6:00 PM from 155 vehicles per hour to around 35 vehicles per hour by 10:00 PM.

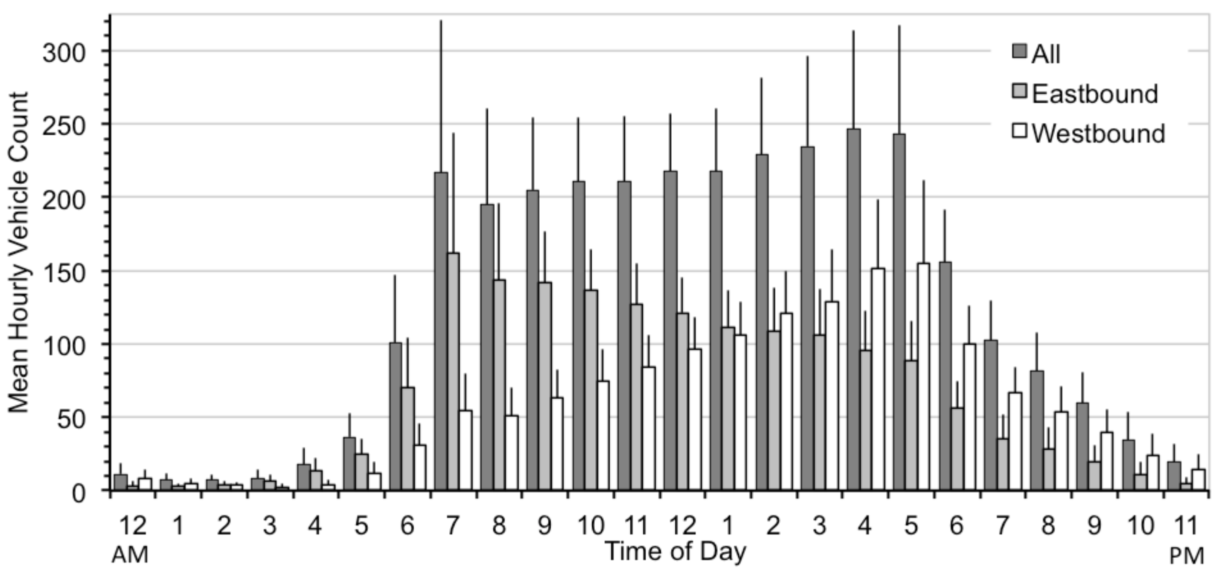


Figure 6.8: Mean hourly vehicle count.

The most interesting aspect shown in Figure 6.8 is the directionality bias in the traffic flow. During the peak morning hour from 7:00 AM to 8:00 AM, eastbound traffic was almost twice the volume as the westbound traffic. By the peak evening hours, 4:00 PM to 6:00 PM, that ratio had reversed and the westbound traffic volume was greater than the eastbound traffic volume by 50 to 75 percent. Overall, the traffic patterns observed through the test site are similar to typical commuting patterns, suggesting that many of the drivers traversing the test site are probably familiar with the road and the area. Although the video was not extensively analyzed, aside from cars, there were a fair number of light trucks, light trucks pulling trailers, and recreational vehicles observed during the fall months.

6.2.3 Vehicle Speeds

Mean vehicle speeds data set was calculated for every hour by first determining the mean speed of each vehicle detected by the SMS radar system, and then determining the mean speed for each direction of travel by averaging the speeds of all the vehicles traveling that direction during the time period. No attempt was made to detect or account for vehicles either turning on to or off of the main test site road. As noted in the previous section of this report, the vehicle counts for each direction did vary by hour, so the resulting mean speeds are based on differing sample sizes. This resulted in 13774 samples (6887 hours per lane), and 324 samples were discarded due to a lack of data, typically because no vehicles were observed traveling through the test site during those time periods.

The observed mean hourly vehicle speeds ranged from 14.4 to 94.8 mph, with an overall mean of 58.1 mph (SD 3.3). (See Table 6.3) As shown in Figure 6.9, the distribution of mean hourly vehicle speeds was fairly compact, and 97 percent of the observed mean hourly speeds fell between 47 and 65 mph. Mean hourly speeds above 70 mph accounted for only 0.4 percent of the data (about 53 hourly observations), typically occurring between 11:00 PM and 5:00 AM. Furthermore, the mean hourly vehicle speeds for these observed hours were only based on the data of 1 to 5 vehicles.

Table 6.3: Overall mean hourly vehicle speeds (mph).

Direction	Min	Max	Median	Mean	Std. Dev.
Eastbound	14.4	88.1	57.7	57.5	3.1
Westbound	31.8	94.8	59.1	58.7	3.3
Total (Both Directions)	14.4	94.8	58.3	58.1	3.3

To examine the hourly vehicle speed data set, a generalized linear model was created in SPSS assuming an underlying normal distribution for the vehicle speeds. The model included month, day of the week, hour of the day, direction of travel, and weather conditions. It also included all of the 2-way interactions with direction of travel, except for the interaction with weather. All of the main effects were significant (see Table 6.4), but most the interactions with direction of travel were not.

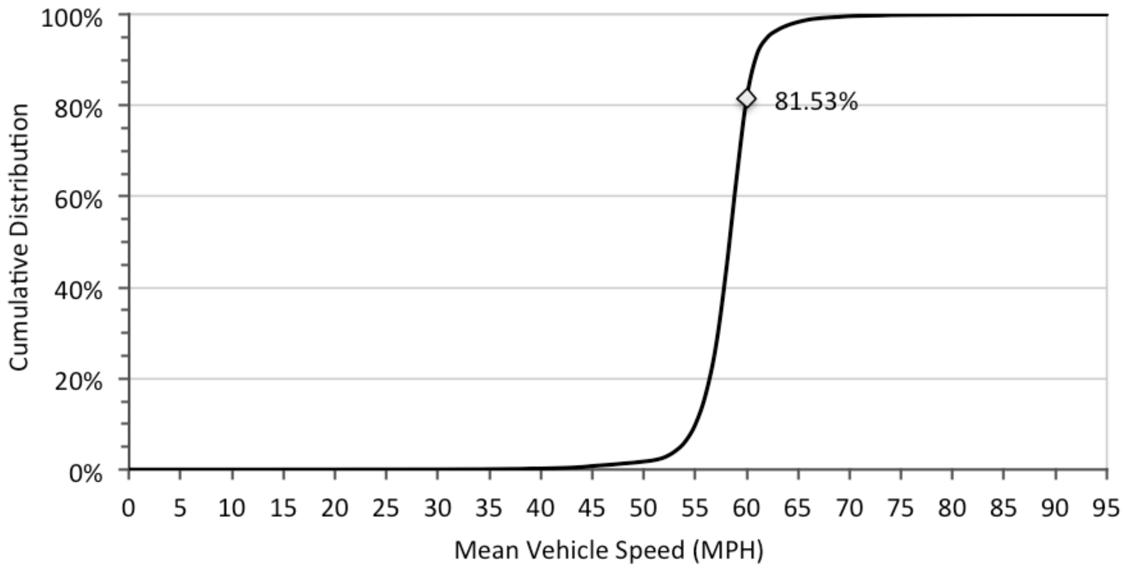


Figure 6.9: Cumulative distribution of mean hourly speeds.

Table 6.4: Mean hourly vehicle speed generalized linear model test results.

Model Parameter	Wald Chi-Square	Degrees of Freedom	Significance
(Intercept)	245066.25	1	$p < 0.001$
Study Month	113.27	9	$p < 0.001$
Day of the Week	46.91	6	$p < 0.001$
Hour of the Day	679.43	23	$p < 0.001$
Travel Direction	472.39	1	$p < 0.001$
Weather Conditions	63.74	3	$p < 0.001$
Month * Direction	15.16	9	$p = 0.087$
Day * Direction	10.28	6	$p = 0.113$
Hour * Direction	92.69	23	$p < 0.001$

Although most of the modeled effects were statistically significant, most of the modeled effects were not practically significant. Although statistically significant, the overall difference in the mean hourly speeds between eastbound and westbound traffic (Table 6.3) was only 1.2 mph. As shown in Figure 6.10, the mean hourly vehicle speeds were almost identical across the 10 months of the study, but the mean speeds were slightly less during the winter months of November, December, and January when compared to the late summer and early fall months. The mean hourly speeds in the winter months was 57.8 mph (SD 3.3), while the mean hourly speeds in the late summer and early fall months tended to be up around 58.5 mph (SD 3.2). Similarly, when examining the hourly speeds by the day of the week, the mean speed for Wednesdays was only 57.8 mph (SD 3.4) while the other weekdays averaged closer to 58.2 mph (SD 3.2). With the large sample size of hourly speeds, very small differences could be found to be statistically significant.

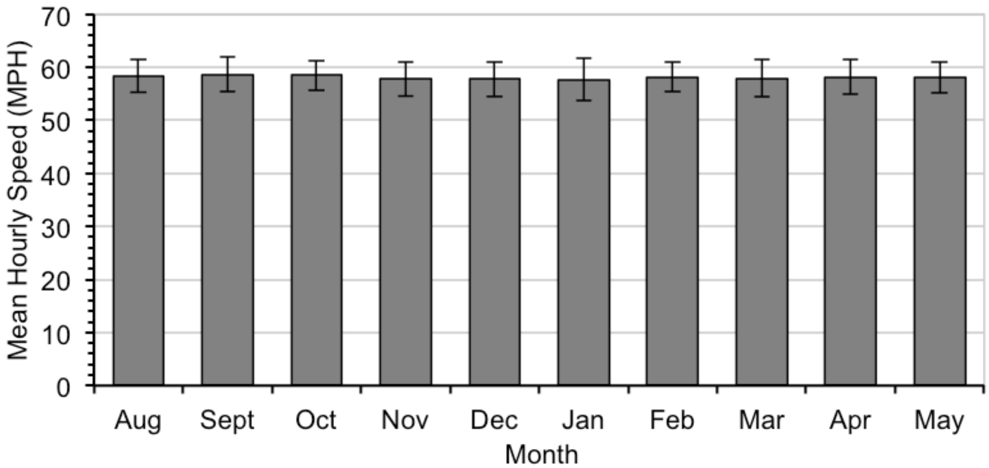


Figure 6.10: Mean hourly speeds by month.

Similarly, although hour of the day was significant, the largest difference in mean vehicle speeds between any two hours was only 2.8 mph. The hour with the highest mean speed was 4:00 AM with a mean 59.2 mph (SD 4.4), and the hour with the lowest mean speed was 8:00 PM with a mean of 56.4 mph (SD 2.1). As shown in Figure 6.11, the mean speed of the eastbound traffic was almost always slightly faster than the mean speed of the westbound traffic, and the variability, standard deviation, increased from 10:00 PM through 5:00 AM. The significant interaction between hour of the day and the direction of travel simply indicated that difference between the eastbound and westbound traffic varied from 0.1 to 2.2 mph by time of day. The mean difference in speed between the two directions was generally higher during the day and lower in the evenings and overnight.

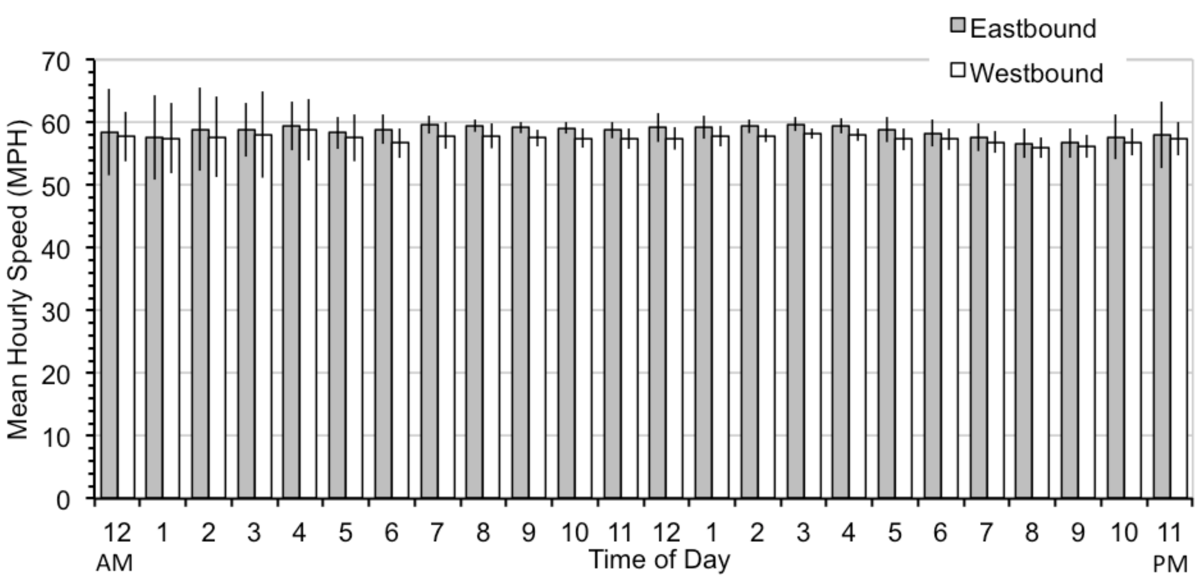


Figure 6.11: Mean hourly speeds.

Finally, weather conditions can be one of the most important factors in predicting traffic speeds, and in this analysis, the factor for weather conditions was significant. The nearest weather station to the test site that contained a complete set of data was located at the Montague-Siskiyou County Airport, approximately 25 miles northeast of the test site. This particular station is run by the National Weather Service, and it was chosen based on both reliability and data availability. It should be noted that this station is 25 miles away, and in this mountainous region of Northern California, the weather at the test sight might not have been exactly the same as the weather recorded at this weather station.

There was a slight reduction in the mean hourly speed when either rain or snow was reported. During clear or foggy weather, the mean hourly speed was 58.5 mph (SD 3.2), and that mean hourly speed dropped to 57.2 mph (SD 3.4) when rain was present. When snow was present, the mean hourly speed dropped to 56.3 mph (SD 5.7). Using a post-hoc pairwise comparison test, the mean hourly speeds during rain and snow were significantly different from clear or foggy conditions, and they were significantly different from each other. However, it should be noted that the weather station only reported conditions on an hourly basis, and it did not report the amount or magnitude of the rain or snow during those conditions. Thus, both a drizzle and a downpour are classified as rain, and both a flurry and a blizzard are classified as snow.

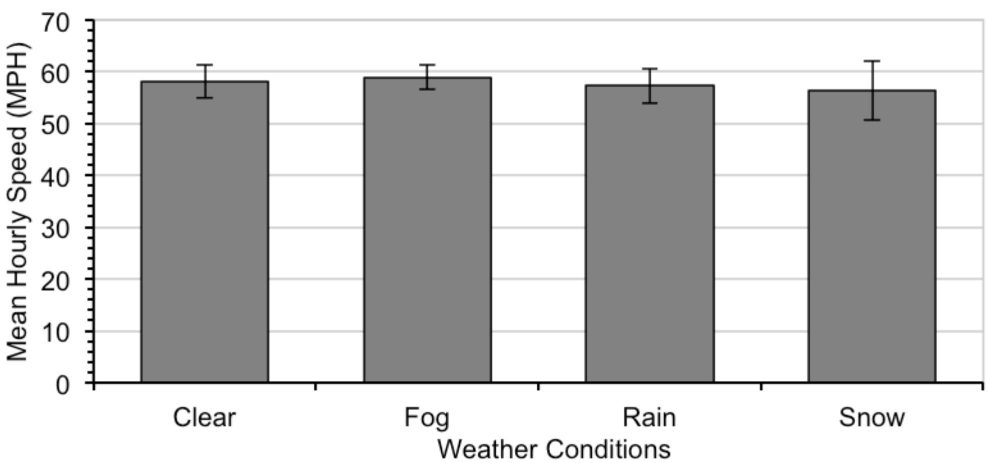


Figure 6.12: Mean hourly speed by weather condition.

Comparing PAWS Events Before and After Uncovering the Warning Signs

6.2.4 Overview

During the first 2.5 months of the study from August 3rd through October 16th, 2011, the PAWS system was activated, but the warning signs were covered. This initial part of the data collection serves as a measure of the baseline driving behavior through the test site, allowing for a direct comparison between providing or not providing PAWS warnings to the drivers. During the entire 10 months of data collection, 4882 PAWS events were recorded and analyzed. Approximately 28 percent (1368) were recorded during the baseline time period, and the remaining 72 percent (3514) were recorded during the active warning time period after the dynamic warning signs were uncovered and a warning message was visually communicated to the drivers. However, in each of the analyses, the number of events might be reduced for various reasons such as false alarms or lack of vehicles traveling through the test site during the event.

For the purpose of data recording on the DAS, a typical PAWS event included about 12 minutes of data and video. However, for the purposes of the analysis, PAWS events were redefined to include only the time period when the warning signs were active. The mean warning sign activation was only 3.9 minutes (SD 2.8). The PAWS event analysis period was further expanded included an additional 30 seconds both prior to the warning sign activation and after the warning signs deactivation, since it took between 30 and 45 seconds for vehicles to clear the test site. Thus, the mean PAWS event duration (for the purpose of this evaluation) varied from 3.6 to 4.3 minutes by month. There was no difference in the mean PAWS event duration between the baseline and warning time periods; however, PAWS events suspected of being triggered by turning vehicles were slightly shorter than events suspected of being triggered by animals with means event durations of 3.5 (SD 1.5) and 4.5 (SD 4.6) minutes, respectively.

6.2.5 Vehicle Speeds

The first comparison between the baseline and treatment or warning conditions was based on an examination of the mean vehicle speeds travelling through the test site during the PAWS event using a generalized linear model in SPSS, assuming an underlying normal distribution for the vehicle speeds. The hypothesis was that drivers would slow down and drive more cautiously when the dynamic animal warning signs were illuminated. The results are shown in Table 6.5, and the model included month, day of the week, hour of the day, direction of travel, and weather conditions, and warning status (signs covered vs. uncovered). It also included all of the two-way interactions with direction of travel and with warning status, except for the two-way interaction between month and warning and those with weather. These two-way interactions could not be examined since the baseline time periods were recorded only during the fall. In this analysis, the factors of month, day of the week, hour of the day, and direction were all included in the model because these factors were previously found to significantly affect the hourly speeds recorded through the test site.

Table 6.5: PAWS event vehicle speeds generalized linear model test results.

Model Parameter	Wald Chi-Square	Degrees of Freedom	Significance
(Intercept)	16264.345	1	$p < 0.001$
Study Month	55.659	9	$p < 0.001$
Day of the Week	33.517	6	$p < 0.001$
Hour of the Day	747.171	23	$p < 0.001$
Travel Direction	68.557	1	$p < 0.001$
Weather Conditions	6.229	3	$p = 0.101$
Warning Presence	15.959	1	$p < 0.001$
Month * Direction	18.383	9	$p = 0.031$
Day * Direction	9.899	6	$p = 0.129$
Hour * Direction	283.508	23	$p < 0.001$
Day * Warning	10.682	6	$p = 0.099$
Hour * Warning	131.698	23	$p < 0.001$
Direction * Warning	0.000	1	$p = 0.998$

Of the original factors found to significantly influence the mean hourly travel speeds through the test site, only weather was not found to be significant in this analysis. Although by percentage, adverse weather occurred during events with a frequency similar to the test period as a whole, there were still only 60 PAWS event occurring when it was snowing, and weather was not balanced as evenly distributed as other factors. However, the primary goal of the analysis discussed in this section was to determine whether or not the presence of the dynamic animal warning signs influenced the speed of the traffic traveling through the test site.

The main effect for the warning presence was significant, Wald $\chi^2_1 = 15.959$, $p < .001$, and the interaction between the warning presence and the hour of the day was also significant, Wald $\chi^2_{23} = 131.698$, $p < .001$. Interestingly, the interaction with the direction of travel was not a significant factor in predicting the vehicle speeds during an event, even though the direction of travel had been a significant in predicting the mean hourly speed of the traffic travelling through the test site and even though the westbound traffic was missing one of the warning signs for several months at the beginning of the study.

The mean speed during baseline PAWS events (when the animal warning signs were covered) was 56.2 mph (SD 4.4), and the mean speed during PAWS events when the signs were visible to the drivers was 53.1 mph (SD 6.1), suggesting that overall, there was a 3.1 mph drop in the mean vehicle speed when the animal warning signs were illuminated. Furthermore, the interaction between warning presence and time of day is shown in Figure 6.13. This interaction implied that the reduction in mean vehicle speed when the animal warning signs were illuminated was greater in the evenings and overnight, than during the day. This pattern might be explained by driver expectation. If drivers felt that activations during the daytime hours were more likely to be caused by human activity (turning vehicles), while evening and night activations would be more likely to be caused by wildlife, then the drivers might have slowed down more during the evening and night hours than during the daytime hours.

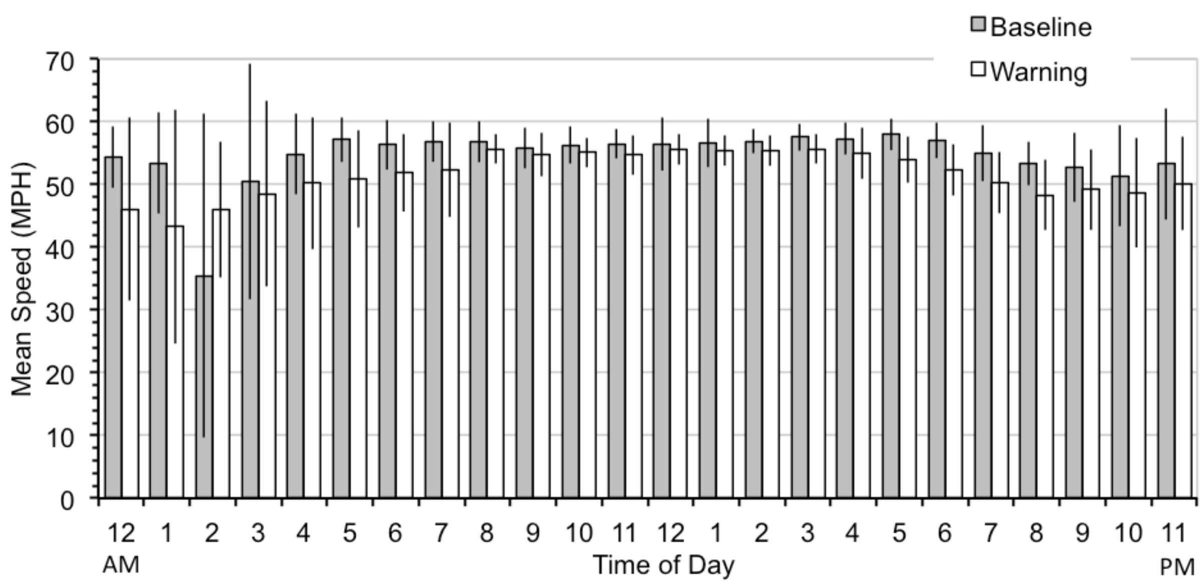


Figure 6.13: Mean speed during PAWS events by hour and by animal warning sign presence.

From 8:00 AM to 5:00 PM, vehicle speeds were reduced by an average of 1.7 mph when the warning signs were illuminated, while from 5:00 PM to 8:00 AM, vehicle speeds were reduced by an average of 4.9 mph. The one exception was 2:00 AM where baseline vehicle speeds (signs covered) averaged 10.1 mph slower than the vehicle speeds when the warning signs were illuminated. However, it should be noted that the baseline (signs covered) estimate of vehicle speeds at 2:00 AM was only based on the observation of five vehicles, three of which were moving very slowly. Although there were 10 baseline PAWS events that occurred around 2:00 AM, there was simply no traffic travelling through the test site during most of those events. In essence, this data point is definitely an outlier rather than a legitimate effect.

6.2.6 Vehicle Decelerations

The second set of comparisons between the baseline and warning conditions was based on an examination of the vehicle deceleration patterns occurring during the PAWS events. Even if drivers did not slow down, it is possible that the presence of the illuminated animal warning signs would prompt drivers to be more alert, allowing them to detect the wildlife in the roadway more quickly. By being more alert, drivers encountering wildlife should react faster, and thus, less abruptly. If this were the case, then one possible hypothesis would state that reductions in the mean or peak deceleration rate should be seen between the baseline and warning conditions.

In order for a vehicle to be counted as decelerating, the vehicle must have decelerated by more than 10 mph with a peak deceleration rate greater than 0.05 g. This criterion eliminated vehicles with only minor fluctuations in speed from the data set. Of the 4882 PAWS events, decelerating vehicles were only observed during 2825 or 58.9 percent of the cases. Of those cases, 27.2 percent occurred during the 2.5 month baseline period, and 72.8 percent occurred during the 7.5 months after the animal warning signs were uncovered, which is roughly equivalent to the 25/75 percent split that would be expected based solely on the length of time recorded for each condition. The drop in speed during a deceleration event was 32.6 mph (SD 14.6), and this was not surprising given that most of the decelerations were due to turning vehicles or the presence of wildlife in the roadway.

The first analysis of the vehicle deceleration patterns examined the mean deceleration rate of the vehicles observed to be decelerating during the PAWS events. For each vehicle, the mean deceleration rate was computed over the vehicle's deceleration event. Overall, the mean vehicle deceleration rate during PAWS events was 0.091 g (SD 0.037). For reference, around 0.05 g of deceleration can be achieved in some vehicles by simply letting off the throttle. Typically, around and above 0.1 g of deceleration requires the application of the vehicles brakes, and 0.2 g of deceleration is typically a moderate braking.

A generalized linear model was created in SPSS to examine the effects of month, day of the week, time of day, weather, and presence of the animal warning signs. Since deceleration rate was the dependent measure, the model used the assumption of an underlying gamma distribution with a logarithmic link function. The model included all of the main effects, but only the interactions between warning and day of the week and warning and hour of the day could be examined due to missing cells. Of the factors examined, only the main effects of month (Wald $\chi^2_9 = 30.389$, $p < .001$), time of day (Wald $\chi^2_{23} = 54.422$, $p < .001$), and absence or presence of the PAWS warning (Wald $\chi^2_1 = 8.117$, $p = .004$), were significant.

However, although statistically significantly different, there were no discernible patterns or trends based on either month or hour of the day, and the differences in the mean decelerations rates were very small. By month, the mean deceleration rates ranged from 0.083 g to 0.098 g (see Figure 6.14), and by hour the mean deceleration rates ranged from 0.068 g to 0.111 g. There was a minor reduction in the mean deceleration rate once the animal warning signs were uncovered for the driving population. The mean deceleration rate during the baseline time period was 0.098 g (SD 0.038) while the mean deceleration rate once the warning signs were uncovered was only 0.088 g (SD 0.037). Again, although statistically significant, these differences in the mean declaration rates are very minor and are probably not practically significant.

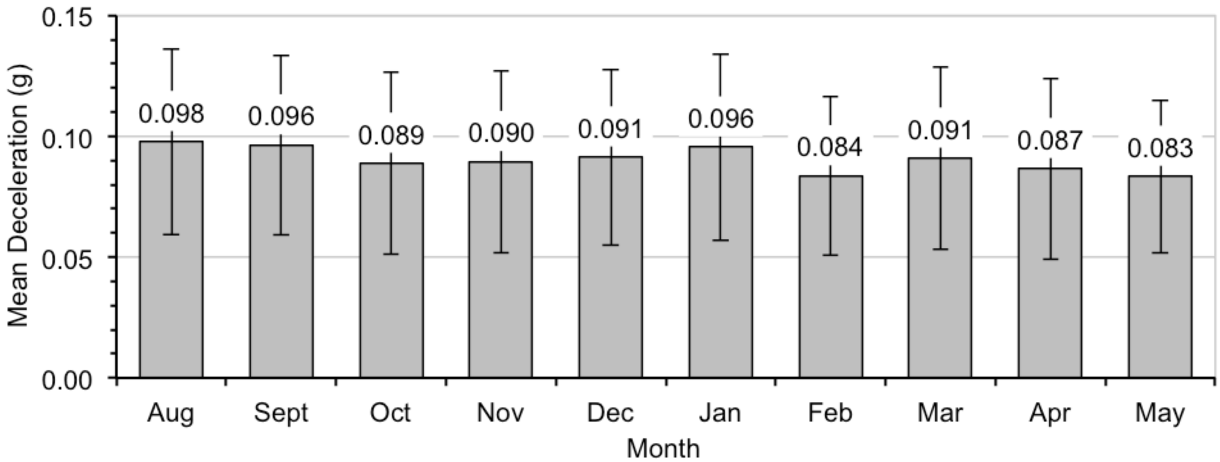


Figure 6.14: Mean deceleration rate by month.

The second analysis of vehicle deceleration patterns examined the peak deceleration rates of the vehicles observed to be decelerating during PAWS events. Overall, the mean peak deceleration rate during PAWS events was 0.201 g (SD 0.092). Similar to the analysis of the mean deceleration rate, a generalized linear model, assuming an underlying gamma distribution with a logarithmic link function, was created in SPSS to examine the effects of month, day of the week, time of day, weather, and presence of the animal warning signs. Again, only the main effects of month (Wald $\chi^2_9 = 33.904$, $p < .001$), time of day (Wald $\chi^2_{23} = 75.171$, $p < .001$), and absence or presence of the animal warning signs (Wald $\chi^2_1 = 4.257$, $p = .039$), were significant. The mean peak deceleration rates are shown by month in Figure 6.15.

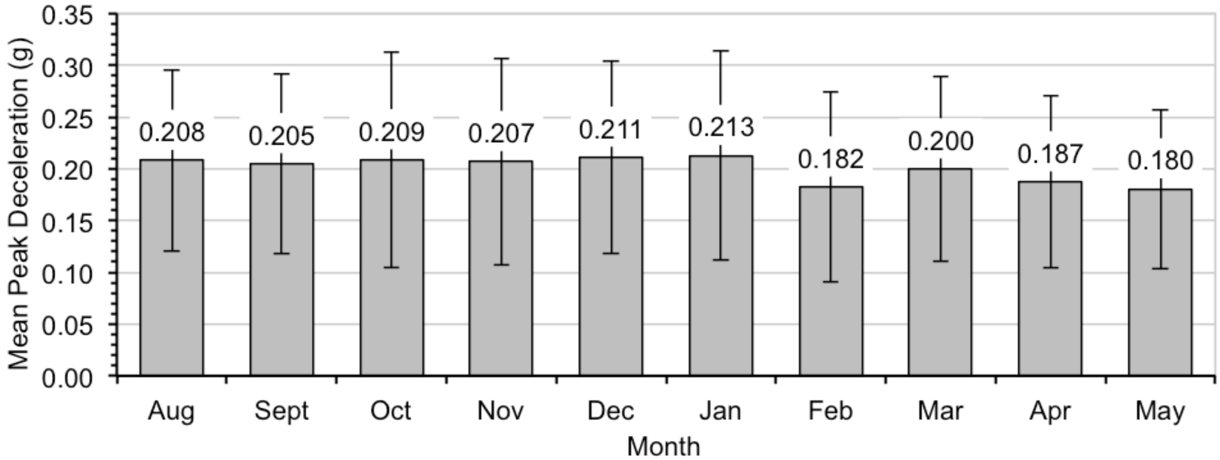


Figure 6.15: Mean peak deceleration rate by month.

Although there was a significant main effect found for the presence of the animal warning signs, the reduction in the mean peak deceleration rate was only from 0.210 g (SD 0.089) to 0.198 g (SD 0.092) once the warning signs were uncovered. Additionally, there was a significant main effect found for the month of the study, and the overall trend showed higher mean peak deceleration rates during the earlier months of the study as compared to the later months of the study. Unfortunately, the effect of the animal warning signs is confounded by time, since the animal warning signs were covered from August through October, and uncovered from November through May. Since elevated mean peak deceleration rates were also seen though the months of November, December and January, it is unlikely that the animal warning signs really influenced the peak deceleration rates. It is more likely that indeterminate seasonal variations were a larger factor in predicting the peak deceleration rates.

6.3 Comparing Pre-Events to PAWS Events

6.3.1 Overview

The previous section of this report examined PAWS events using the period of time at the beginning of the study (when the animal warning signs were covered) as a measure of the baseline driver behavior. While using this initial time period as a baseline allows for a very direct comparison of like conditions (i.e., the conditions surrounding PAWS events), this experimental design comes with the downside of introducing time as a confounding factor. When looking at 10 months of data, the baseline before treatment experimental design might not be sensitive to effects that may manifest or change over time. As an example, the baseline before treatment design is not always sensitive to the effects of adaptation over time. A strong effect seen shortly after the treatment began could dissipate over time, or the effect could be amplified or reduced by some other time-related variable.

The analysis performed in this section examines the data that was collected using pre-event time periods as a measure of the baseline driver behavior. For each PAWS event resulting in the activation of the dynamic warning signs, a matching period of time was located just prior to the PAWS event. The matched baseline segment was generally several minutes prior to the PAWS event, it needed to be of approximately the same duration as the subsequent PAWS event, and the matched baseline segment could not be part of a previous PAWS event. Given that this experimental design requires the animal warning signs to be illuminated, the analysis only looks at data after the signs were uncovered, from October 17th, 2011, through May 30th, 2012.

During the roughly 8-month analysis period, 3514 PAWS events (53.1 percent of the data set) and 3108 matched baseline time periods (46.9 percent of the data set) were included. Fewer matched baseline time periods were expected given the selection criteria that excluded pre-event time periods during closely spaced PAWS events. The matched baseline time periods tended to be about 90 seconds longer than the PAWS events. The mean PAWS event (including the previously discussed 30 seconds both prior to and post event) was 4.9 minutes (SD 3.0), while the mean matched baseline segment was 6.4 minutes (SD 2.4). Neither baseline nor event durations appeared to vary much by month, day of the week, or time of day.

In the previous analyses, both the mean vehicle speed and vehicle deceleration behavior were examined, comparing the baseline (signs covered) to the treatment (signs uncovered). In the current analysis, it only makes sense to compare mean vehicle speeds between the baseline (pre-event) and treatment (PAWS event) cases. During pre-event conditions, there would simply be no expectation of vehicles to be slowing since there was no wildlife detected, and the resulting data corroborated this hypothesis. Very few decelerating vehicles were noted during the pre-event baseline segments. Only about 1 vehicle was found to be decelerating for every three baseline segments, while a mean of 1.2 vehicles was found to be decelerating during each PAWS event segment.

6.3.2 Vehicle Speeds

The comparison between the baseline (pre-warning) and PAWS warning conditions examined the mean vehicle speeds travelling through the test site using a generalized linear model in SPSS, assuming an underlying normal distribution for the vehicle speeds. The hypothesis was that drivers would slow down and drive more cautiously when the dynamic animal warning signs were illuminated as compared to the pre-event speeds. The results are shown in Table 6.6, and the model included month, day of the week, hour of the day, weather conditions, and warning presence (pre-event vs. PAWS event). It also included two-way interactions between warning presence and month, hour of the day, and weather since the warning by hour interaction had previously been found to be significant and the other two interactions could not be tested using the previously examined experimental design.

The factors of month, day of the week, hour of the day, and weather were already noted to subtly influence the overall speeds of the vehicles traveling through the test site, and thus, their significance in this analysis is both expected and unremarkable. More relevant to this analysis is that the main effect for warning presence and the interactions between warning presence and both month and hour are all significant. Overall, the mean speed prior to a PAWS event was 58.3 mph (SD 3.2) and the mean speed while the animal warning signs were illuminated was 53.1 mph (SD 6.1), or about 5.1 mph slower. Although the interaction between warning presence and month was statistically significant, there was very little change in the magnitude of the speed difference between pre-event and event conditions. (See Figure 6.16). The month of

November provided the largest difference between the baseline and treatment conditions with a mean speed difference of 5.8 mph, while May provided the smallest difference at only 4.5 mph.

Table 6.6: Pre-event vs. PAWS event vehicle speeds generalized linear model test results.

Model Parameter	Wald Chi-Square	Degrees of Freedom	Significance
(Intercept)	47731.126	1	$p < 0.001$
Study Month	40.785	7	$p < 0.001$
Day of the Week	21.527	6	$p = 0.001$
Hour of the Day	964.205	23	$p < 0.001$
Weather Conditions	13.874	3	$p = 0.003$
Warning Presence	198.556	1	$p < 0.001$
Month * Warning	19.777	7	$p = 0.006$
Hour * Warning	361.46	23	$p < 0.001$
Weather * Warning	2.688	3	$p = 0.442$

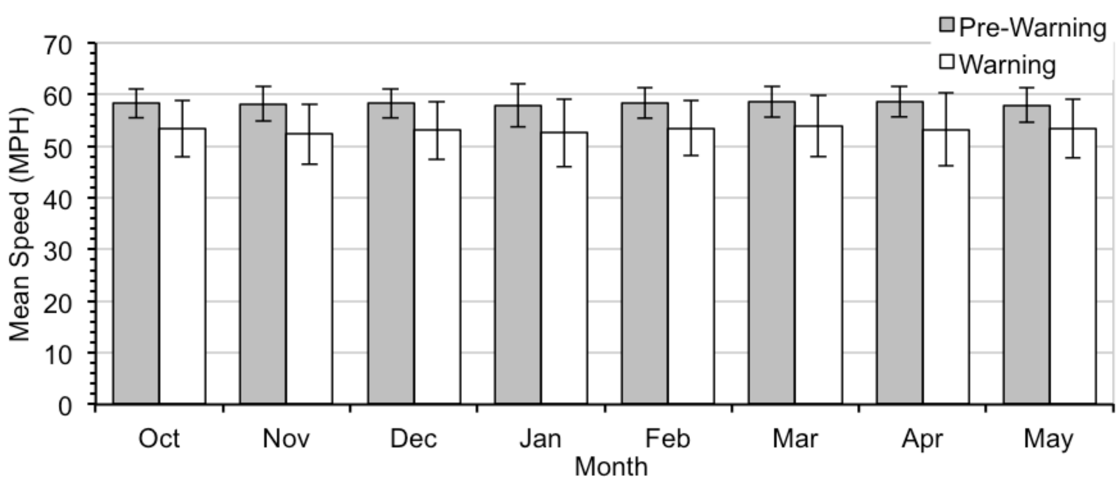


Figure 6.16: Mean speed by month and warning presence using pre-warning as baseline.

The interaction between warning presence and hour of the day was also significant, and this interaction is shown in Figure 6.17. Similar to the previous analysis using a different measure of the baseline, this interaction shows that the reduction in mean vehicle speed when the animal warning signs were illuminated was greater in the evenings and overnight, than during the day. From 8:00 AM to 6:00 PM, vehicle speeds were reduced by an average of 3.6 mph when the warning signs were illuminated, while from 6:00 PM to 8:00 AM, vehicle speeds were reduced by an average of 8.3 mph.

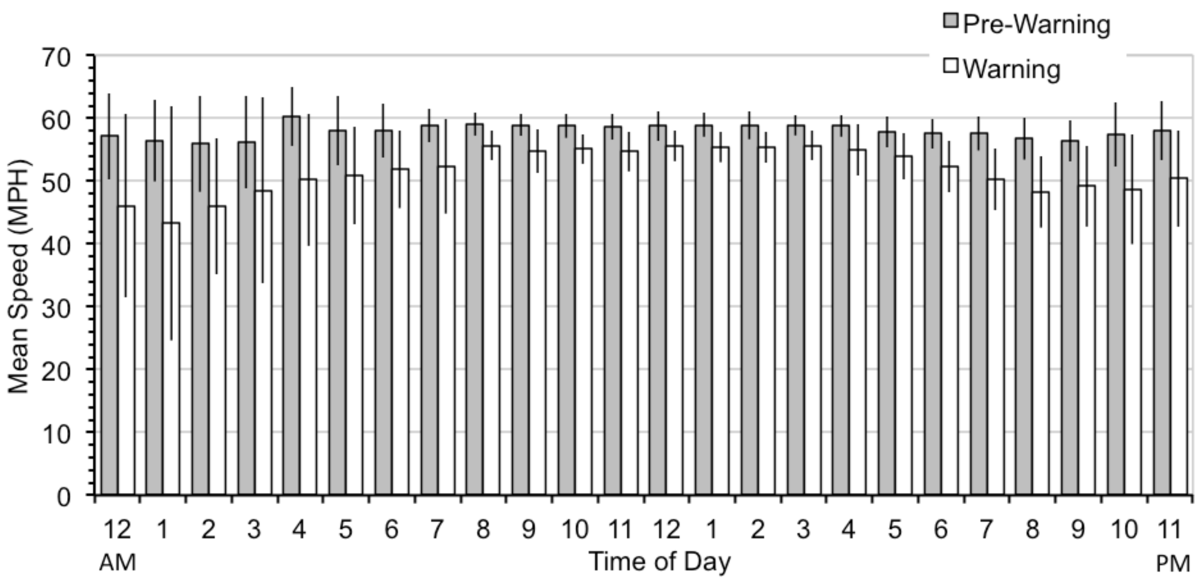


Figure 6.17: Mean speed by hour and warning presence using pre-warning as baseline.

7 CONCLUSIONS

Analysis of the Ft. Jones Test Site Data

7.1.1 PATH Animal Warning System (PAWS) Performance

The California PATH Animal Warning System (PAWS) and Data Acquisition System (DAS) operated on a nearly continuous basis at the Ft. Jones test site for roughly ten months (290 days) of data collection from August of 2011 until May of 2012. During this time, a total of 4882 PAWS events were generated, and the subsequent analysis of those events showed that the system appeared to function as designed. Since one of the animal detection radar beams crossed a side road, approximately 3292 events (67.4 percent) were likely triggered by vehicles onto that side road, while 1335 events (27.4 percent) were likely triggered by deer or other wildlife. Only 67 events (1.4 percent) were likely due to animal detection system sensor malfunctions.

An average of 11.4 vehicle-triggered events and 4.6 wildlife triggered events were generated each day. Increased vehicle-triggered events occurred in August and September during the harvest season, while increased wildlife-triggered events were seen in November, December, April, and May, corresponding to the months typically associated with increased deer activity. Wildlife-triggered events were also more likely to occur between the hours 5:00 PM and 9:00 AM. Finally, neither weather nor any other unexplained systematic bias appeared to influence the number of PAWS events generated.

7.1.2 General Driving Behavior in the Test Site

Hourly vehicle counts ranged anywhere from 0 to 421 vehicles, with a mean of 128.2 vehicles per hour. The overall vehicle counts were similar between travel directions with means of 67.7 eastbound and 60.5 westbound vehicles per hour; however, there was a directionality bias throughout the day. Eastbound traffic was heavier in the mornings while westbound traffic was heavier in the afternoons and evenings. The peak morning hour was from 7:00 AM to 8:00 AM with a mean of 216 vehicles per hour, while the peak evening hours were from 4:00 PM to 6:00 PM, averaging 215 vehicles per hour. Traffic volume dropped sharply overnight, averaging less than 18 vehicles per hour through morning.

The traffic counts described for the test site in this report are likely inflated due to imperfect radar tracking and filtering. Some vehicles could be reacquired, and counted as a new vehicle by the radar system. Additionally, bicycle and farm vehicles were detected by the SMS radar and counted as vehicles. Although the video was not extensively analyzed, aside from cars, there were a fair number of light trucks and light trucks pulling trailers. Significant heavy truck traffic was not noted, but recreational vehicles were observed during the fall months. The purpose of analyzing the traffic patterns was to verify whether or not the patterns observed in the test site were similar to typical commuting patterns. Based on this analysis, it can be concluded that many of the drivers traversing the test site are probably commuting, and thus, they would be familiar with both the road and the area in general.

The overall mean speed through the test site was 58.1 mph and the 85th percentile speed was between 60 and 61 mph. There were significant, but very minor variations in the mean speeds by month, hour of the day, day of the week, and weather conditions. The hour of the day with the highest mean speed was 4:00 AM at 59.2 mph, while the hour with the lowest mean speed was 8:00 PM at 56.4 mph. Monthly and daily variations amounted to a less than 1 mph difference in the mean speed. Inclement weather showed speed decreases of less than 2 mph, but it should be noted that weather data did not really distinguish the intensity of the weather. Thus, a drizzle and a downpour were both simply treated as rain. Overall, this analysis concludes that the mean speed through the test site was relatively stable during the data collection period.

7.1.3 Driving Behavior Changes Due to the PAWS Events

The main goal of this study was to try to understand whether or not the dynamic animal warning signs triggered by the PAWS system influenced the behavior of the drivers in the test site. In general, an experimental design must designate some conditions as baseline driver behavior and some conditions as the treatment for comparison. This study employed two different and complimentary experimental designs to try to understand whether or not the dynamic animal warning signs influenced driver behavior.

In the first analysis, the baseline conditions consisted of PAWS events or warning signs activations over the first 2.5 months of the study. During this time period, the dynamic animal warning signs were covered so that drivers could not see them, even though the PAWS system was fully operational. The treatment conditions consisted of PAWS events or warning signs activations over the remaining 7.5 months of the study after the dynamic animal warning signs were uncovered, allowing drivers to see them. This design allowed for a direct comparison between providing or not providing animal warning signs to the drivers.

One hypothesis proposed by this study was that the dynamic animal warning signs might reduce the traffic speeds when illumined, and this was confirmed. The dynamic animal warning signs had a significant effect on the traffic speeds when illuminated. Mean traffic speeds were reduced from 56.2 mph during PAWS events when the warning signs were covered to 53.1 mph during PAWS events when the warning signs were illuminated. The resulting 3.1 mph drop in the mean traffic speeds dwarfed most of the other effects that had been previously noted to influence the mean traffic speeds, and the dynamic animal warning signs appeared to be even more effective in the evening and overnight hours with an average mean speed reduction of 4.9 mph.

Using this same methodology, mean and peak vehicle deceleration rates were also examined, but the interpretation of this data was less clear. There were significant overall reductions in both the mean and peak declaration rates of the decelerating vehicles when the dynamic animal warning signs were activated, but these reductions only amounted to something on the order of 0.01 to 0.03 g. While these differences may have been statistically significant, the practical significance may be debatable. At most, if drivers were reducing their speed through the test site, then this result might suggest that drivers who did spot wildlife needed to brake slightly less hard to avoid them. However, given the large number of car-triggered animal warning sign activations, a much more detailed analysis of actual wildlife-triggered events would need to be undertaken to confirm or refute this hypothesis.

While the first experimental design provided for the most direct comparison between like conditions, there is always a possibility for driver adaption over time or other time-based effects to influence data when the baseline conditions occur early in the course of a long study. In order to mitigate these, a second analysis was conducted using a different experimental design. In this design, the time segment just prior to a PAWS event was used as a measure of the baseline conditions. By comparing traffic speeds just prior to an event with the traffic speeds during a PAWS event, a baseline that is not limited to the beginning of the 10 month study could be established. However, this second experimental design is not without criticism. During the pre-event baseline conditions, no wildlife was presumably detected, while during the event warning conditions, wildlife was presumably detected. Thus, using this methodology, the differences in mean speeds might be due either to drivers reducing their speed to be more cautious or drivers reducing their speed because they have actually spotted wildlife in the roadway.

Using this second experimental design, the analysis concluded once again that the illumination of the dynamic animal warning signs was associated with a reduction in the mean vehicle speeds through the test site. The mean pre-event speed was 58.3 mph while the mean speed while the animal warning signs were illuminated was 53.1 mph, resulting in a 5.1 mph speed reduction. Furthermore, the speed reduction remained relatively constant ranging from 4.5 to 5.8 mph throughout the 7.5 months of the study following the uncovering of the dynamic animal warning signs. Also, similar to what was seen using the first experimental design, the mean speed reductions tended to be greater in the evenings and overnight, averaging 8.3 mph.

Overall, the results of the two different experimental methodologies agreed that there was some reduction in the mean speeds of the drivers when the dynamic animal warning signs were illuminated, and those speed reductions were greater during the evening, overnight, and early morning hours when deer and other wildlife tend to be more active. There was also some hint of evidence that the declaration rates required when drivers spotted animals on the roadway may also have been reduced, but this conclusion was less strong and would require a more detailed analysis to further understand. Finally, it can also be concluded that there was no evident driver adaptation over time to the warnings provided by the PAWS system. The reductions in mean speed continued throughout the 7.5 months of the study when the dynamic animal warning signs were uncovered.

System Reliability

The results of the reliability tests at the test-bed in Lewistown MT, suggest that the system that was installed along SR 3 near Ft Jones, CA, may not quite meet the expectations of the stakeholders (based on previous surveys). However, the system was not far below these reliability expectations and system reliability may be improved through making the system less likely to desensitize when the beam is blocked for more than a few moments or when multiple breaks happen shortly after each other. The reliability of the system may be affected by winds suggesting that solid foundations, poles and a solid connection between the sensors and the poles are important. Increasing levels of humidity may also somewhat affect system reliability but the size of the species (ranging from sheep to llamas and horses) did not influence the probability of detections by the system.

The results of reliability tests of the system along SR 3 near Ft Jones, CA suggest that the system has no blind spots and that it can detect black-tailed deer and similar sized other large mammals reliably along the entire length of the road section equipped with the sensors. Beam 5 was not in operation at the time of testing though as a result of damage to the sensors when a car went off the road and hit a pole with equipment. The damaged sensor was not replaced yet at the time of testing. The researchers found evidence of a deer desensitizing a beam once in the 30 days that the data were analyzed for. However, there may have been more instances that were not visible on the video images. Further analyses of the detection log of the system showed that the average number of records with detections per day was not very high; about 20. This is important because if the warning signs would be on most of the day it would be too similar to warning signs that are always turned on and that are not connected to sensors. Nonetheless, based on a comparison to video images of cameras that were attached to some of the posts, most of these detections did not relate to the target species (black-tailed deer), and one could consider efforts to minimize the number of detections that do not relate to the target species. Most of the detections related to vehicles turning on and off SR 3, particularly at Air Force Way (beam 3).

System Effectiveness

There are multiple ways to measure the effectiveness of an animal detections system. For example, one may measure vehicle speed and compare vehicle speeds between situations when the warning lights are on and situations when the warning lights are off, one may measure driver alertness in specially equipped vehicles with research equipment or in a driving simulator, or one may measure the number of animal-vehicle crashes. For the purpose of this report by WTI, the researchers only investigated the potential effect of the operational animal detection system on animal-vehicle crashes.

The number of reported black-tailed deer carcasses in “control” road sections just before and after the road section with the animal detection system along SR 3 near Ft Jones, CA, appears to have declined from 2009 onwards. Assuming that the search and reporting effort for the carcasses indeed remained constant throughout the years, this suggests that the black-tailed deer population in the area has declined in the last years. This is consistent with some of the remarks of the public (see Chapter 8). There was one black-tailed deer carcass reported inside the road section with the system after the warning signs were unveiled on 17 October 2011. This animal was located towards the edge of the road section with the system and the animal detection system is only present on one side of the road at that location. Given the relatively low number of large mammal carcasses, especially from 2009 onwards, the relatively short road section with the system, and the relatively short time period during which the system was present with the warning signs attached, it is not really possible to conclude whether the animal detection system reduced the number of large mammal-vehicle collisions or not.

Survey

The results of the survey indicate that most respondents want the system removed. The most common concerns relate to the perceived cost of the system (not to be confused with the additional costs of research equipment and costs associated with conducting the research), the perception that the system is in the wrong location, that the warning signs being too bright at night, and the perception that the system is not reliable.

Recommendations

In the United States the total number of crashes (all types combined) has remained relatively stable over the last few decades. However, wildlife-vehicle collisions, primarily with large ungulates have increased by about 50% in the same time period (Huijser et al., 2008). This means that the number of wildlife-vehicle collisions is increasing and that they form a growing proportion of the total number of crashes that occur. These facts are among the primary reasons why the level of effort to address these types of collisions has been increasing.

One of the most effective and robust measures aimed at reducing wildlife-vehicle collisions and at providing safe crossing opportunities for wildlife is wildlife fencing in combination with wildlife underpasses and overpasses (Huijser et al., 2009a). However, these measures require relatively high upfront cost and are most practical in combination with new road construction or major road reconstruction. Animal detection systems require lower upfront costs (though the researchers currently project them to be more expensive on the long term because of their shorter life span and because these systems are not mass produced yet) and are more practical to implement along existing roads without major road reconstruction (for other pros and cons of animal detection systems vs. wildlife fences in combination with wildlife underpasses and overpasses see Huijser et al., 2008b).

The limited data on the effectiveness of animal detection systems suggest they can reduce wildlife-vehicle collisions with a similar percentage as wildlife fences in combination with wildlife underpasses and overpasses. However, animal detection systems must still be considered experimental as there are often challenges with the reliability of systems that need to be addressed. Other animal detection system projects have often been abandoned because of unreliable systems, an unwillingness or inability to address technological challenges, negative public opinion, loss of interest by decision makers and lack of operation and maintenance funds to continue operating the system after a research project has been completed and when associated funds are no longer available.

The system along SR 3 may well become more reliable, perhaps "sufficiently reliable", if certain modifications are made to the system (see below). Since it is rare to have a reliable system with associated research equipment in place, the researchers suggest continuing the research into the reliability and effectiveness of the system after potential system modifications have been implemented. Only then can we, as a society, make progress with the design and implementation of these systems and learn whether they indeed have a future as an alternative to wildlife fencing in combination with wildlife underpasses and overpasses.

If the system along SR 3 near Ft Jones, CA, is to stay in place, then the researchers suggest the following modifications:

Reliability improvements:

1. The sensors in beam 5 need to be replaced, potentially with sensors from another manufacturer as the current sensors may no longer be available. Without replacing the broken sensors in beam 5 the system is not fully functional which may lead to drivers misunderstanding inactivated warning signs on that road segment.

2. Many respondents complained about perceived unreliability of the system, including false positives caused by vehicles turning on and off the road. The vast majority (93%) of all correct detections for which the cause was identified related to vehicles turning on and off the road. Before the project was initiated it was known that the system reports vehicles that break the beam as a detection. Therefore this is a design issue that may need to be revisited rather than a failure of the detection technology. The number of these "false positives" can be greatly reduced if vehicles turning on and off the road no longer result in activated warning signs. The researchers suggest installing a detection loop at the side roads. If a vehicle is detected then the detection by the animal detection system can be declared "invalid" and the warning lights will not turn on. While there are two access roads in the road section with the system (in beam 3 and 4) one may choose to only install a loop at the access road that receives the highest use (Air Force Way in beam 3). Note that large wildlife species, including black-tailed deer, and humans will still trigger the system when they break the beam at the access road(s).
3. Some respondents reported deer on the road near the end of the section with the system without activated warning signs. The current system ends in different locations on opposite sides of the road. The researchers suggest revisiting this design as this may result in animals on or near the road without the warning signs being activated. As a general rule the researchers suggest that detection zones on opposite sides of the road should always start and end at the same location.

Reducing downtime and operation and maintenance costs:

1. Consider putting up short sections of guard rail around the posts to minimize damage to the system if a car runs off the road as it may take substantial time and funds to get the system repaired and back into operation.

Improving communication to drivers and the general public:

1. The brightness of the warning signs needs to be reduced during the night. While the current brightness of the sign may be what is needed to have the warning signs be visible during the day, the signs blind drivers and can lead to potentially hazardous situations based on the comments from the respondents. A different and bettering dimmer may be attached to the warning signs to adjust the brightness for different amounts of ambient light.
2. The current project was primarily a design, implementation and research project. Most research projects take place outside of the view of the public and the products are only shown to the public after extensive testing. Unfortunately animal detection systems need to be installed along a real road to investigate their effectiveness and not everyone may understand or accept that these systems may still have problems when they are first installed. In general, it is a good idea to investigate the reliability of a system at a closed access facility (see e.g. Chapter 4 and 5), before installing it along a real roadside. In addition, it is a good idea to investigate the reliability along a real roadside before attaching the warning signs, if the constraints of the project allow for this. This reduces the likelihood of reliability issues and it also reduces possible misunderstanding and annoyance by the public.

3. While the current project did include a website with general information about animal detection systems and the system that was installed along SR 3 near Ft Jones, CA, the current project was not a public education project. The current project was mostly aimed at designing and installing the system and investigating its reliability and effectiveness in the time period that was available. The current project was not aimed at providing the public with information about the results of the study as those results only became available towards the end of the project. If the system is to stay in place, and if system modifications are to be implemented, the researchers suggest a communication program that includes information on the system and the results of the study. Communication through a website and local and regional media are unlikely to be sufficient; it is desirable to have multiple public presentations in the area that allow for questions and discussion on relevant topics. Given the results of the survey it is especially important that the public is informed about funds associated with the research and development of animal detection systems vs. the actual costs with implementations if and when these systems are mass produced. It is also important to inform the public about the various parameters besides the number of large mammal-vehicle crashes that need to be considered when selecting a road section for an animal detection system.

Conduct sufficient research to answer the research questions:

1. The researchers are of the opinion that the current project was able to measure the reliability of the animal detection system fairly well. Additional reliability research may be advisable after potential system modifications have been implemented. Without such data one cannot be sure if thresholds for reliability have been met and one cannot inform the public about the reliability of the system.
2. The researchers are of the opinion that the current project did not allow sufficient time to investigate the effectiveness of the system with regard to large mammal-vehicle collisions. The researchers suggest monitoring large mammal carcasses in the control sections and in the road section with the animal detection system for multiple years (e.g. at least 3-5 more years) and then analyzing the data once again.

Improving project organization:

1. The researchers recommend a clear distinction in roles and responsibilities. Most notably, perhaps a research organization is not best equipped to install a system and be responsible for the implementation of construction codes, and the time period and budget available for the research is better protected if these roles and responsibilities are separated. It may be best if a research organization can focus on the design of a system, to make sure that the research questions are likely to be answered, and on conducting the actual research.
2. Carefully define the success parameters and threshold values for an animal detection system project. Being able to answer the research questions is obviously among the parameters. Other parameters can include thresholds for the reliability and effectiveness. While the experience and opinions of the public are very valuable in deciding on location, minimum performance criteria for reliability and effectiveness, and potential modifications to an animal detection system, public acceptance of, or opinion on, the long term future for animal detection systems should probably not be based on a system that may have design or reliability issues after its initial installation. It should probably be based on a strategic plan (see below). The public can and probably should have a role in

such a strategic plan but only if it is based on multiple systems that have been in place for considerable time in different regions where potential design and reliability issues have been corrected and where a communication plan has been executed to communicate about the purpose, reliability and effectiveness of the system.

3. Create a decision tree where the results (based on the success parameters) show what the next steps will be with regard to the development of animal detection systems, research into their reliability and effectiveness, and the potential future implementation of robust systems. The researchers suggest a general strategic approach to address increasing numbers of large mammal-vehicle collisions. Based on the results from previous projects animal detection systems, as stand alone or in combination with wildlife fences, should probably be part of this strategic approach; some systems have shown to be extremely reliable, and reliable and operational animal detection systems that have been investigated with regard to their effectiveness have shown that they can reduce collisions with large mammals substantially (roughly between 58% and nearly 100% reduction). While more and better data are still needed for system reliability and effectiveness, the most important research questions probably lie with the type of warning signs, associated text, potentially associated advisory or mandatory reductions in speed limit, and potential communication to drivers as they are approaching the site of a recent detection. Without a strategic approach individual animal detection system projects may not be as efficient as they could in answering questions that are essential for potential larger scale implementation. So far, there has been no coherent design, research and implementation program for animal detection systems anywhere in the world. Most research and/or implementation projects for animal detection systems have ended, but not always as a logical conclusion based on predefined success parameters and thresholds and a broader outlook for the potential future of animal detection systems. As a result, other animal detection system projects typically have to start once again with investments in detection technologies, site selection, and system construction, before the remaining research questions can be addressed.

APPENDIX A – WTI REPORT ON THE RELIABILITY AND EFFECTIVENESS OF THE AWS

Evaluation of the Reliability and Effectiveness of an Animal Detection System in a Test-Bed and along SR 3 near Ft Jones, CA

Final Report
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16. Abstract

This document reports on an animal detection system project in northern California. It describes the site that was selected for the installation of an animal detection system, and the rationale for the selection of a particular animal detection system technology. In addition, this document contains data on reliability tests of the system at a controlled access facility, environmental conditions that may affect system reliability, reliability and effectiveness of the system at the site in California, and a summary of driver's experiences with and opinions on the system. The researchers conclude with a series of recommendations.

17. Key Words	18. Distribution Statement
Animal, Detection system, Carcasses, Collisions, Crashes, Deer, Drivers, Effectiveness, Habitat connectivity, Highway, Mitigation measures, Public, Recommendations, Reliability, Safety, Survey, System, Test, Ungulates, Warning, Wildlife, Wildlife crossing, Wildlife-vehicle collision	Unrestricted. This document is available through WTI-MSU.

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ABSTRACT

This document reports on an animal detection system project in northern California. It describes the site that was selected for the installation of an animal detection system, and the rationale for the selection of a particular animal detection system technology. In addition, this document contains data on reliability tests of the system at a controlled access facility, environmental conditions that may affect system reliability, reliability and effectiveness of the system at the site in California, and a summary of driver's experiences with and opinions on the system.

The system that was selected is a microwave break-the-beam system manufactured by ICx Radar Systems (Scottsdale, AZ). The off-site reliability test took place at a test-bed specifically constructed to investigate the reliability of animal detection systems. The test-bed consisted of an animal enclosure, space for multiple animal detection systems, and six infra-red cameras with continuous recording capabilities. The animal enclosure included shelter, water, and an area alongside the fence that was designated for feeding. These three resources were located in different parts of the enclosure to maximize animal movements through the detection areas. The detection system recorded the date and time of each detection. In addition, there were infra-red 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 number of false positives was relatively low but the number of false negatives was relatively high. The percentage of all intrusions in the detection area that was detected was relatively low. Based on the values for the reliability parameters, the system does not meet the recommended minimum norms for the reliability of animal detection systems. Specifically, the percentage of false negatives is too high, and the percentage of intrusions detected is too low. However, when the downtime of the system was excluded, the percentage of false negatives dropped to about 4%. This suggests that the system can meet the suggested norms for reliability if the beam remains operational. In conclusion, the substantial downtime of the system (7.67%) during the tests with animals is a major concern, suggesting that the system may not be operational for substantial lengths of time.

Off-site tests showed that winds from the north and west were associated with higher false negative rates than east winds, and winds from the south were associated with lower false negative rates than east winds. This suggests that wind conditions play an important role in the ability of the system to correctly detect the presence of large mammals. Perhaps that stronger wind, especially from the north and west, caused the sensors to get slightly out of alignment. When the receiver does not receive a signal for a longer time period, the beam goes out of operation, allowing false negatives to occur. Higher temperatures were associated with an increase in false negatives. However, it is not clear how an increase in temperature would cause the radar detection system to generate more false negatives. There were relatively few false negatives during the night. This suggests that daylight is somehow associated with false negatives, but it is also possible that daylight is generally associated with stronger winds during the day, particularly from the north and west. An increase in humidity was associated with an increase in false negatives. Interestingly, the animal species did not matter enough to be included in the top model. This suggests that the system detects species that resemble sheep, llamas or horses in body size similarly. The results of this analyses suggest that it is very important that the poles and the sensors are firm and do not move in the wind.

A human triggered the system along SR 3 in California at about 66 ft (20 m) intervals. The results indicated that the system is capable of detecting a human and therefore is likely to also be able to detect large ungulates such as black-tailed deer. While the system did not have any blind spots, three of the beams did show evidence of desensitizing during testing, even with at least three minutes between consecutive triggers. This means that while the system is likely to detect deer as they approach and leave the road, the system may not be triggered another time if an animal continuously blocks the beam or if multiple animals cross the beam. Since the warning signs are programmed to remain on for three minutes after the last detection the desensitizing of the beams is likely to only affect a relatively small number of the deer crossings. Nonetheless, it is possible that deer are on or near the road without the warning lights being activated. While this can be considered a problem this phenomenon is also possible if the beams would not desensitize at all. For example, if an animal crosses a beam but then stays in the right-of-way (having fully passed the beam) or on the road for more than three minutes, the warning lights would also turn off with a deer still present.

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

The number of reported black-tailed deer carcasses along SR 3 in California appears to have declined from 2009 onwards. This decline occurred both in the control sections and the road section with the system. Assuming that the search and reporting effort for the carcasses indeed remained constant, this suggests that the black-tailed deer population in the area has declined in the last years. This is consistent with some of the remarks of the public. Given the relatively low number of large mammal carcasses, especially from 2009 onwards, the relatively short road section that has the system installed, and the relatively short time period during which the system was present with the warning signs attached, it is not really possible to conclude whether the animal detection system may have reduced the number of large mammal-vehicle collisions.

The results of the survey among drivers of the road section with the system along SR 3 in California indicated that most respondents want the system removed. The most common concerns relate to the cost of the system, the perception that the system is in the wrong location, the brightness of the warning signs at night, and the perception that the system is not reliable.

The researchers conclude with a series of recommendations related to improving the reliability of the system and reducing potential downtime and operation and maintenance costs, improving the warning signs and communications with drivers and the general public, conducting sufficient research to answer the research questions, and improving project organization.

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1 INTRODUCTION

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Background

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 has been detected, signs are activated warning drivers that large animals may be on or near the road at that time. Previous research has shown that, depending on road and weather conditions, the warning signs can cause drivers to reduce their speed (see review in Huijser & McGowen, 2003; Kinley et al., 2003; Gagnon et al., 2010; 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 (97%; Gagnon et al.,

2010) and Montana (58–67%; Huijser et al., 2009b). Since the effectiveness of animal detection systems depends on driver response, reliable warning systems are essential.

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 off site: Investigation of the reliability of the system at a controlled access facility in central Montana.
- System reliability on site: Investigation of the reliability of the system along SR 3 near Ft Jones, CA.
- Effectiveness on site: Investigation of the effectiveness of the system in reducing collisions with large mammals along SR 3 near Ft Jones, CA.

These objectives are discussed in the following chapters.

2 SITE DESCRIPTION

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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 section along SR 3 (Ft. Jones Rd.), near Ft Jones, CA (Figure 1). The section that had the animal detection system installed was about 1,030 m (0.64 mi) long between mi marker 36.6 and 37.3 (Sharafsaleh et al., 2010).
Below is a brief description of the site near Ft Jones, CA, where the animal detection system was installed in September 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.

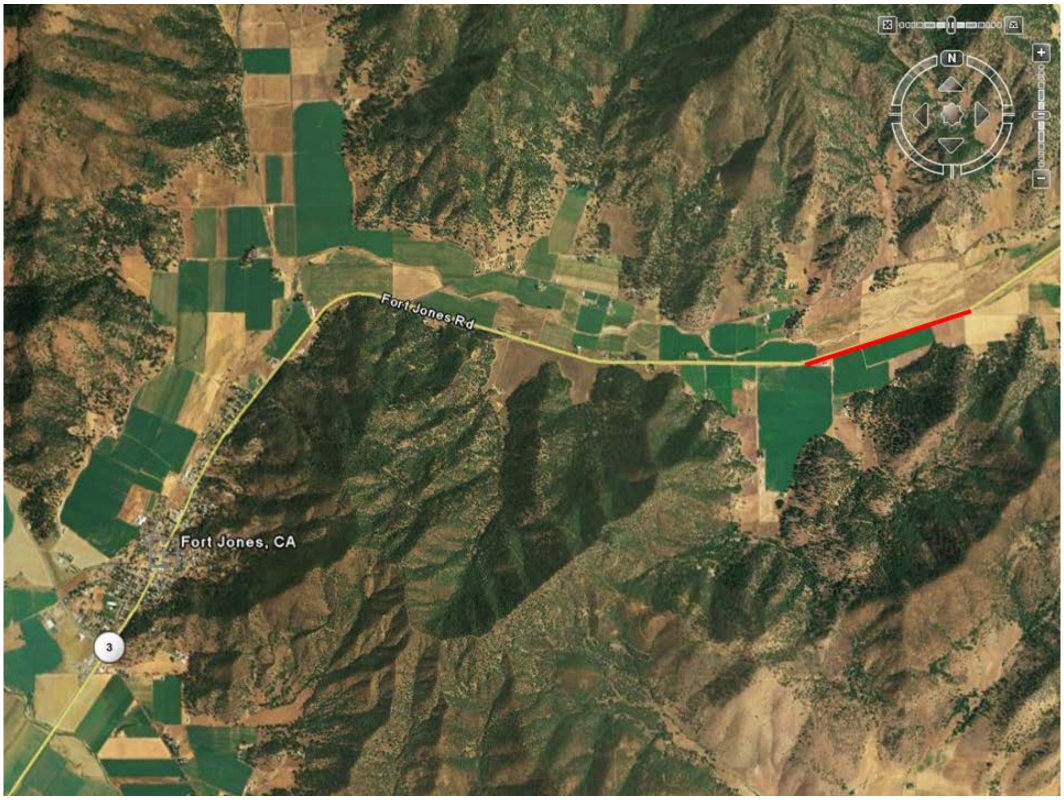

Figure 2.1. The road section (in red, about 1,030 (0.64 mi) long) with the location of the animal detection system along SR 3 (Ft. Jones Rd.) near Ft Jones, CA.

3 SYSTEM SELECTION

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System selection took place based on the following criteria:

- Reliability and effectiveness data from previous publications (e.g. 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:
  - The system must be able to operate with (ice) fog that occurs occasionally at the site.
  - The desire from Caltrans and California PATH to implement an animal detection system over a longer road section (originally 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.
  - 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 also 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 along SR 3 near Ft Jones in September 2009.

4 SYSTEM RELIABILITY IN A TEST-BED

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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 cables and wires associated with animal detection systems, infra-red 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 5). 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 were:

- Evaluate false positives and false negatives: Because the infra-red cameras that are 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 valid detections, false positives (system reports a detection but there is no animal present) or false negatives (an animal is present but the system does not report a detection) occurred. This is in contrast to the animal detection system along SR 3 near Ft Jones, CA, where the video cameras associated with the system to study driver behavior did not cover the full length of the road section with the animal detection system as it was not designed to detect animals crossing the different detection zones. Thus for the location along SR 3 near Ft Jones, the researchers were not always certain whether a detection was false or not. While the analyses of patterns in the detection data (see Chapter 6) may provide an indication of false positives and false negatives, the evidence is circumstantial. Furthermore, while triggering the system at regular distances (e.g. every 20 meters) using humans as a model for wildlife (see Chapter 6) does allow for investigation of potential false negatives and blind spots, 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 could 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 along SR 3 near Ft Jones, where the number of animal movements and thus sample size cannot be controlled.

- Effect of environmental conditions: A weather station was located near the test-bed. This allowed 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 along SR 3 near Ft Jones, where the number of animal movements is likely to be too small for an accurate assessment of system reliability, and where data on local environmental conditions may not readily be available. In summary, this effort not only allowed the researchers to measure the reliability of the system, but also allowed the researchers to understand which environmental conditions may influence the performance of the system.
- 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 along SR 3 near Ft Jones only black-tailed deer are present; there are no elk or moose in the area.

This chapter reports on the reliability of the microwave radio signal break-the-beam system manufactured by ICx Radar Systems. The reliability measurements took place in the test bed for animal detection systems near Lewistown, MT.

Methods

4.1.1 Test-Bed Location and Design

The RADS test-bed is part of the TRANSCEND cold region rural transportation research facility and is located along a former runway at the Lewistown Airport in central Montana (Figure 2). 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.

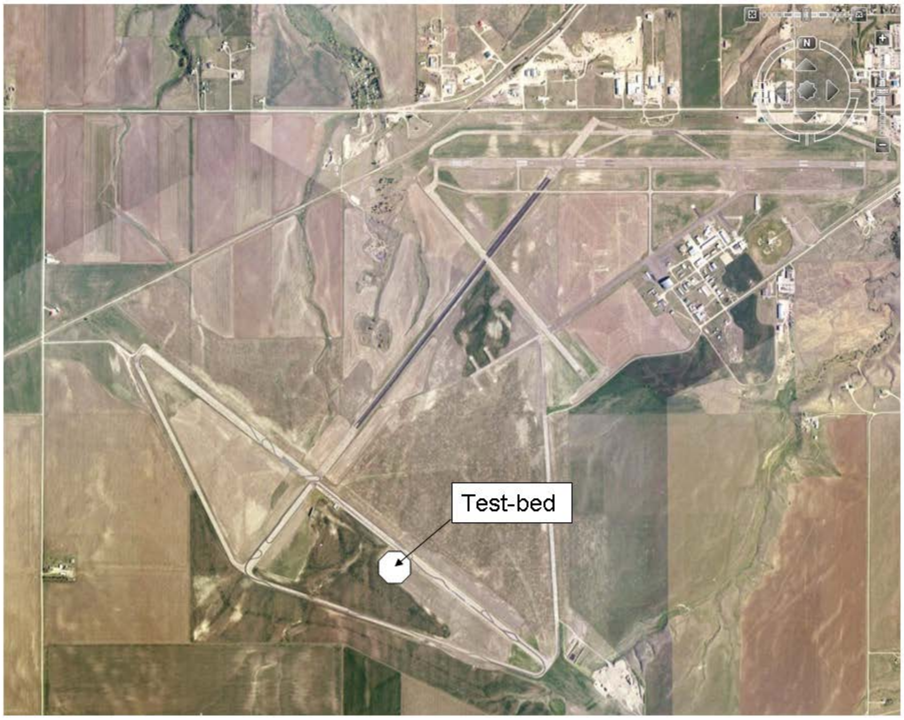

Figure 4.1. The location of the test-bed along a former runway at the Lewistown Airport in central Montana. The current municipal airport is located on the upper right of the photo.

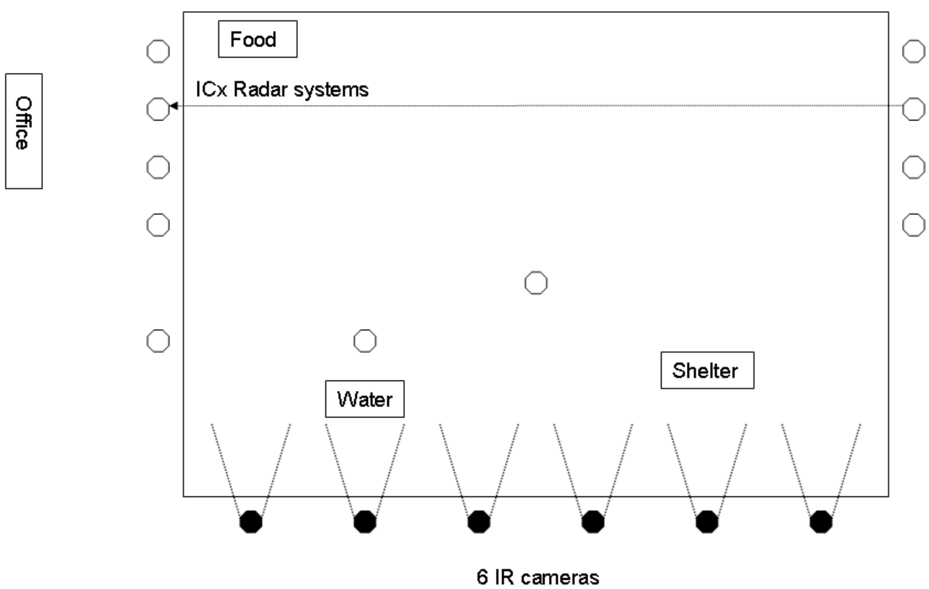

Figure 4.2. Test-bed design including an animal enclosure, the animal detection system tested for this project (open circles represent poles on which sensors can be attached), the six infra-red (IR) cameras aimed at the enclosure from the side (solid circles), and the office with data recording equipment. The arrow shows the direction towards which the transmitter is pointed.

Figure 4.3. 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 4.4. The infra-red cameras that monitor animal movements in the enclosure (Photo: Marcel Huijser, WTI/MSU).

4.1.2 *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 along SR 3 near Ft Jones, CA, in September 2009. The system for the test site in Lewistown, MT 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 4.5. 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 infra-red 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 infra-red cameras, which also had a date and time stamp, to investigate the reliability of the system.

Figure 4.6. The detection line was marked with cones to be able to record the position of the animals (Photo: Marcel Huijser, WTI/MSU).

4.1.3 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 canadensis*) or moose (*Alces alces*). In Montana, it is not legal to have deer, elk or moose in captivity. Therefore the researchers used 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 4.1 and 4.2). The body size and weight of the individual horses, llamas, and sheep used in this experiment are shown in Table 4.3. Some of the test animals are shown in Figure 4.7 to 4.9. The horses that were used in the test.

Table 4.1: Height and length of wildlife target species and horses and llamas.

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	3'-3'5" (90-105 cm)	3'10"-7'6" (116-199 cm)	Whitaker (1997)
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), Wikipedia (2007)
Llama	3'-3'11" (91-119 cm)		Llamapaedia (2007)
Goat	25"-30" (64-76 cm)		ADM Alliance Nutrition Inc (2011)
Sheep	25"-50" (63-127 cm)		Minnesota Zoo (2011)

Note: Black-tailed deer are a subspecies of mule deer.

Table 4.2: 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)
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), Wikipedia (2007)
Llama	250-450 lbs (113-204 kg)		Llamapaedia (2007)
Goat	110-225 lbs (50-101 kg)	160-264 lbs (72-119 kg)	ADM Alliance Nutrition Inc (2011)
Sheep	100-350 lbs (45–160 kg)	100-225 lbs (45-100 kg)	Wikipedia (2008)

Table 4.3: Body size and weight of the horses, llamas, and sheep used in the experiment.

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	2'4" (71 cm)	170 lbs (77 kg)
Sheep 2	2'5" (74 cm)	225 lbs (101 kg)

(Pers. com. Lethia Olson, livestock supplier. The measurements were taken in November 2009.)

Figure 4.7. The horses that were used in the test.
(Photo: Marcel Huijser, WTI/MSU.)

Figure 4.8. One of the two llamas that were used in the test.
(Photo: Marcel Huijser, WTI/MSU.)

Figure 4.9. One of the two sheep that were used in the test.
(Photo: Marcel Huijser, WTI/MSU.)

4.1.4 Test Periods

In 2009 and 2010 there were three ten day test periods with animals:

- Test period 1: December 17, 2009 (at midnight) through December 26, 2009 (end at midnight).
- Test period 2: July 30, 2010 (at midnight) through August 8, 2010 (end at midnight).
- Test period 4: September 2, 2010 (at midnight) through September 11, 2010 (end at midnight).

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

In addition, there were two ten day test-periods without domesticated animals present in the enclosure:

- Test period 1: December 7, 2009 (at midnight) through December 16, 2009 (end at midnight).
- Test period 2: January 5, 2010 (at midnight) through January 14, 2010 (end at midnight).

The detection data from these two periods were screened for the potential presence of detections (which may indicate false positives), and extreme environmental conditions (based on weather data from a nearby meteorological station). The researchers selected 10 hours from each ten day period for review. These hours (20 hours in total) were non-randomly selected based on potential suspicious detection patterns (i.e., detections were reported while there are no domesticated animals present), and extreme environmental conditions.

4.1.5 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 were 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 the 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 some animal detection systems (e.g. potential for desensitization of the sensors), 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” (i.e. the imaginary line between the transmitter and receiver) 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 recorded 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:

  - The sensors are desensitized after a detection and may need some time before they can detect another animal. The manufacturer recommended three minutes reset time for the sensors to become fully sensitive again after a detection (see Huijser et al., 2009c).
  - The warning signs of an animal detection system need to stay activated for a certain amount of time after a detection has occurred. 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 not considered a false negative.

  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 a false negative.

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.

4.1.6 Data Analyses

Time periods that were classified as downtime or time periods for which no detection data were available due to external circumstances (e.g., power outage) were excluded from the analyses. The following parameters were calculated for the system:

- The average number of valid detections per hour:

$$\overline{N}_{t(valid\ detections)} = \frac{\mathrm{N}_{\mathrm{t\ (valid\ detections)}}}{\mathrm{N}_{\mathrm{h(with\ data\ available)}}}$$

Where:

$\mathrm{N}_{\mathrm{t\ (valid\ detections)}}$ = total number of valid detections

$\mathrm{N}_{\mathrm{h\ (with\ data\ available)}}$ = total number of hours for which detection data were available

- The percentage of false positives:

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

Where:

F_N^+ = total number of false positives

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

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

- The average number of false positives per hour:

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

Where:

F_N^+ = total number of false positives

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

- The percentage of false negatives:

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

Where:

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

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

$N_{d\text{ (center line)}}$ = 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:

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

Where:

F_N^- = total number of false negatives

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

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

- The percentage of intrusions detected (i.e., animal presence in or immediately adjacent to the line of detection):

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

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 476 valid detections in 90 hours that detection data were available for, resulting in an average of 12.65 valid detections per hour.

There was 1 false positive in 90 hours that detection data were available for. The percentage of false positives was 0.01%. There were 0.01 false positives per hour.

There were 61 false negatives (56 false negatives; 1 false negatives 1, 4 false negatives 2) in 90 hours that detection data were available for. The false negatives related to all three species: 27 for sheep, 13 for llamas, and 21 for horses. The number of false negatives when the system was operational was much lower: 13 for sheep, 5 for llamas, and 2 for horses (20 in total). The percentage of false negatives was 11.36. There were 0.68 false negatives per hour.

There were 111 intrusions in the detection area and 88.48% of all intrusions in the detection area were detected.

The beam went out of operation regularly, causing the system to generate false negatives. The beam appears to come back in operation by itself after varying amounts of time. The total number of hours that the system was "down" was 6 hours and 54 minutes (7.67%).

The results of the reliability tests, with and without domesticated animals present in the enclosure, are shown in Table 4 and 5. All false negatives in test 1 related to sheep and all false negatives in test 3 related to horses.

Table 4.4: Results of the reliability tests with animals (stratified random).

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

Table 4.5: Results of the reliability tests without animals (non-random).

	Test 1	Test 2	Total
Hours analyzed (N)	10	10	20
Valid detections (N)	0	0	0
Valid detections/hour (N)	0.00	0.00	0.00
False positives (N)	1	0	1
False positives (%)	0.01	0.00	0.01
False positives/hour (N)	0.10	0.00	0.05
False negatives (N)	0	0	0
False negatives (%)	0.00	0.00	0.00
False negatives/hour (N)	0.00	0.00	0.00
Intrusions (N)	0	0	0
Intrusions detected (%)	n/a	n/a	n/a
Downtime (hours)	0:00	4:00	4:00
Downtime (%)	0.00	40.00	20.00

Discussion and Conclusion

The number of false positives was relatively low but the number of false negatives was relatively high. The percentage of all intrusions in the detection area that was detected was relatively low (see Huijser et al., 2009c). Based on the values for the reliability parameters, the RADS III system does not meets the recommended minimum norms for the reliability of animal detection systems (see Huijser et al., 2009c). Specifically, the percentage of false negatives is too high, and the percentage of intrusions detected is too low. However, when the downtime of the system was excluded, the percentage of false negatives dropped to about 4%. This suggests that the system can meet the suggested norms for reliability if the beam remains operational. In conclusion, the substantial downtime of the system (7.67%) during the tests with animals is a major concern, suggesting that the system may not be operational for substantial lengths of time.

5 THE EFFECT OF ENVIRONMENTAL CONDITIONS ON SYSTEM RELIABILITY

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Introduction

In this chapter the researchers report on the possible effects of environmental conditions on the reliability of the system manufactured at the test bed near Lewistown, MT.

Methods

5.1.1 Detection Data Selection

For this chapter both detection data types were included (see also section 4.2.4):

- Stratified random with animals present: There were three test periods with animals present, each consisting of ten test days. For each test day three one-hour-long sections of video were randomly selected for review. This resulted in 90 hours of images analyzed (see table 4).
- Non-random without animals present: There were two test periods without domestic animals present, each consisting of ten days (see table 5). Non-random time periods were selected from these days. These time periods were chosen based on unusual detection patterns and certain extreme or interesting weather conditions. 10 hours were selected and analyzed for each of the two test periods. This resulted in 20 hours of images analyzed.

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

5.1.2 *Environmental Variables and Animal Species*

Environmental variables consisted of weather data and the animal species (horse, llama or sheep) present in the detection area or crossing the detection line. Detections caused by species other than these three domesticated species were not observed.

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

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

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

5.1.3 *Statistical Analyses*

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

For this chapter the researchers distinguished two types of situations:

- An animal is in the detection area or crosses the detection line (see chapter 4); and
- The system erroneously indicates an animal (False Positive or FP).

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

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

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

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

Thus there were five different possible response categories:

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

The numbers of false positives and different types of false negatives were not used as reliability parameters for the current analysis. Instead the researchers chose to relate the number of errors to the number of correct detections through logistic regression models. Logistic regression models use categorical responses to model probabilities of success using the logistic link function ($\log(\pi/(1-\pi))$), which leads to modeling on the log-odds scale.

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

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

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

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

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

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

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

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

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

The following variables were considered in step-down AIC-driven model selection to generate a set of candidate models to compare AIC values. Models within two AIC units of the top model were considered for selection. Within these constraints, the selection process focused on the simplest model that contained the variables that were present in most of the models within two AIC units of the top model. The units or categories for each variable are given between brackets. For categorical variables the effect is calculated in relation to a "standard" category). For example, for wind direction, the effect of northern, southern or western winds is calculated compared to eastern winds). Similarly, the effect of high winds is calculated by comparing the presence of high winds to the absence of high winds.

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

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

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

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

Some error types had very low numbers. If the frequency of a certain type of error was ≤10, the type of error concerned was excluded from the models.

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

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

Results

The sample size for some of the response categories was relatively low (Table 6). The researchers set a minimum of ten errors for each type of error before initiating the statistical analysis. With less than ten errors for an error type the results are very sensitive to the conditions under which these few errors occurred and become very unreliable. The minimum number of errors was met for false negatives (FN), but not for false negatives 1 and 2 (FN1 and FN2), nor for false positives (FP) (Table 6). The FN1 was observed for a llama and the four FN2s were split evenly between horses and sheep.

Table 5.1: The type and number of errors observed for the animal detection system over a time period of 110 hours.

Type	False Negative (FN)	False Negative 1 (FN1)	False Negative (FN2)	False Positive (FP)	Correct Detection (CD)
Count	56	1	4	2	476

Only a limited number of wind gust, high wind, and low visibility measurements were made and none were associated with errors, so these variables were not included in the initial model. There were 24 wind direction observations classified as "variable". The top AIC model for false negatives vs. correct identification included wind direction, temperature, day/night, and relative humidity (Table 7). North and west winds had higher error rates than east winds, with west and variable winds having lower error rates than east winds. No errors were associated with variable winds. Higher temperatures and relative humidity had higher error rates and night had lower rates than day time observations. In this data set with three types of animals, differences in detection different animal species were not found to be important.

Table 5.2: Coefficient estimates for top STS 3 model.

Coef	Est	SE	z
(Intercept)	-8.92	1.60	-5.57
WD-North	0.62	0.38	1.65
WD-South	0.68	0.42	1.63
WD-West	-0.31	0.49	-0.64
WD-Variable	-15.78	804.63	-0.02
Temperature	0.19	0.04	4.46
Night	-0.90	0.40	-2.23
Relative Humidity	0.06	0.01	4.35

Discussion and Conclusion

Wind from the north and west were associated with higher false negative rates than east winds, and winds from the south were associated with lower false negative rates than east winds. This suggests that wind conditions play an important role in the ability of the system to correctly detect the presence of large mammals. Perhaps that stronger wind, especially from the north and west, caused the sensors to get slightly out of alignment. When the receiver does not receive a signal for a longer time period, the beam goes out of operation, allowing false negatives to occur. Higher temperatures were associated with an increase in false negatives. However, it is not clear how an increase in temperature would cause the radar detection system to generate more false negatives. There were relatively few false negatives during the night. This suggests that daylight is somehow associated with false negatives, but it is also possible that daylight is generally associated with stronger winds during the day, particularly from the north and west. An increase in humidity was associated with an increase in false negatives. Interestingly, the animal species did not matter enough to be included in the top model. This suggests that the system detects species that resemble sheep, llamas or horses in body size similarly. The results of this analyses suggest that it is very important that the poles and the sensors are firm and do not move in the wind.

6 THE RELIABILITY OF THE SYSTEM ALONG SR 3 NEAR FT JONES, CA

Introduction

In September 2009 an animal detection system was installed along SR 3 (Ft. Jones Rd.), near Ft Jones, CA. The road section that had the animal detection system installed was about 1,030 m (0.64 mi) long between mi marker 36.6 and 37.3 (Sharafsaleh et al., 2010). In this chapter the authors report on the reliability of the system along SR 3. The system, including warning signs, was put into operation on 17 October 2012. There are six detection zones for the animal detection system, three on each side of the road (Figure 11), and there are five video cameras (Figure 12). For more details about the site, the detection technology, the video cameras, and other equipment that was installed along SR 3 see Sharafsaleh et al. (2010).
The researchers were informed that part of the animal detection system has been down since late June 2011 due to an accident. A car hit the first pole (pole H, see Figure 11) on the right hand side of the road when traveling from Yreka to Ft Jones. While the pole has been replaced a replacement sensor for the animal detection system could not be installed because the manufacturer of the system has changed ownership and the product is no longer supported. This meant that animals that approached the road from the north between pole H and E could not be detected during the 30 days that were analyzed for detection patterns. The remaining five beams were operational.

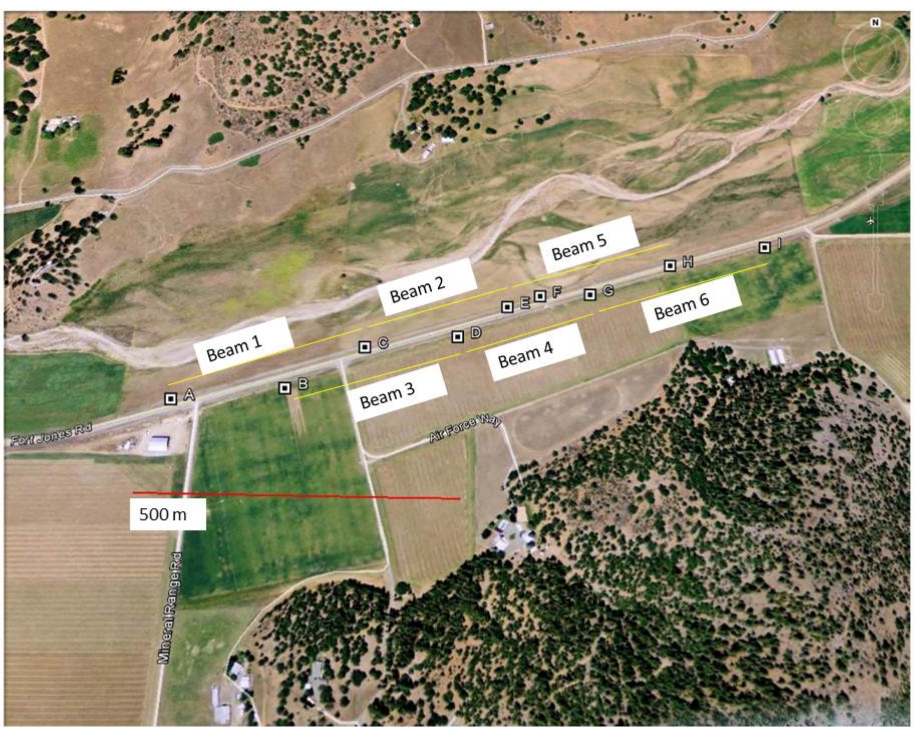

Figure 6.1. Layout of the animal detection system along SR 3 near Ft Jones, CA. Letters indicate poles, numbers and yellow lines indicate beams.

Figure 6.2. The location and direction (yellow arrows) of the video cameras associated with the animal detection system along SR 3 near Ft Jones, CA.

Methods

The authors investigated the reliability of the system along SR 3 through two methods:

- A researcher intentionally triggered the system at regular intervals to identify potential blind spots.
- The detection log of the animal detection system was compared to the images recorded by the video cameras to identify potential correct detections and false positives.

6.1.1 *Triggering the System at Regular Intervals*

On 2 and 3 April 2012 a researcher (1.82 (6ft) tall, 79 kg (175 lbs)) triggered the system at about 66 ft (20 m) intervals by crossing through the beam in the different detection zones (see Figure 11 for the location of the detection zones). Typically the researcher crossed a beam on one side of the road at walking speed, continued walking across the road, and then crossed the beam on the other side of the road. The crossing of two beams and the road typically took about 15-20 seconds. The researcher then waited at least 3 minutes before crossing through the beams again about 66 ft (20 m) further down the road. The purpose of the three minutes waiting time before triggering a beam again was to avoid potentially desensitizing the beam while the warning signs were still turned on (the warning signs stayed on for three minutes after the last detection). The researcher compared the time and number of times the different beams were crossed to the detection log to investigate the presence of potential blind spots or missed detections ("false negatives).

6.1.2 *Analysis of Detection Data and Video Images*

The detection data logged by the animal detection system were compared to the images recorded by the video cameras. This comparison was conducted for over a period of 30 days. The cameras were mainly designed to record driver behavior and the movement of their vehicles. The resolution of the images is too low to be confident in detecting medium or large mammal species at the far end of a detection zone. In addition, the range of the video cameras was limited to about 100 ft (30 m) during the night further restricting the distance covered by the cameras (Pers. com, Zu Kim, California PATH). However, when a car happened to pass by the headlights illuminated the road and the right-of-way allowing for greater range of the cameras during that brief period.

When a detection occurred, video images from the following time periods were saved from all six cameras:

- Thirty seconds preceding the three minute period in which the detection occurred.
- The three minute period in which the detection occurred

If a second detection occurred within three minutes of the first detection the clock was reset and another three minutes of images was recorded. Because the cameras are positioned on tall posts (about 10 ft (3.05 m)) the cameras do not record events that may occur immediately below the camera, effectively creating a blind spot for anything that could trigger the system at those locations in the right-of-way.

If there is no detection by the system, the video recorders remain inactive and are not saving images. The above means that the researchers were able to identify what triggered the system for a selection of the detections, particularly during the day. Because of the blind spots directly beneath the cameras and the limited range of the cameras the researchers could not be certain that a detection was a false positive or perhaps a correct detection after all negatives (see Chapter 4 for the definition of these error types). The researchers could only conclude that they were not able to identify what may have triggered the animal detection system. In addition, the researchers were not able to identify potential false negatives as there were no images recorded unless a detection had occurred.

The researchers investigated the detection patterns for a period of 30 days in the fall of 2011. The 30 days were divided into three ten day periods:

- Period 1: 1 September 2011 at 0:01 hrs – 10 September 2011 at 23:59
- Period 2: 18 October 2011 at 0:01 hrs – 27 October 2011 at 23:59
- Period 3: 1 December 2011 at 0:01 hrs – 10 December 2011 at 23:59

Having the 30 test days spread out over several months had the following advantages:

- The researchers were better able to evaluate the performance of the system over a longer period of time as it became less likely that potential temporary errors or temporary correct functioning of the system would dominate the data.
- The researchers were able to evaluate the performance of the system under a greater variety of environmental conditions. Note that environmental conditions are known to influence the reliability of the system (see Chapter 5).

The researchers used the three minute time periods in which a detection occurred as the experimental unit. This means that each three minute period with a detection resulted in one record in the database, regardless of how many detections may have occurred in that three minute time period, or how long the beam was broken for during that three minute period. If two detections occurred in the same three minute period in beams that are on opposite sides of the road it indicated a potential crossing. Similarly, if a detection occurred on the opposite side of the road in the previous of following three minute period it also indicated a potential crossing. Detections that related to potential crossings resulted in one record in the database rather than two records.

The researchers evaluated each three minute time period with a detection as a “correct detection” (objects were identified that could be expected to trigger the system), “trigger not identified”, “no video data available” (due to a system error when saving data), and apparent system errors (e.g. all beams were triggered at the same time).

Results

6.1.3 Triggering the System at Regular Intervals

The researcher (1.82 (6ft) tall, 79 kg (175 lbs)) successfully triggered al beams, except beam 5 which was not functional because of missing equipment (see section 6.1). There were three beams (beams 3, 4 and 6) where there was evidence that the beam missed at least one detection. Subsequent retesting at those locations showed that the missed detections were the result of the beam having become desensitized rather than the presence of blind spots. Note that the first evidence of desensitizing beam 3 was after eight crossings (at least three minutes apart), including a vehicle that pulled off the road for a few minutes. Beam 4 and 6 both desensitized after four crossings (at least three minutes apart).

6.1.4 *Analysis of Detection Data and Video Images*

Over the 30 days there were 586 records (Table 8). The researchers were able to identify what triggered the system in about 74% of all cases. In 21% of the cases the researchers were not able to identify what may have caused the detection. In a relatively small number of cases (<4%) the video data were not available for analyses. About 1% of the records appear to be related to a system error in which all beams reported a break at the same time. All but six records were associated with the warning lights turning on. Five of these six records related to records classified as “system errors”, and the one remaining record related to a record classified as “trigger not identified”. The vast majority of the correct detections related to vehicles (with or without associated humans outside the vehicle) (Table 9). Deer were present in about 4% of the correct detections.

Table 6.1: Classification of the three minute time periods in which detections occurred.

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

Table 6.2: Breakdown of what triggered the system (all classified as “correct detection”).

	Count (N)	Count/day (N)	Percentage (%)
Vehicle	404	13.47	92.87
Deer	19	0.63	4.37
Human	11	0.37	2.53
Unidentified animal species	1	0.03	0.23
Total	435	14.5	100.00

Most of the records that related to vehicles were recorded between 6 am and 9 pm (Figure 6.3). Most of the records where the trigger could not be identified were recorded at the end of the afternoon and during the night. Deer were identified during the day as well as the night. The vast majority of all records where a vehicle triggered the system related to beam 3 and a much smaller number related to beam 4 (Figure 6.4).

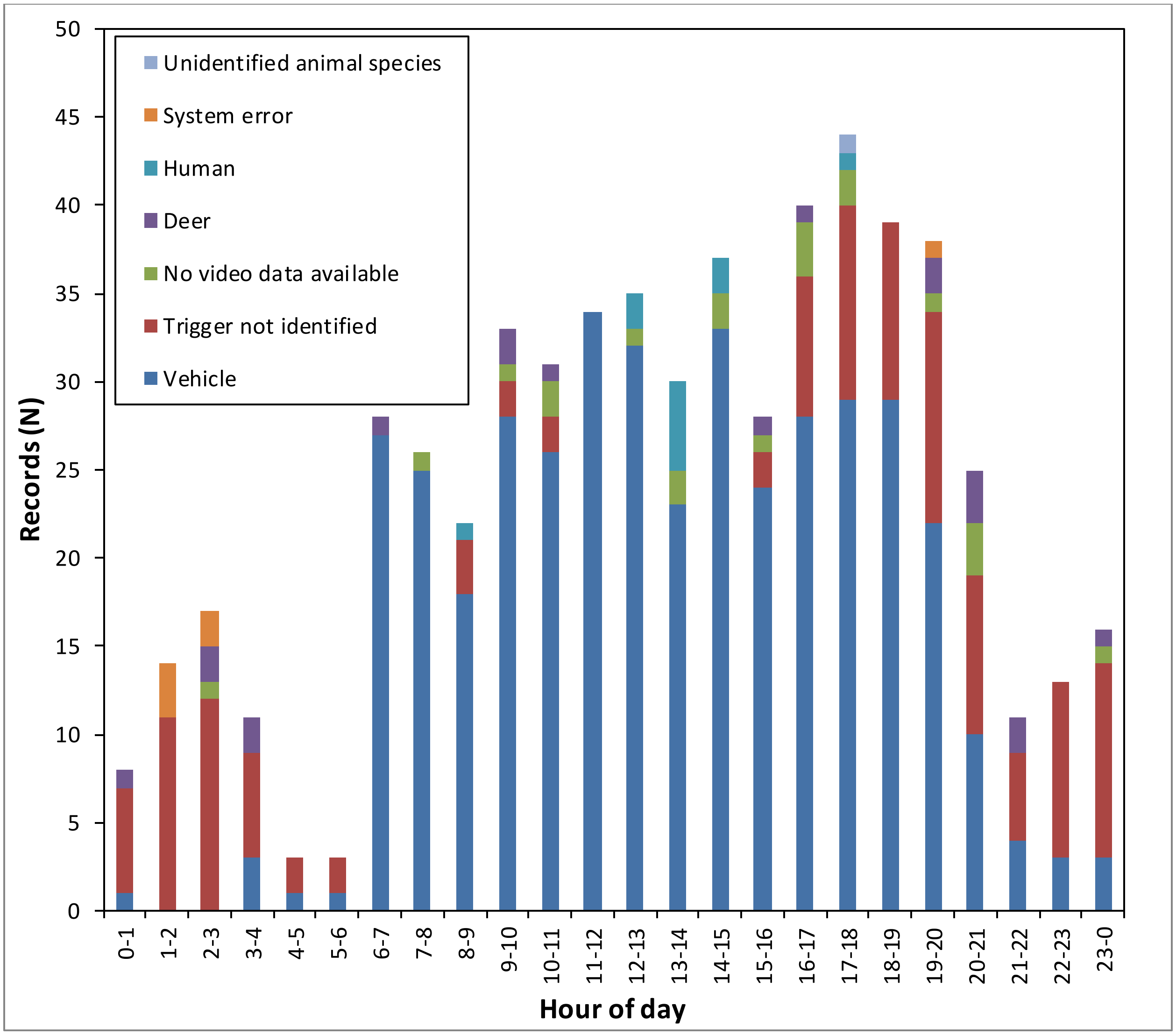

Figure 6.3. Number of records for the different categories by hour of day.

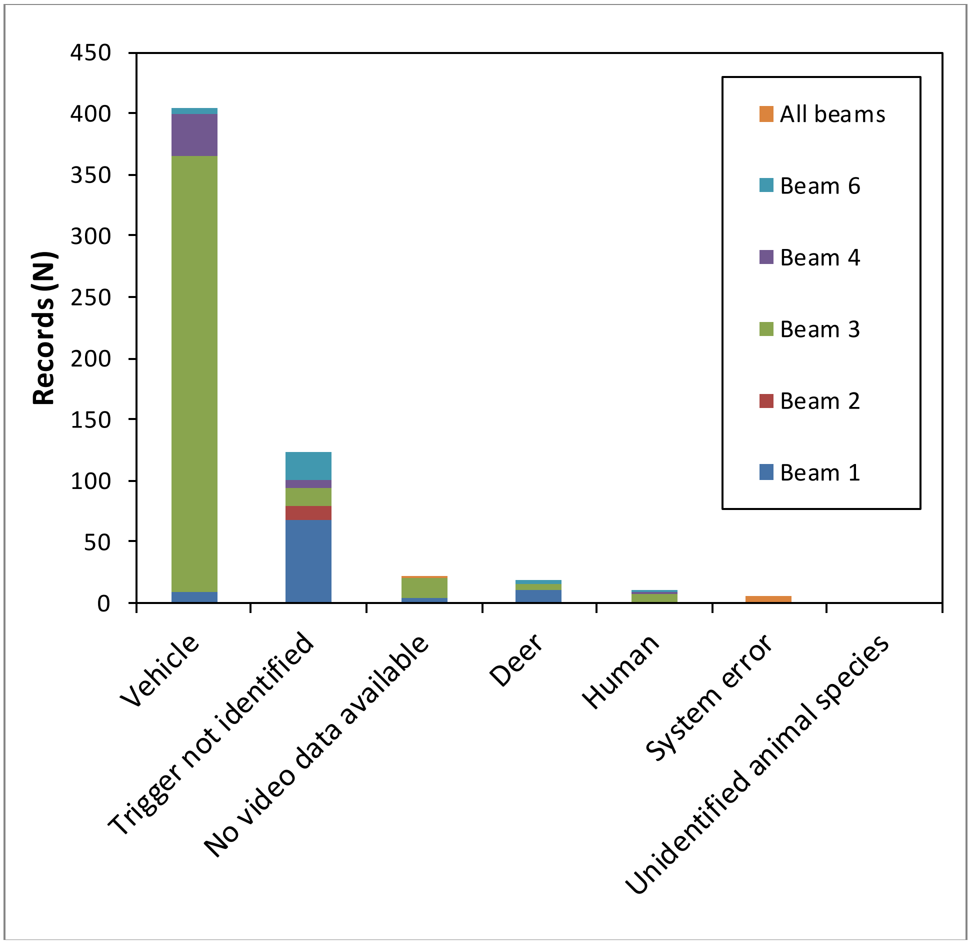

Figure 6.4. Number of records for the different categories by beam number.

Discussion and Conclusion

6.1.5 Triggering the System at Regular Intervals

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

6.1.6 *Analysis of Detection Data and Video Images*

The comparison of the detection data from the animal detection system with the video images from the cameras showed that at least 74% of all detections can be considered "correct". Because of the limited range of the cameras, especially during the night, it is likely that the percentage of correct detections is substantially higher; most of the triggers that were not identified were in the late afternoon and during the night when the range of the cameras was very limited, except for triggers that carried lights (e.g. vehicles). There were some system errors but except for one system error they did not result in the activation of the warning signs. About 93% of the correct detections related to vehicles turning on and off SR 3. The vast majority of the vehicle detections came from beam 3 that cuts across Air Force Way. A much smaller number of detections came from beam 4 where vehicles turned on and off a farm road. Other vehicle detections related to vehicles parking or turning around in the right-of-way. Only about 4% of the correct detections related to black-tailed deer. However, compared to vehicles the number of deer that triggered the beam is more likely to have been underestimated as deer cannot be identified on night images if they are further away than about 100 ft (30 m) from the cameras.

6.1.7 *Management Considerations*

- Blind spots or false negatives: Apart from beam 5 the system appeared reliable and did not have any blind spots. The absence of blind spots was not surprising considering the even terrain (i.e. no depressions where the beam would shoot over the head of large mammals). To bring beam 5 back into operation the sensor on pole H needs to be replaced. If the manufacturer can no longer supply the appropriate sensor consider installing sensors from a different company. See e.g. Huijser et al. (2009) for suggestions for other systems.
- Desensitizing: If an animal (or a car or human) blocked the beam for more than about 10 seconds some beams became desensitized and no longer reported the beam as being broken. The same situation occurred if the beam was broken multiple times shortly after each other. In those cases deer may be present in the right-of-way or on the road without the warning lights being activated. The researchers found evidence of a deer desensitizing a beam once in the 30 days that the data were analyzed for. However, there may have been more instances that were not visible on the video images. While no animal detection system is likely to detect all large animals that approach the road under all conditions, the information described above may be considered when deciding on the type of system, the specific characteristics of the technology, and it may also help the manufacturer with potential further system refinement.
- False positives: The average number of records with detections per day was not very high; about 20. This is important because if the warning signs would be on most of the day it would be too similar to warning signs that are always turned on and that are not connected to sensors. Nonetheless, most of these detections do not relate to the target species (black-tailed deer), and one could consider efforts to minimize the number of detections that do not relate to the target species. Most of the detections related to vehicles turning on and off SR 3, particularly at Air Force Way. To minimize these "unwanted" triggers one may consider installing a detector loop for vehicles that would cancel a detection by the animal detection system. Large animals, including deer, would

still trigger the beam if they use the side road as they are not detected by the vehicle detector loop.

7 ANIMAL-VEHICLE CRASHES

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Introduction

The road section with the animal detection system and adjacent road sections were monitored for road-killed large mammals. The monitoring took place both before and after the system was installed and before and after the warning signs were attached. This chapter summarizes the reported animal-vehicle crashes and evaluates the effectiveness of the system with regard to this parameter.

Methods

Caltrans personnel monitored a 5 mi (8.05 km) long road section of SR 3 between Yreka and Ft Jones (mi post 33.5–38.5) for large mammal carcasses between 18 June 2008 and 2 April 2012 (Figure 15). System installation (September 2009) and the attachment of the warning signs to the system (17 October 2011) occurred during the monitoring period. The system was installed between mi markers 36.6-37.3. The road sections that were monitored outside of the road section where the system was installed was referred to as the “control”. Note that only one side of the road was equipped with the system towards both ends of the road section with the system (Figure 15).

Figure 7.1. The road section (mi posts 33.5-38.5) that was monitored for large mammal carcasses along SR 3 near Ft Jones, CA

Note: The red lines indicate the road section with the animal detection system on the north and south side of the highway.

Results

There were 59 large mammal carcasses recorded between mi post 33.5–38.5 between 18 June 2008 and 2 April 2012. All carcasses were of black-tailed deer. The number of black-tailed deer carcasses in the control road sections was relatively high in 2008 despite that monitoring was only just over six months that year (Figure 16). The data show that fewer black-tailed deer carcasses were reported in 2009 through 2011. The data from 2012 are based on monitoring from January through early April only.

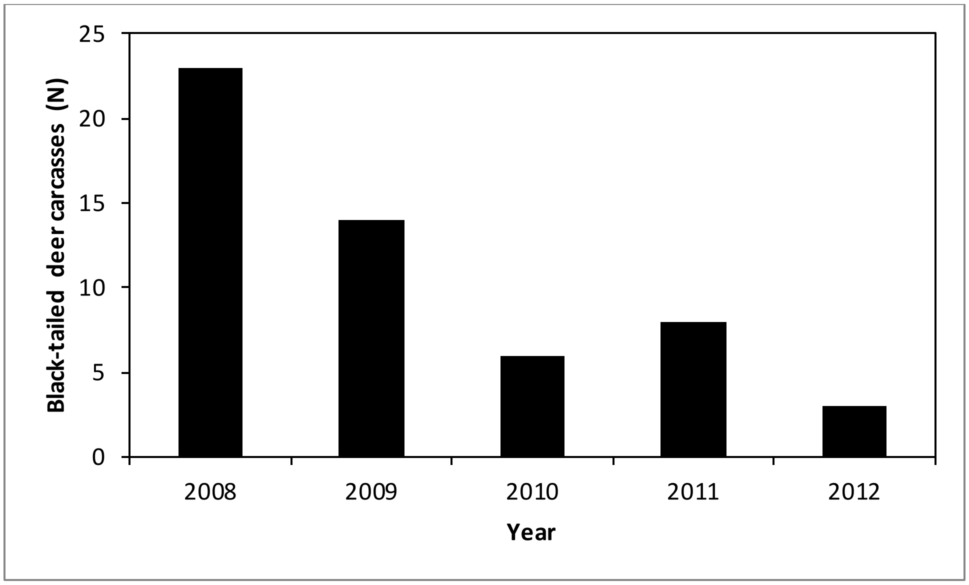

Figure 7.2. Number of black-tailed deer carcasses reported in the control sections in 2008-2012.

Note: Counts for 2008 (mid-June – December) and 2012 (January-early April) are not based on a full year.

The number of reported black-tailed deer carcasses was lowest in winter (January-March), with higher numbers through the spring (April-May) and summer (July-September) and also in the autumn and early winter (November-December) (Figure 17).

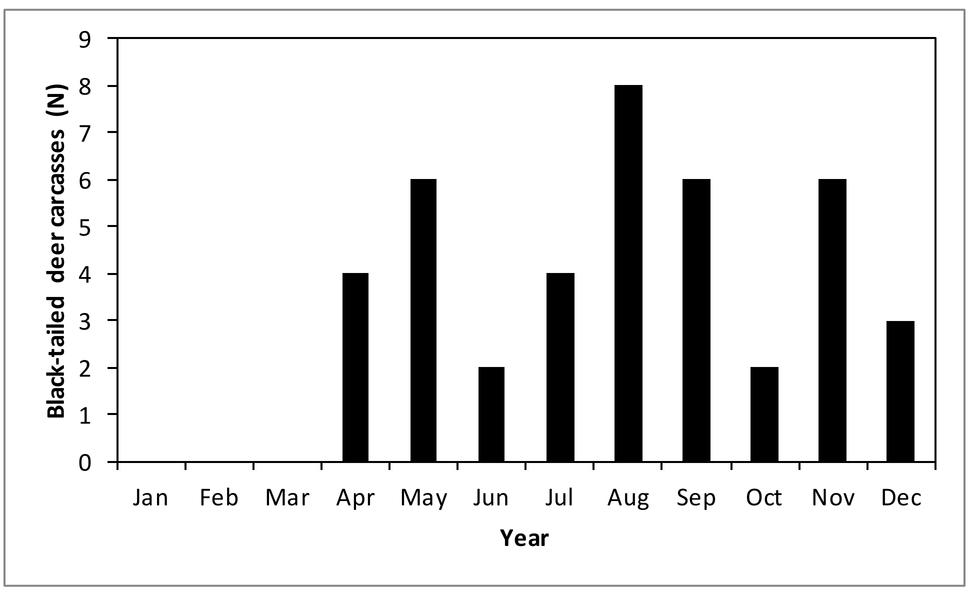

Figure 7.3. Number of black-tailed deer carcasses reported in the control sections per month (July 2008 – June 2011).

The number of reported black-tailed deer carcasses per mile was higher in the control sections than in the section with the system, both before and after installation (Figure 18). After the warning signs were unveiled the numbers were similar in the control sections and the road section with the system. There was one black-tailed deer carcass reported after the warning signs were attached at mi marker 36.64, just inside the road section with the system but where the system is only present on the north side of the road and not on the south side.

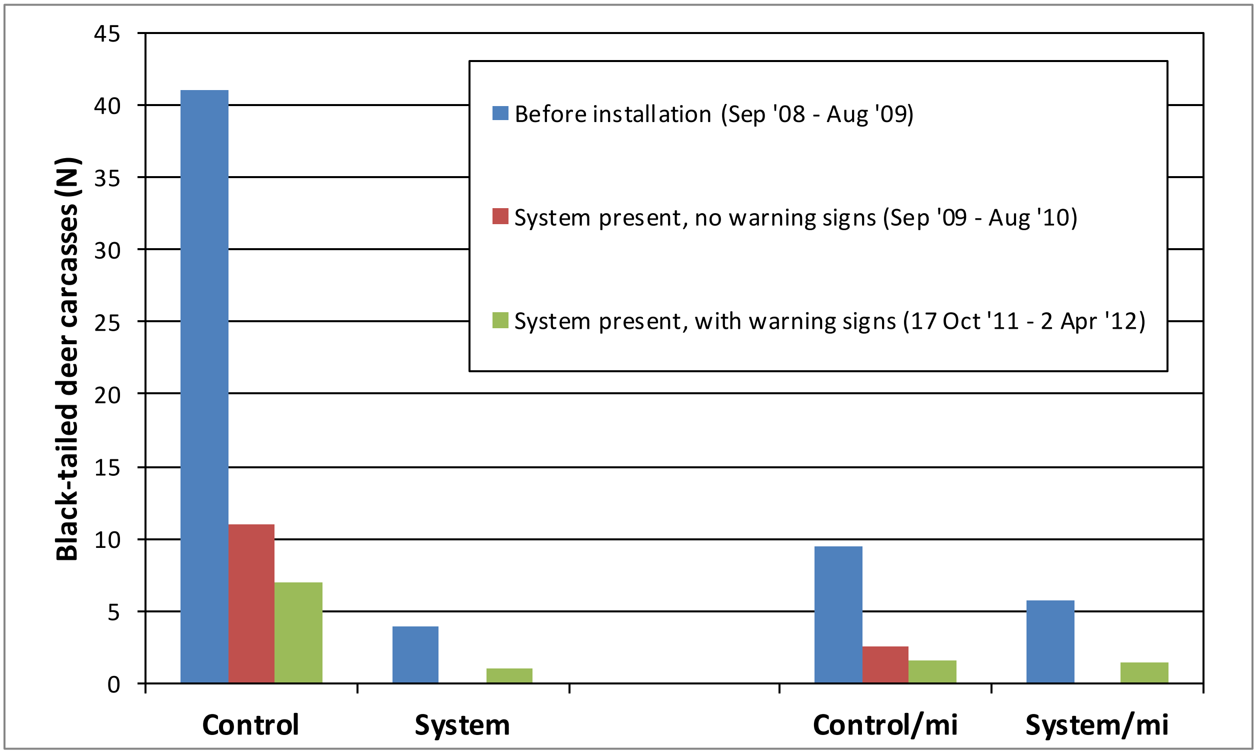

Figure 7.4. Number of black-tailed deer carcasses reported in the control sections and in the road section with the system in different periods before and after system installation and before and after the warning signs were attached.

Discussion and Conclusion

The number of reported black-tailed deer carcasses appears to have declined from 2009 onwards. This decline occurred both in the control sections and the road section with the system. Assuming that the search and reporting effort for the carcasses indeed remained constant, this suggests that the black-tailed deer population in the area has declined in the last years. This is consistent with some of the remarks of the public (see Chapter 8).

Given the relatively low number of large mammal carcasses, especially from 2009 onwards, the relatively short road section that has the system installed, and the relatively short time period during which the system was present with the warning signs attached, it is not really possible to conclude whether the animal detection system may have reduced the number of large mammal-vehicle collisions.

The researchers suggest monitoring large mammal carcasses in the control sections and in the road section with the animal detection system for multiple years (e.g. at least 3-5 more years) and then analyzing the data once again. The researchers also suggest beginning and ending the animal detection system at the same location on opposite sides of the road as the one road killed animal that was reported in the road section with the system was located in a road section where the system was only present on the north side of the road. Thus it is possible that the animal concerned approached the road from the south side and remained undetected. On the other hand, since the carcass was reported right at the edge of the road section with the system, it is also possible that the deer crossed the road outside the road section with the system but that the carcass ended up in the road section with the system (e.g. it may have been dragged by the vehicle or the wounded animal may have moved a short distance to the location where the carcass was reported).

8 SURVEY

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Introduction

The researchers conducted a survey with regard to people's experiences with and opinions on the animal detection system along SR 3 near Ft Jones, CA. The survey targeted people who drove that particular road section when the animal detection system was installed and functioning. While the survey was linked to from a website that provided basic information about animal detection systems in general and about some of the characteristics of the specific system installed along SR 3, the survey was not preceded by an outreach campaign that provided information on the reliability and effectiveness of the system. The reliability and effectiveness data were not available until June 2012, at the end of the research project.

Methods

The survey was accompanied with an introductory letter (see Appendix A). The survey questions (including the responses) are also summarized in Appendix A. The survey was conducted through a website (SurveyMonkey). The survey was started on 22 February 2012 and responses entered until 5 June 2012 were included for the purposes of this report.

Results

The responses to the survey questions are summarized in Appendix A. Only the key results are presented in this chapter. There were 128 respondents who started the survey and 121 of them (94.5%) completed the survey.

More than half (50.9%) of the respondents always worry about large wild ungulates when traveling in rural areas in CA. The respondents tend to drive pick-up trucks, SUVs or vans (53.9%) or passenger cars or vans (43.8%). Almost all of the respondents traveled the road section with the animal detection system at least once in the 30 days before answering the survey, about 79% of them drive this road section at least two times per week, and almost all of the respondents noticed the animal detection system. About 54% of the respondents think animals are on or near the road when the warning signs are activated and an additional 35% think that there may be animals on or near the road. When the warning signs are not activated about 30% of the respondents think that animals are not on or near the road while 31% of the respondents think there is no message and an additional 26% thinks there may still be animals on or near the road. Almost 70% of the respondents would like to see the system removed while 15% would like to keep the system in place.

The respondents were given the opportunity to describe why they would like to have the system removed or stay in place. Their free text response was categorized by the researchers (Table 10).

Note that not all respondents provided a response and that some respondents provided remarks that fell in multiple categories. Respondents that would like to have the system removed mostly expressed concerns with the costs of the animal detection system, the lights that are too bright at night, the perception that most deer cross elsewhere rather than where the system is located, and perceived poor reliability (specifically false positives caused by vehicles and humans) and effectiveness of the system. Respondents that prefer to keep the system in place also mentioned concerns with false positives (particularly by vehicles turning on and off the highway), and that most deer cross elsewhere rather than where the system is located. Other categories had relatively few counts, including the responses from respondents who had no preference for keeping the system in place or removing it. A number of the respondents who said that the lights were too bright wrote that it hindered their ability to see the deer on or along the road.

Table 8.1: Remarks of respondents accompanying their statement to have the system removed, to have the system stay in place, or having expressed no preference).

Remarks	**N**
Remove system	
Too expensive	16
Lights too bright	13
Wrong location, most deer cross elsewhere	12
Unreliable	11
Not effective	6
False positives (vehicles, owls, livestock, ATVs, humans)	5
System not understood, not accepted	3
Prefer to mow grass	3
Prefer fences	2
Prefer people pay more attention	2
False sense of security	1
System not maintained well	1
Signs are ignored	1
Signs have been mostly covered	1
Impact on landscape aesthetics	1
Road section with system too short	1
Privacy concerns cameras	1
Keep system in place	
False positives (vehicles, humans)	2
Wrong location, most deer cross elsewhere	2
Greater waste to take it down	1
Prefer to mow grass	1
Prefer people pay more attention	1
Cars reduce speed	1

Fewer animals hit	1
Longer evaluation time needed	1
Wonders about annual operation costs	1
Wonders about effectiveness	1
No preference	
Warning signs on, no deer seen	1
Deer present, warning signs off	1
Vehicles trigger system too	1
Prefer to mow grass	1
Prefer less costly mitigation	1
Impact on landscape aesthetics	1
Longer evaluation time needed	1
Lights too bright	1
Unreliable	1
Too expensive	1
Greater waste to take it down	1

Similar proportions of the respondents saw animals along the road section with the animal detection system since the warning signs were activated on 17 October 2011; about 48% saw animals and about 48 % did not. Only one respondent named the observed animals with the species name: black-tailed deer. In this case the warning signs were activated, the driver reported to have become more tentative and looked for animals and found the animal detection system to be helpful in that situation.

Almost 39% of the respondents found animal detection systems to be a good idea. The question related to animal detection systems in general, not the specific system installed along SR 3 near Ft Jones. However, more of the respondents, about 45%, did not find animal detection systems to be a good idea and about 15% did not know whether they found them to be a good or a bad idea.

The respondents were given the opportunity to describe why they thought animal detection systems are a good idea or a bad idea. Their free text response was categorized by the researchers (Table 11). Note that not all respondents provided a response and that some respondents provided remarks that fell in multiple categories. Respondents that thought animal detection systems are a bad idea mostly expressed concerns with the costs of the animal detection system, the specific animal detection system along SR 3 near Ft Jones being in the wrong location, perceived unreliability of the system along SR 3, a preference that driver pay more attention while driving, a preference for other types of mitigation measures including mowing of the right-of-way, the lights of the system along SR 3 being too bright, and the road section with the system not being long enough. Respondents that thought animal detection systems are a good idea mostly stated that false positives, particularly caused by vehicles turning on and off the road, needed to be reduced. They also stated that the specific system along SR 3 is in the wrong location, that animal detection systems result in fewer animal-vehicle crashes, and that the reliability of animal detection systems needs to be improved. Respondents that did not know if animal detection systems are a good or a bad idea also expressed concerns with the costs and reliability of animal detection systems.

Table 8.2: Remarks of respondents accompanying their statement that animal detection systems are a bad idea, a good idea, or having expressed that they do not know.

Remarks	**N**
Bad idea	
Too expensive	10
Wrong location, most deer cross elsewhere	5
Unreliable	5
Prefer people pay more attention	5
Prefer fences, driver education, deer whistles, roadway lighting, or standard signs	5
Prefer to mow grass	4
Lights too bright	3
Road section with system too short	3
Distraction to drivers	2
Not effective	1
False positives (vehicles, owls, livestock, ATVs, humans)	1
False sense of security	1
Impact on landscape aesthetics	1
Liability concern for transportation agency	1
Not enough warning time	1
Good idea	
Eliminate false positives (vehicles, humans)	7
Wrong location, most deer cross elsewhere	4
Fewer animal-vehicle crashes	4
Improve reliability	3
Should be explained better to public	1
Distraction to drivers	1
Wonder about cost-effectiveness	1
Do not know	
Prefer less costly mitigation	2
Need to be reliable	2
Lights too bright	1
Too expensive	1
Wrong location, most deer cross elsewhere	1
Reliability concern	1

The majority of the respondents expect an animal detection system to detect all large animals that approach the road (Figure 19). Only 46% of the respondents are satisfied with the system detecting 96-99% of all large animals that approach the road. When asked what percentage of the detections is allowed to be false (i.e. not related to the target species) more than half of the respondents stated that 6-10% false detections would be acceptable (Figure 20). More than half of the respondents were satisfied if animal detection systems reduce wildlife-vehicle crashes by at least 86-90% (Figure 21).

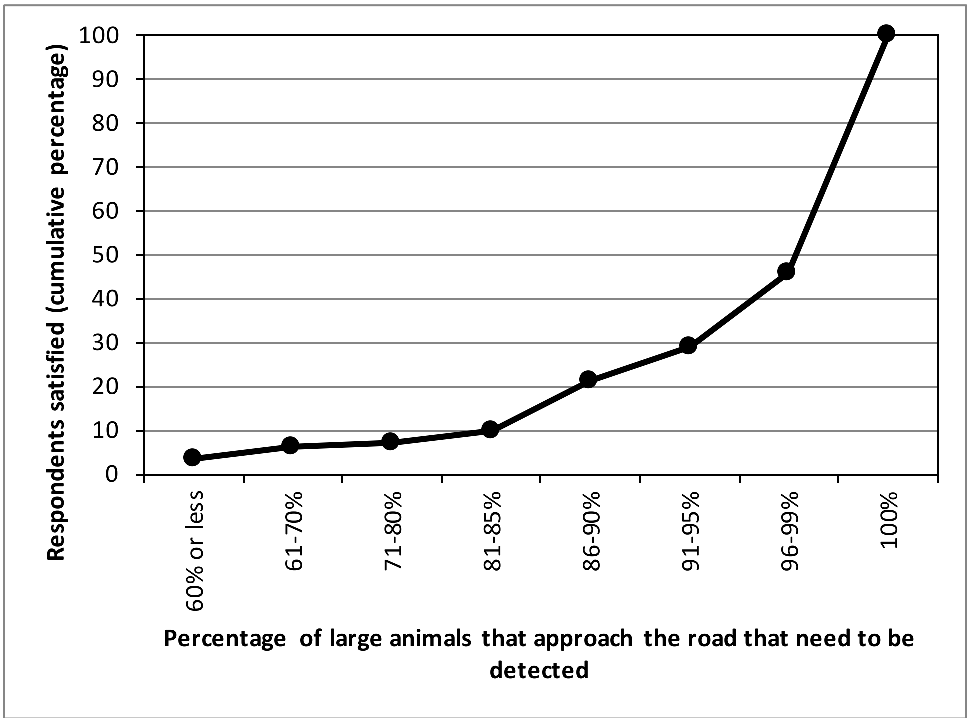

Figure 8.1. Cumulative percentage of the respondents that are satisfied with detecting an increasing percentage of large animals that approach the road.

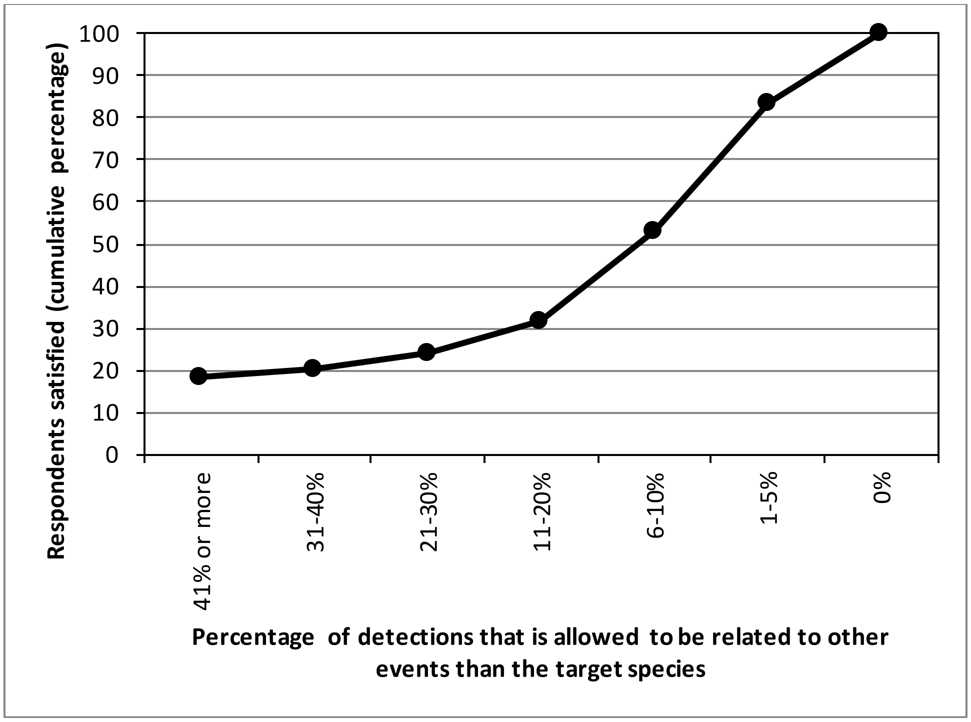

Figure 8.2. Cumulative percentage of the respondents that are satisfied with a decreasing percentage of the detections that related to other events than the target species.

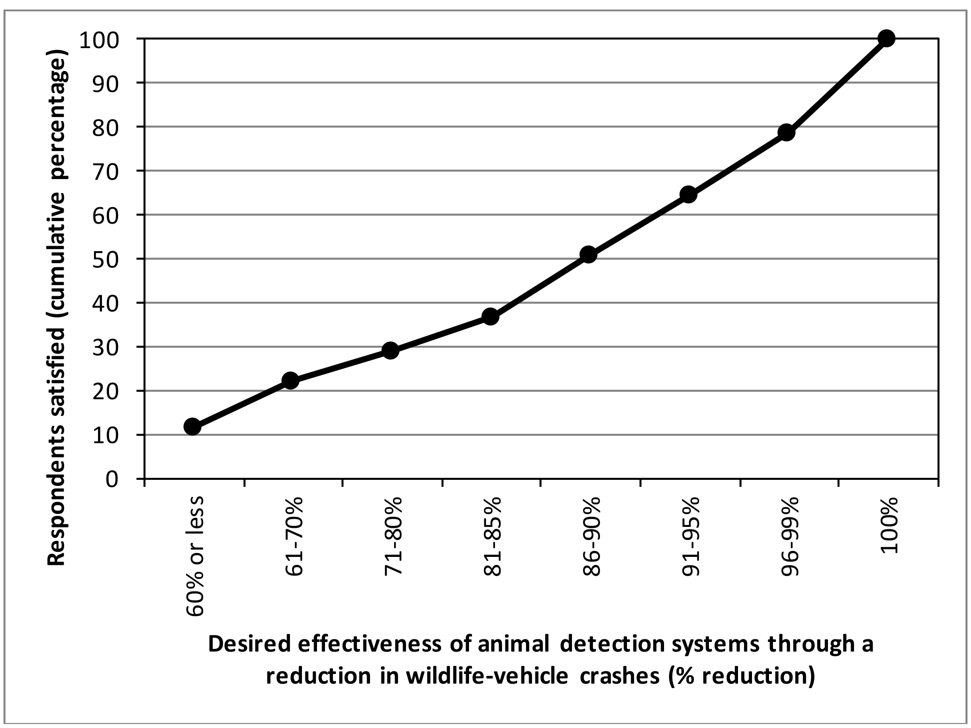

Figure 8.3. Cumulative percentage of the respondents that are satisfied with an increasing reduction in animal-vehicle crashes.

Half of the respondents (50%) want animal detection systems to save at least the same amount of money as the cost of the systems. The savings would result from a reduction in collisions and associated costs. About 30% of respondents want animal detection systems to save more money than they cost and about 10% allow the systems to cost some money.

When asked what the most important improvements are to animal detection systems about 77% of the responses indicated that reliable systems are a very important potential improvement. About 66% indicated clear and easy to understand warning signs are very important as well. Fewer respondents indicated inexpensive (45%) and smaller and less obtrusive systems (about 43%) are very important.

At the end of the survey the respondents were given the opportunity to provide additional comments on animal detection systems in general and the specific animal detection system along SR 3 near Ft Jones. Their free text response was categorized by the researchers (Table 12). Note that not all respondents provided a response and that some respondents provided remarks that fell in multiple categories. The most common remarks or concerns were about the costs associated with animal detection systems, that the particular animal detection system along SR 3 is in the wrong location, that this particular system is unreliable and that it suffers from false positives, particularly from vehicles turning on and off the road. Furthermore the lights are considered too bright, especially at night as they blind and distract the drivers, and the system is perceived to be ineffective. In addition respondents were concerned about the impact of the system on landscape aesthetics, and they think the road section with the system is too short and that it may not be practical or cost-effective to implement these systems over longer distances. Other comments related to preferring other types of mitigation measures and providing better information about the purpose and functioning of the system.

Table 8.3: Remarks of respondents when asked about additional thoughts and comments about animal detection systems.

Remarks	N
Too expensive	28
Wrong location, most deer cross elsewhere	28
Unreliable	19
False positives (vehicles, owls, livestock, ATVs, humans)	16
Lights too bright	14
Not effective	14
Impact on landscape aesthetics	9
Road section with system too short	7
Prefer people pay more attention	6
Systems and signs are distracting drivers	6
Prefer to mow grass	5
Not enough public outreach about system	4
Prefer fences	3
Prefer enforcement of speed limit	3
Upset about delays in getting system operational	3
Deer changed where they cross road because of the lights	3
Prefer roadway lighting	2
Poles are hazard (too close to road)	2
Prefer speed limit reduction at night	2
Prefer standard warning signs	2
Prefer wildlife overpasses	2
System is effective	1
False negative (deer on road, signs off)	1
Drivers speed up when lights are off	1
Reduce false positives (dogs, cows)	1
Prefer habitat improvement for deer	1
Liability concern for Caltrans?	1
Drivers think this is the only place where deer may cross	1
Fewer animals hit	1
Prefer driver education	1
Prefer speed bumps	1
Prefer sensors for deer on cars	1
Warning sign hard to interpret	1
Cows do not graze near system (lights)	1

6.1. Discussion and Conclusion

The results of the survey indicate that most respondents want the system removed. If the future of the system is to be decided by the respondents, regardless of whether they have been informed of the reliability and effectiveness research, then the conclusion is clear. Note that the most common concerns relate to the perceived cost of the system (not to be confused with the additional costs of research equipment and costs associated with conducting the research), the perception that the system is in the wrong location, the brightness of the warning signs at night, and the perception that the system is not reliable.

If the future of the system is to be decided based on the results of the reliability and effectiveness research (see Chapter 4, 5, 6, and 7), then the conclusion is less clear. The reliability data suggest that the system may not quite meet the expectations of the stakeholders, but it is not very far off and the reliability may be improved if the beam does not desensitize as quickly when the beam is blocked or when multiple breaks happen shortly after each other (perhaps the manufacturer can change settings). The reliability does fall below the expectations of the general public who filled out the survey for the system along SR 3. Nonetheless, when the respondents were asked slightly differently about false positives the respondents lowered their expectations with regard to system reliability.

If the system is to stay in place, at least for a certain period, then certain modifications or actions are necessary or desirable:

1. The brightness of the warning signs needs to be reduced during the night. The current brightness leads to blinding and potentially hazardous situations based on the comments from the respondents.
2. The sensors in beam 5 need to be replaced, potentially with sensors from another manufacturer as the current sensors may no longer be available. Without replacing the broken sensors in beam 5 the system is not fully functional which may lead to drivers misunderstanding inactivated warning signs.
3. Many respondents complained about perceived unreliability of the system, including false positives caused by vehicles turning on and off the road. The vast majority (93%) of all correct detections for which the cause was identified related to vehicles turning on and off the road. Before the project was initiated it was known that the system reports vehicles that break the beam as a detection. Therefore this is a design issue that may need to be revisited rather than a failure of the detection technology. The number of “false positives” can be greatly reduced if vehicles turning on and off the road no longer result in activated warning signs. The researchers suggest installing a detection loop at the side roads. If a vehicle is detected then the detection by the animal detection system can be declared invalid and the warning lights will not turn on. While there are two access roads in the road section with the system (in beam 3 and 4) one may choose to only install a loop at the access road that receives the highest use; Air Force Way in beam 3. Note that large wildlife species, including black-tailed deer, and humans will still trigger the system when they break the beam at the access road(s).
4. Some respondents reported deer on the road near the end of the section with the system. The current system ends in different locations on opposite sides of the road. The researchers suggest revisiting this design as this may result in animals on or near the road without the warning signs being activated. The researchers suggest that detection zones on opposite sides of the road should always start and end at the same location.

5. The current project did include a website with general information about animal detection systems and the technology installed along SR 3 near Ft Jones. However, the current project was mostly aimed at installing the system and investigating its reliability and effectiveness in the time period that was available. The current project was not aimed at providing the public with information about the results of the study as those results only became available towards the end of the project. The researchers suggest a communication program that includes information on the system and the results of the study. Communication through a website and local and regional media are likely to be insufficient; it is desirable to have multiple public presentations in the area that allow for questions and discussion on relevant topics.

9 CONCLUSIONS

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System Reliability

The results of the reliability tests at the test-bed in Lewistown, MT, suggest that the system that was installed along SR 3 near Ft. Jones, CA, may not quite meet the expectations of the stakeholders (based on previous surveys). However, the system was not far below these reliability expectations, and system reliability may be improved through making the system less likely to desensitize when the beam is blocked for more than a few moments or when multiple breaks happen shortly after each other. The reliability of the system may be affected by winds, suggesting that solid foundations, poles, and a solid connection between the sensors and the poles are important. Increasing levels of humidity may also somewhat affect system reliability, but the size of the species (ranging from sheep to llamas and horses) did not influence the probability of detections by the system.

The results of reliability tests of the system along SR 3 near Ft. Jones, CA suggest that the system has no blind spots and that it can detect black-tailed deer and similar sized other large mammals reliably along the entire length of the road section equipped with the sensors. Beam 5 was not in operation at the time of testing though, as a result of damage to the sensors when a car went off the road and hit a pole with equipment. The damaged sensor was not replaced yet at the time of testing. The researchers found evidence of a deer desensitizing a beam once in the 30 days that the data were analyzed for. However, there may have been more instances that were not visible on the video images. Further analyses of the detection log of the system showed that the average number of records with detections per day was not very high (about 20). This is important because if the warning signs would be on most of the day it would be too similar to warning signs that are always turned on and that are not connected to sensors. Nonetheless, based on a comparison to video images of cameras that were attached to some of the posts, most of these detections did not relate to the target species (black-tailed deer), and one could consider efforts to minimize the number of detections that do not relate to the target species. Most of the detections related to vehicles turning on and off SR 3, particularly at Air Force Way (beam 3).

System Effectiveness

There are multiple ways to measure the effectiveness of an animal detections system. For example, one may measure vehicle speed and compare vehicle speeds between situations when the warning lights are on and situations when the warning lights are off; one may measure driver alertness in specially equipped vehicles with research equipment or in a driving simulator; or one may measure the number of animal-vehicle crashes. For the purpose of this report by WTI, the researchers only investigated the potential effect of the operational animal detection system on animal-vehicle crashes.

The number of reported black-tailed deer carcasses in "control" road sections just before and after the road section with the animal detection system along SR 3 near Ft. Jones, CA, appears to have declined from 2009 onwards. Assuming that the search and reporting effort for the carcasses indeed remained constant throughout the years, this suggests that the black-tailed deer population in the area has declined in the last years. This is consistent with some of the remarks of the public (see Chapter 8). There was one black-tailed deer carcass reported inside the road section with the system after the warning signs were unveiled on 17 October 2011. This animal was located towards the edge of the road section with the system and the animal detection system is only present on one side of the road at that location. Given the relatively low number of large mammal carcasses, especially from 2009 onwards, the relatively short road section with the system, and the relatively short time period during which the system was present with the warning signs attached, it is not really possible to conclude whether the animal detection system reduced the number of large mammal-vehicle collisions or not.

Survey

The results of the survey indicate that most respondents want the system removed. The most common concerns relate to the perceived cost of the system (not to be confused with the additional costs of research equipment and costs associated with conducting the research), the perception that the system is in the wrong location, that the warning signs are too bright at night, and that the system is not reliable.

Recommendations

In the United States the total number of crashes (all types combined) has remained relatively stable over the last few decades. However, wildlife-vehicle collisions, primarily with large ungulates, have increased by about 50% in the same time period (Huijser et al., 2008). This means that the number of wildlife-vehicle collisions is increasing and that they form a growing proportion of the total number of crashes that occur. These facts are among the primary reasons why the level of effort to address these types of collisions has been increasing. One of the most effective and robust measures aimed at reducing wildlife-vehicle collisions and at providing safe crossing opportunities for wildlife is wildlife fencing in combination with wildlife underpasses and overpasses (Huijser et al., 2009a). However, these measures require relatively high upfront cost and are most practical in combination with new road construction or major road reconstruction. Animal detection systems require lower upfront costs (though the researchers currently project them to be more expensive on the long term because of their shorter life span and because these systems are not mass produced yet) and are more practical to implement along existing roads without major road reconstruction. (For other pros and cons of animal detection systems vs. wildlife fences in combination with wildlife underpasses and overpasses see Huijser et al., 2008b). The limited data on the effectiveness of animal detection systems suggest they can reduce wildlife-vehicle collisions with a similar percentage as wildlife fences in combination with wildlife underpasses and overpasses. However, animal detection systems must still be considered experimental as there are often challenges with the reliability of systems that need to be addressed. Other animal detection system projects have often been abandoned because of unreliable systems, an unwillingness or inability to address technological challenges, negative public opinion, loss of interest by decision makers, and lack of operation and maintenance funds to continue operating the system after a research project has been completed and when associated funds are no longer available.

The system along SR 3 may well become more reliable, perhaps “sufficiently reliable”, if certain modifications are made to the system (see below). Since it is rare to have a reliable system with associated research equipment in place, the researchers suggest continuing the research into the reliability and effectiveness of the system after potential system modifications have been implemented. Only then can we, as a society, make progress with the design and implementation of these systems and learn whether they indeed have a future as an alternative to wildlife fencing in combination with wildlife underpasses and overpasses.

If the system along SR 3 near Ft. Jones, CA, is to stay in place, then the researchers suggest the following modifications:

Reliability improvements:

1. The sensors in beam 5 need to be replaced, potentially with sensors from another manufacturer as the current sensors may no longer be available. Without replacing the broken sensors in beam 5 the system is not fully functional which may lead to drivers misunderstanding inactivated warning signs on that road segment.
2. Many respondents complained about perceived unreliability of the system, including false positives caused by vehicles turning on and off the road. The vast majority (93%) of all correct detections for which the cause was identified related to vehicles turning on and off the road. Before the project was initiated it was known that the system reports vehicles that break the beam as a detection. Therefore this is a design issue that may need to be revisited rather than a failure of the detection technology. The number of these “false positives” can be greatly reduced if vehicles turning on and off the road no longer result in activated warning signs. The researchers suggest installing a detection loop at the side roads. If a vehicle is detected then the detection by the animal detection system can be declared “invalid” and the warning lights will not turn on. While there are two access roads in the road section with the system (in beam 3 and 4) one may choose to only install a loop at the access road that receives the highest use (Air Force Way in beam 3). Note that large wildlife species, including black-tailed deer, and humans will still trigger the system when they break the beam at the access road(s).
3. Some respondents reported deer on the road near the end of the section with the system without activated warning signs. The current system ends in different locations on opposite sides of the road. The researchers suggest revisiting this design as this may result in animals on or near the road without the warning signs being activated. As a general rule the researchers suggest that detection zones on opposite sides of the road should always start and end at the same location.

Reducing downtime and operation and maintenance costs:

1. Consider putting up short sections of guard rail around the posts to minimize damage to the system if a car runs off the road as it may take substantial time and funds to get the system repaired and back into operation.

Improving communication to drivers and the general public:

1. The brightness of the warning signs needs to be reduced during the night. While the current brightness of the sign may be what is needed to have the warning signs be visible during the day, the signs blind drivers and can lead to potentially hazardous situations based on the comments from the respondents. A different and better dimmer may be attached to the warning signs to adjust the brightness for different amounts of ambient light.
2. The current project was primarily a design, implementation, and research project. Most research projects take place outside of the view of the public and the products are only shown to the public after extensive testing. Unfortunately animal detection systems need to be installed along a real road to investigate their effectiveness and not everyone may understand or accept that these systems may still have problems when they are first installed. In general, it is a good idea to investigate the reliability of a system at a closed access facility (see e.g. Chapter 4 and 5), before installing it along a real roadside. In addition, it is a good idea to investigate the reliability along a real roadside before attaching the warning signs, if the constraints of the project allow for this. This reduces the likelihood of reliability issues and it also reduces possible misunderstanding and annoyance by the public.
3. While the current project did include a website with general information about animal detection systems and the system that was installed along SR 3 near Ft Jones, CA, the current project was not a public education project. The current project was mostly aimed at designing and installing the system and investigating its reliability and effectiveness in the time period that was available. The current project was not aimed at providing the public with information about the results of the study as those results only became available towards the end of the project. If the system is to stay in place, and if system modifications are to be implemented, the researchers suggest a communication program that includes information on the system and the results of the study. Communication through a website and local and regional media are unlikely to be sufficient; it is desirable to have multiple public presentations in the area that allow for questions and discussion on relevant topics. Given the results of the survey it is especially important that the public is informed about funds associated with the research and development of animal detection systems vs. the actual costs with implementations if and when these systems are mass produced. It is also important to inform the public about the various parameters besides the number of large mammal-vehicle crashes that need to be considered when selecting a road section for an animal detection system.

Conduct sufficient research to answer the research questions:

1. The researchers are of the opinion that the current project was able to measure the reliability of the animal detection system fairly well. Additional reliability research may be advisable after potential system modifications have been implemented. Without such data one cannot be sure if thresholds for reliability have been met and one cannot inform the public about the reliability of the system.
2. The researchers are of the opinion that the current project did not allow sufficient time to investigate the effectiveness of the system with regard to large mammal-vehicle

collisions. The researchers suggest monitoring large mammal carcasses in the control sections and in the road section with the animal detection system for multiple years (e.g. at least 3-5 more years) and then analyzing the data once again.

Improving project organization:

1. The researchers recommend a clear distinction in roles and responsibilities. Most notably, perhaps a research organization is not best equipped to install a system and be responsible for the implementation of construction codes, and the time period and budget available for the research is better protected if these roles and responsibilities are separated. It may be best if a research organization can focus on the design of a system, to make sure that the research questions are likely to be answered, and on conducting the actual research.
2. Carefully define the success parameters and threshold values for an animal detection system project. Being able to answer the research questions is obviously among the parameters. Other parameters can include thresholds for the reliability and effectiveness. While the experience and opinions of the public are very valuable in deciding on location, minimum performance criteria for reliability and effectiveness, and potential modifications to an animal detection system, public acceptance of, or opinion on, the long term future for animal detection systems should probably not be based on a system that may have design or reliability issues after its initial installation. It should probably be based on a strategic plan (see below). The public can and probably should have a role in such a strategic plan but only if it is based on multiple systems that have been in place for considerable time in different regions where potential design and reliability issues have been corrected and where a communication plan has been executed to communicate about the purpose, reliability and effectiveness of the system.
3. Create a decision tree where the results (based on the success parameters) show what the next steps will be with regard to the development of animal detection systems, research into their reliability and effectiveness, and the potential future implementation of robust systems. The researchers suggest a general strategic approach to address increasing numbers of large mammal-vehicle collisions. Based on the results from previous projects animal detection systems, as stand alone or in combination with wildlife fences, should probably be part of this strategic approach; some systems have shown to be extremely reliable, and reliable and operational animal detection systems that have been investigated with regard to their effectiveness have shown that they can reduce collisions with large mammals substantially (roughly between 58% and nearly 100% reduction). While more and better data are still needed for system reliability and effectiveness, the most important research questions probably lie with the type of warning signs, associated text, potentially associated advisory or mandatory reductions in speed limit, and potential communication to drivers as they are approaching the site of a recent detection. Without a strategic approach individual animal detection system projects may not be as efficient as they could in answering questions that are essential for potential larger scale implementation. So far, there has been no coherent design, research and implementation program for animal detection systems anywhere in the world. Most research and/or implementation projects for animal detection systems have ended, but not always as a logical conclusion based on predefined success parameters and thresholds and a broader outlook for the potential future of animal detection systems. As a result, other animal

detection system projects typically have to start once again with investments in detection technologies, site selection, and system construction, before the remaining research questions can be addressed.

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APPENDIX A: SURVEY

Invitation to participate in survey

We are inviting you to participate in an animal detection system research project. The first phase of this project was funded by the United States Department of Transportation (USDOT) and the current phase is funded by the California Department of Transportation (Caltrans). The survey is conducted by researchers at the Western Transportation Institute at Montana State University. Through this survey, we hope to understand the various opinions and experiences of the public that travels the road section with the animal detection system.

Before you participate in the survey, please read the additional information below.

The survey asks you a number of questions about your opinions on and experiences with the animal detection system along SR 3 near Ft Jones, CA. The survey is aimed at the public that travels this particular road section. This survey is intended for people 18 years of age or older. It will take approximately 20 minutes and is anonymous. Your responses will not be linked to you in any manner. Your participation is entirely voluntary. You do not have to take this survey if you prefer not to. Your responses will not be accessible to the public; the raw data will be kept in a locked cabinet. We do not know of any risks to you if you decide to participate in this survey and we guarantee that your responses will not be linked to you as an individual.

Please select one answer per question unless the instructions say otherwise. If the options do not match your situation exactly, please select the answer that best describes your situation. If you cannot answer a certain question, or if you do not want to answer a certain question, please skip it and move on to the next question.

This survey was determined to be exempt from review by the Institutional Review Board, Montana State University—Bozeman. If you have any concerns about your rights as a participant in this study you may contact the Human Research Protection Office at (406) 994-6783. If you have any questions about the survey, please contact Dr. Marcel Huijser at (406) 543-2377 (for additional contact details see below).

Once the study has been completed you can download a copy from the following website: http://www.westerntransportationinstitute.org.

Sincerely,

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