Measures to prevent and reduce the impact of collisions involving wildlife

Potential of advanced driver assistance systems and ITSs in infrastructure

Ellen F. Grumert
Jiota Nusia

Foto: Allan Wallberg/Mostphotos.com

VTI rapport 1198A
Utgivningsår 2023
vti.se/publikationer

VTI rapport 1198A

Measures to prevent and reduce the impact of collisions involving wildlife

Potential of advanced driver assistance systems and ITSs in infrastructure

Ellen F. Grumert

Jiota Nusia

Authors: Ellen F. Grumert, VTI, Jiota Nusia, VTI
Reg. No., VTI: 2023/0031-8.3
Publication: VTI rapport 1198A
Published by VTI 2023

Publikationsuppgifter – Publication information

Title/Titel

Measures to prevent and reduce the impact of collisions involving wildlife – Potential of advanced driver assistance systems and ITSs in infrastructure/Åtgärder för att förebygga och minska effekter av viltolyckor – Potentialen med förarstödssystem och ITS i infrastrukturen

Författare/Authors

Ellen F. Grumert (VTI, http://orcid.org/0000-0001-5531-0274)

Jiota Nusia (VTI, http://orcid.org/0000-0003-2025-2355)

Utgivare/Publisher

VTI, Statens väg- och transportforskningsinstitut/
Swedish National Road and Transport Research Institute (VTI)
www.vti.se/

Serie och nr/Publication No.

VTI rapport 1198A

Utgivningsår/Published

2023

VTI:s diarienr/Reg. No., VTI

2023/0031-8.3

ISSN

0347–6030

Projektnamn/Project

The potential of ITS measures in vehicles and infrastructure to reduce collisions with wild animals/ITS åtgärder i fordon och infrastruktur som en lösning för minskade viltolyckor

Uppdragsgivare/Commissioned by

Drive Sweden/Vinnova

Språk/Language

Engelska/English

Kort sammanfattning

Trots åtgärder för att minska antalet viltolyckor i Sverige har utvecklingen gått åt fel håll. Mellan åren 2010 och 2021 har antalet viltolyckor ökat med 37 % på statliga vägar. Ökningen av antalet trafikolyckor med vilt på svenska vägar beror främst på en ökad trafikmängd, samt höga hastigheter på de delar av vägnätet där vilt är vanligt förekommande. Över hälften av viltolyckorna sker på vägar med 4 000 fordon per dygn och skyltad hastighet över 80 km/h. För vildsvin, dovhjort och kronhjort bidrar även en ökad utbredning och växande populationer till ökningen.

Hastighet är en avgörande faktor för uppkomsten av viltolyckor och dess effekter. Detektering av vilt, avancerade förarstödssystem i fordon och infrastrukturella Intelligenta Transport System (ITS) (t.ex. viltvarnare och variabla hastighetsgränser på strategiskt utsatta platser) är viktiga möjliggörare för att minska antalet viltolyckor. Forskning och teknikutveckling gällande utformningen av vägars sidoområden, djurens beteenden och ekologi, m.m. är därför nödvändig.

Syftet med denna förstudie är identifiera existerande och nya förarstödsystem och system i infrastrukturen som kan bidra till att undvika eller mildra effekten av en viltolycka på det lågtrafikerade vägnätet där andel viltolyckor per trafikant är högt relativt antalet viltolyckor per km och där det inte är ekonomiskt försvarbart att vidta fysiska åtgärder. Kunskap från myndigheter, näringsliv och akademi kombineras för att hitta möjligheter som kan bidra till att minska antalet viltolyckor på väg.

Rapporten innehåller följande:

- En sammanställning av de åtgärder som tillämpas idag för att minska antalet viltolyckor, både infrastrukturella och fordonsspecifika åtgärder.
- En beskrivning av existerande förarstödsystem och infrastrukturella ITS som kan hjälpa till att undvika eller lindra effekter av kollision med vilt, t.ex. viltvarningar och variabla hastighetsgränser.
- En beskrivning av vilka utvecklingsbehov som finns i dagens förarstödsystem och infrastrukturella ITS för att öka nyttan och minska antalet viltolyckor, samt hur, och om, de kan användas i kombination för att ytterligare öka nyttan med systemen.
- En framåtblickande strategi för att möjliggöra att nya/mer utvecklade system når marknaden.

Nyckelord

Viltolyckor, intelligenta transportsystem, förarstödssystem, infrastrukturåtgärder

Abstract

Despite measures to reduce the number of wildlife-vehicle collisions (WVCs) in Sweden, the trend is pointing in the wrong direction. The number of WVCs has increased by 37% between 2010 and 2021. Besides the fluctuating numbers of wildlife, the increase in the number of WVCs on Swedish roads is due to an increase in traffic, as well as high speeds on the parts of the road network where wildlife is common. More than half of WVCs occur on roads used by 4,000 or more vehicles per day and with speed limits above 80 km/h. For wild boar, fallow deer and red deer, increased distribution in Sweden and growing populations are also contributing to the increase in WVCs.

Speed is a crucial factor in the occurrence of WVCs and their effects. Detection of wildlife, advanced driver support systems in vehicles and infrastructural Intelligent Transport System (ITS) measures such as warnings indicating wild animals and variable speed limits at strategically riskful locations are important enablers to reduce the number of WVCs. Research and technology development regarding the design of roadside areas, animal behaviour and ecology, and so forth, is therefore necessary.

The purpose of this prestudy is to identify both existing and new driver support systems and systems in infrastructure that can help to prevent or reduce the impact of WVCs on parts of the road network where the proportion of WVCs per road user is high and where physical measures cannot be justified. Knowledge from authorities, industry and the academic community has been gathered with a view to identifying opportunities for solutions that could reduce the number of WVCs.

This report includes the following:

- A summary of available measures – both infrastructural measures and advanced driver support systems – that were developed to prevent WVCs and reduce their impact.
- A description of existing advanced driver support systems and infrastructural ITSs that can help prevent or reduce the impact of WVCs, such as wildlife warnings and variable speed limits.
- A description of the future development needed in the advanced driver support systems and infrastructural ITSs of today in order to increase the benefit and reduce the number of WVCs, plus an analysis of whether these systems can be used in combination to further increase the benefit.
- A forward-looking strategy to enable new/more developed systems to reach the market.

Keywords

Wildlife-vehicle collisions, intelligent transport systems, driver support system, infrastructural solutions

Preface

This report presents results from a prestudy on whether advanced driver assistance systems and infrastructural ITSs can contribute to a reduction in the number of collisions involving wildlife, and if so how. The project has been conducted as a collaborative project with emphasis on cooperation and dialogues with stakeholders from an ecological perspective, a vehicle perspective (vehicle manufacturers, sensor development, software development) and a transport system perspective, including roadside areas and maintenance measures. The intention has been to build up a group of stakeholders who can work together as part of a developed project towards the common goal of reducing the number of wildlife collisions on our roads.

The project has been led by the **Swedish National Road and Transport Research Institute (VTI)**, with project manager Ellen Grumert and assistant Jiota Nusia. VTI has been responsible for the research activities and coordination within the project, with previous knowledge of research related to the effects of ITSs and advanced driver assistance systems.

The **Swedish Transport Administration (Trafikverket)** has been involved in the project by attending project meetings, conducting individual dialogues, providing expertise and forging contacts with relevant stakeholders and networks. Different parts of the Swedish Transport Administration were involved as a means of covering the different aspects for which they are responsible in respect of collisions involving wildlife. The Swedish Transport Administration has previously had good knowledge of problems related to collisions involving wildlife, including statistics and behavioural aspects and wildlife patterns close to roads, road design and measures to prevent collisions involving wildlife, and so forth. They also have expertise in respect of traffic information/data and traffic management, and also on requirements defined for vehicles: this is useful information in the context of the project. The TRIEKOL research programme, which is funded by the Swedish Transport Administration, also covers a variety of aspects of problems in respect of collisions involving wildlife.

Volvo Cars has played an active part in the project by attending project meetings and conducting individual dialogues. They have also provided important contacts with stakeholders of relevance for the project. Volvo Cars provides knowledge and expertise in the field of advanced driver assistance systems that aim to improve safety for drivers and passengers, covering both existing and important future fields of development.

Both VTI and the Swedish Transport Administration are members of the National Wildlife Accident Council (*Nationella Viltolycksrådet* – NVR), and information has been gathered through the project network.

A number of stakeholders have provided valuable knowledge related to different aspects and areas of collisions involving wildlife. We would like to extend our warmest thanks to you for taking the time to talk to us: see Appendix B for a list of stakeholders.

The project has been funded by Vinnova as part of the Drive Sweden strategic research programme. This project is in line with the goals of using advanced technology to improve traffic safety and the environment, and is thereby contributing to the sustainable transport system of the future.

Linköping, October 2023

Ellen Grumert
Project manager

Granskare/Examiner

Björn Lidestam, VTI.

Contents

1. Introduction

Physical measures in transport infrastructure, such as fences preventing wildlife accessing roads, fauna passages and ecoducts, were proven to be cost-effective on roads with a traffic demand of 4,000 vehicles per hour or more and speed limits above 80 km/h, corresponding to 8% of the Swedish road network. In the national transport plan for 2022–2033, the budget for measures to reduce wildlife-vehicle collisions (WVCs) stands at around 1/10 of the current amount needed for action on this type of road network. If we are to reduce WVCs on the remaining 92% of the road network, there is a need for other types of measures to complement the above-mentioned physical measures.

Today's advanced driver assistance systems, a subgroup of in-vehicle Intelligent Transport Systems (ITSs), aim to reduce the impact of WVCs. These have been developed to warn drivers of wildlife in the vicinity of the vehicle and/or to assist drivers by providing automated braking. For the effectiveness of existing and future ITSs, it is essential for detection of wildlife and the corresponding potential collision risks to be communicated to drivers in such way that drivers understand that there is an increased upcoming collision risk; even in situations where drivers themselves have failed to spot an animal. Going forward, the effectiveness of ITSs will also hinge on drivers' acceptance of and trust in these systems, which makes it crucial to avoid false warnings and emergency braking when there is no wildlife nearby.

Accurate, high-resolution **training data** is crucial if a high proportion of 'true' detections is to be achieved. The training data should include critical situations (wildlife in motion and heading towards the road and vehicles: namely, presenting a high collision risk) and non-critical situations (wildlife standing still at the roadside). It is also important to investigate how the roadside areas on roads where wildlife is frequently observed should be maintained and designed to guarantee good wildlife **visibility** without encroaching too extensively on natural habitats.

Warnings on variable message signs near to at-grade fauna passages and speed reductions indicated by variable speed limit signs are infrastructural ITSs that can be implemented to reduce and prevent WVCs as referred to in the literature. Warnings on variable message signs have also been tested in Sweden to an extent. Driver compliance needs to be high if the systems are to be effective. Moreover, the systems have to be weighted towards other transport goals: in particular, the goal of achieving high transport system efficiency may conflict with the notion of reducing speed limits in order to improve traffic safety. Hence, careful consideration needs to be given to these two goals, and the benefits need to be evaluated with respect to both.

Apart from using ITSs in infrastructure and vehicles to reduce WVCs, there is a great deal of potential in using **systems that make use of communication between vehicles and infrastructure (V2X)** to warn drivers approaching other vehicles that have detected wildlife along the road, and also to obtain warnings and advice from ITS measures in infrastructure.

1.1. Aim and purpose

The goals of the 2030 Agenda for Sustainable Development consider both traffic safety and the environment to be important aspects in a future sustainable transport system. Less detrimental use of the ecosystem and biodiversity is more likely to be achieved by identifying effects on the ecosystem and biodiversity at an early stage, before new systems are in place: this is an important part of the 2030 Agenda (Sustainable Development Goal 15).

The **purpose** of this prestudy is to focus on identifying ITS systems in vehicles and infrastructure that have been developed to prevent or reduce the impact of WVCs and that can contribute to the following aspects.

- *Reduced suffering for wildlife.*

  67,500 wildlife collisions were reported on Swedish roads in 2021, and the true number is probably much higher than this.

- *Reduced costs for society in respect of injuries and damage to vehicles, as well as costs related to rescue activities, hunters to search for injured animals, and so forth.*

  Seiler (2023) has estimated that WVCs cost society at least ten to fifteen billion Swedish kronor (SEK) per year, and the trend is increasing.

- *Increased biodiversity in many parts of the road network.*

  In the long term, barriers that prevent wildlife from moving freely may become less important if the technology becomes more dynamically adjustable, moving away from physical infrastructural measures and towards digital roadside infrastructure and in-vehicle applications.

- *The technology is fundamental for automated vehicles.*

  Automated vehicles have to account for all traffic situations if they are to be incorporated in future road traffic. This includes detection and avoidance of wildlife entering the road network.

- *Actions as a complement to physical infrastructure measures.*

  The Swedish Transport Administration is planning to implement physical measures – fences and safe passages for wildlife – on around 8% of the road network. ITSs in infrastructure and vehicles can enable measures on the other 92% of the road network.

The **aim** is for the project partners to work in close cooperation and investigate the possibilities of using advanced driver assistance systems and infrastructural ITSs, either individually or jointly, as part of a solution to reduce the number of WVCs, particularly on low-volume parts of the road network. This can be divided into two objectives, as follows.

1. Identify promising advanced driver assistance systems and infrastructural ITSs designed to reduce numbers of WVCs.
2. Propose important fields of development for advanced driving assistance systems and infrastructural ITSs designed to reduce numbers of WVCs.

1.2. Methodology

This project is a prestudy consisting of two important parts: a literature review, and a series of dialogues with relevant stakeholders from the automotive industry, road infrastructure owners, the academic community, research institutes, authorities and suppliers of technical equipment and systems.

Promising existing driver support systems and infrastructural ITS measures aimed at reducing the number of WVCs are identified in the **literature review**. Systems aiming at influencing both drivers and wildlife are included. A brief overview of how WVCs on roads are managed in other countries is provided. Furthermore, contacts regarding the matter have already been established between the Swedish Transport Administration and other international organisations.

By inviting stakeholders from different organisations to **individual dialogues**, their expertise and different perspectives can be used to identify the gap between existing solutions and the desired situation, as well as identifying which driving forces can be used to influence the industry in the right direction. This will then enhance understanding of the type of research needed to gain knowledge about existing and future systems that may affect the number of WVCs. The individual dialogues were performed in order to investigate whether stakeholders have experience and expertise in respect of wildlife, and if so in what respects. A set of questions formulated to suit each stakeholder was used as a basis for the dialogues. Appendix B provides an overview of all the questions (not adapted to the individual stakeholders). These questions were sent to stakeholders prior to the dialogues, together with some initial introductory text for the project: see Appendix A for an example of the invitation. The dialogues were intended as to form a basis for conversation so that we could learn more about the stakeholder, their role in preventing WVCs and the resources available to them in respect of new and innovative ways of resolving issues related to WVCs.

1.3. Contribution

The results from the project are expected to contribute information on future directions for research in order to enhance and accelerate the development of existing systems and the number of systems available with respect to WVC prevention.

For *vehicle manufacturers*, the results will contribute information about how further development of existing driver support systems should be prioritised given the resources that the industry and infrastructure owners can contribute, and which systems should be included in the connected and autonomous vehicles of the future with a view to reducing WVCs.

For *infrastructure owners*, the project will contribute further information about how infrastructure should be designed to enable efficient vehicle systems that are capable of detecting, mitigating and preventing WVCs, and information about what types of infrastructural ITS measures have the potential to further help to reduce the number of WVCs.

In addition, the project is expected to lead to future international collaboration of importance for the future development of useful and successful driver support systems and infrastructural ITSs, with assistance from different stakeholders with varying areas of expertise.

1.4. Boundaries

This is a prestudy with the aim of identifying promising directions for continued research into reduction of WVCs. Its objective is to help avoid investing major research resources in areas where there is ultimately modest interest from stakeholders. Thus, the project goal is to identify directions for a more extensive project which, in the long term, could assist with introducing new types of systems to the market offering enhanced ability to detect and warn of wildlife, thereby reducing the number of WVCs on our roads. Hence, improvements to existing systems or development of new systems do not form part of this project.

Furthermore, performance of existing systems was not evaluated, and conclusions on system performance are instead based on the results of previous studies found in the literature. A brief summary of measures to prevent WVCs in other countries has been included as part of the literature review. Therefore, a more in-depth review of the conclusions drawn in the prestudy with regard to how wildlife collisions on roads are managed in other countries is suggested for a future study. Additional dialogues with other countries are also suggested.

One of the most important parts of the project has been to identify important stakeholders and involve them in dialogues to ultimately identify which stakeholders may be of interest for a larger project. However, the stakeholders involved in a larger project in the future are not limited to the stakeholders approached during this project. Additional stakeholders and stakeholders from other sectors may be of relevance for a future project proposal.

1.5. Structure of the report

The report consists of two main chapters presenting the findings from the literature review (Chapter 1) and the findings from the dialogues with relevant stakeholders (Chapter 2). Conclusions and recommendations for future research are presented in Chapter 3.

2. Findings from the literature review

It is easy to forget the importance of the road network as a connection providing residents with access to various parts of the country that would otherwise be difficult to reach. However, the road infrastructure affects environmental conditions by dividing and separating minor and major environmental communities, presenting barriers for wildlife and the environment. Animals and other wildlife tend to cross human-built infrastructure as a consequence, causing road traffic collisions leading to deaths and injuries among humans and animals alike. A number of methods have been adopted in order to mitigate, or even eliminate, wildlife-vehicle collisions (WVCs). Traditional methods involve changes to infrastructure to either prevent or facilitate wildlife crossing roads by separating traffic and wildlife by means of measures such as fencing, underpasses or overpasses (Huijser et al., 2021, Gabrielsson et al., 2022). These systems come with some limitations, including high costs related to both implementation and maintenance.

Intelligent transport systems (ITSs) that detect and warn of wildlife provide other methods that help to resolve issues with collisions involving wildlife. The overall function of roadside ITSs and advance driver assistance systems is to prevent WVCs by means of information, recommendations and active driver support. These warnings, recommendations and active driver support can be based on predefined conditions such as fixed time intervals, historical data or real-time data. When real-time data is used, the goal is to detect a specific object (such as a vehicle or an animal), track it and calculate the potential risk of collision, and if necessary to issue a warning to either the driver or the animal by means of in-vehicle or roadside ITSs, based on detection and classification. The most common systems studied in the literature are ITSs. These can be categorised depending on which behaviour they intend to alter. The warning systems aim to influence the behaviour of either drivers or animals: see Figure 1.

Systems affecting animal behaviour are intended to scare animals away from the road by means of either sound or light, or a combination of both. Roadside reflectors were one of the first interventions investigated for prevention of wildlife-vehicle collisions, originating as early as the 1950s (Brieger et al., 2016). These systems detect vehicles and then attempt to alert animals by means of acoustic and/or visual signals. The reflectors are positioned along the roadside, on posts normally sited 25 to 50 m apart. As oncoming vehicle headlights strike the reflectors, the light is refracted in various colours, either towards the road or at right angles away from the road. Reflectors have been developed and tested with various lights. Other systems, sometimes referred to as animal deterrents, combine sound and lights and also aim to prevent animals entering the road by scaring them away (Huijser et al., 2021).

Systems aiming to alter driver behaviour can be categorised as either animal detection systems or vehicle-based driver warning systems. Area-cover systems such as the ones presented in Chapter 2.2.1 are animal detection systems that detect large animals by reacting to changes in the physiological conditions in the area they cover. Area-cover systems detect stimuli such as animal heat, sound and motion. These stimuli are converted into digital signals and then processed and analysed. Furthermore, area-cover systems can be categorised as active or passive, depending on the technological mechanism used to detect animals. Passive systems are made up of either infrared sensors or video detection systems which detect energy emitted by an object. Active systems made up of infrared sensors or microwave radars have transmitters that emit energy pulses and receivers that receive the energy returned from animals.

Break-the-beam systems are another form of animal detection system: see Grace, et.al. (2017), for example. In a manner similar to area-cover systems, these are made up of receivers and transmitters working with infrared, laser or microwave radio signals. Unlike area-cover systems, which detect intruders within the field of view, break-the-beam systems react when a beam between a transmitter and a receiver is broken.

A recently developed electromagnetic detection system constitutes a third animal detection system category (Druta & Alden, 2019). A cable buried in the ground along the road emits an electromagnetic field using a central processor in the cable. Animals are detected as they enter the electromagnetic field. The location of animals can be determined by mapping the position of the disturbed electrical field, and the classification of the animal type is based on conductivity, size and motion.

Vehicle-based driver warning systems may, for example, include navigation-based warnings that provide information about high wildlife risks, wildlife warnings in the vicinity based on detection from vehicles, and so forth.

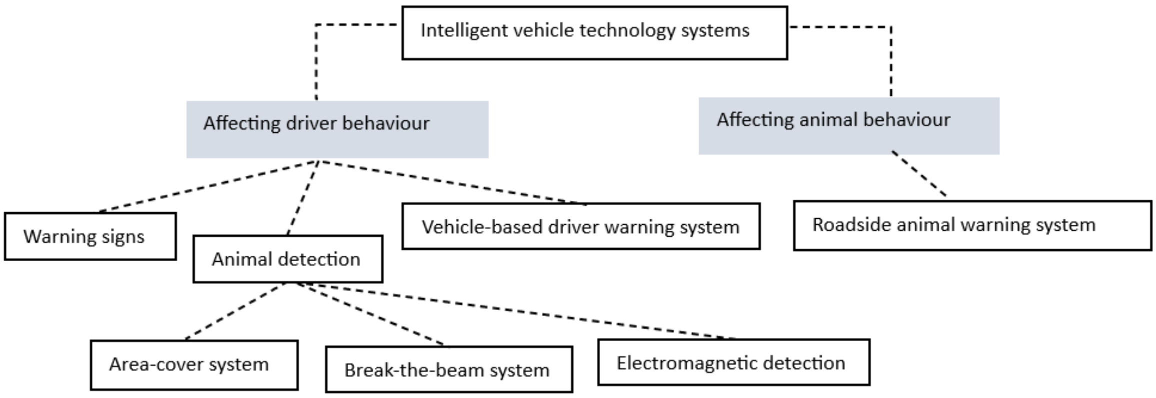


Figure 1. Schematic illustration of intelligent technology systems. Categorised in sections depending on whether they aim to alter driver behaviour or animal behaviour.

Section 2.1.1 provides a deeper insight into system studies and trials. Detection systems that aim to warn drivers, as well as warning signs such as variable message signs to draw the attention of drivers, are presented in Section 2.2 (2.2.1–2.2.2). Additional vehicle-based systems that aim to influence driver behaviour are presented in Section 2.2 (2.2.3).

2.1. Systems influencing animal behaviour

2.1.1. Wildlife warning reflectors

Wildlife warning reflectors were one of the first devices developed with a view to mitigating WVCs, and date back to the 1950s (Brieger et al., 2016). The purpose of wildlife reflectors is to scare wildlife away from the road by redirecting light from the headlights of approaching cars in colours that are unnatural to specific species: see Figure 2. Results from studies were conflicting, and the effectiveness of wildlife reflectors is therefore brought into question. Criticism has also been directed at the designs of studies investigating the efficiency of reflectors, and also at the small samples used (D'Angelo & van der Ree, 2015; Seiler, et al., 2014; Benten et al., 2018). The generalisability and validity of the results is questionable due to the small samples, resulting in poor statistical power. Study designs that look at WVCs in a before-after implementation lack the ability to incorporate factors other than reflectors that could influence the number of collisions, such as environmental changes and population fluctuations (Morrison et al., 2008; Benten et al., 2018). Apart from that, the theoretical approach regarding the colour, wavelength and intensity of the reflected light has been in doubt as this sometimes appears not to have a significant effect on either animal attention or scaring them away, and hence, the effect on mitigating WVCs is questionable (D'Angelo & van der Ree, 2015; Seiler et al, 2014). The intensity of the reflected light may be stronger towards drivers rather than towards wildlife, which could influence the behaviour of drivers rather than wildlife, reflecting light to mitigate WVCs, and thereby acting as driver warning devices (Rowden et al., 2008). This was discovered by Benten et al. (2019), where reactions of both ungulates and drivers were tested on thirteen study sites in

Germany using multicoloured warning reflectors. The study was conducted for one year between 2015 and 2016 and identified no behavioural responses among motorists that slowed their vehicles.

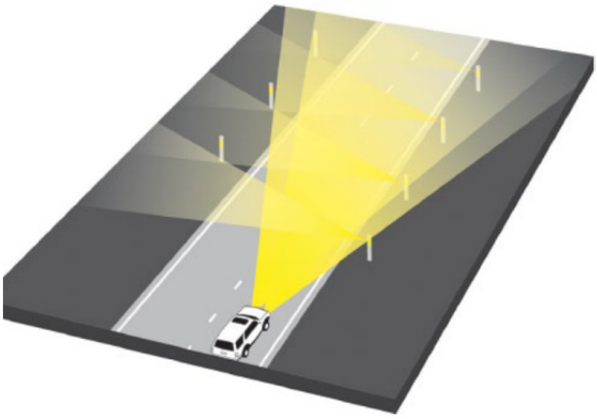


Figure 2. Illustration showing the use of warning reflectors with an approaching car. Adopted from D'Angelo & van der Ree (2015).

A recent report by the Norwegian Public Roads Administration (Wildenschild, 2022) presented a field experiment in northern Norway investigating blue reflectors along four road sections, each ranging between 1.7 and 6.9 km. This report does not state the measured outcome from the experiment, apart from the fact that snow was found to stick to the reflectors when the temperature reached a certain level. This was believed to impair the visibility of the reflectors, making them less effective at scaring away elk.

Benten and several co-authors have conducted numerous studies on wildlife warning reflectors for various species. Benten et al. (2018) hypothesised inefficiency of wildlife reflectors in a randomised crossover experimental design. The reflectors were of modern type, reflecting dark blue, light blue or multicoloured light. They analysed WVCs between 2014 and 2017, looking at data obtained from 151 testing sites, divided equally between reflector colours, and each testing site in central Germany was approximately 2 km in length. The most common species in the areas tested were roe deer and wild boar. They found that wildlife warning reflectors did not reduce the number of WVCs to a relevant extent, and that this inefficiency did not vary regardless of the colours of the reflectors tested. They also observed that various environmental variables such as forest-agricultural land ratio, speed limit and traffic volume did not influence the efficiency of the wildlife warning reflectors, even though these variables impacted on the actual number of WVCs. A later study by Benten et al. (2019) studied the behavioural response of ungulates to multicoloured reflectors and found that the reflectors had no significant impact on road crossing events. They observed that wild boar were more likely to run away from approaching vehicles, while other ungulates were more likely to move calmly away from the reflectors. However, this effect was observed only for the first sixteen days after installation, after which the effect decreased quickly (Benten et al., 2019). A meta-analysis of published literature data provides further evidence against the long-term efficiency of reflectors on WVCs (Brieger et al., 2016). However, an initial change of road-crossing behaviour could be useful in specific situations. Riginos et al. (2018) found deer crossing behaviour to be less risky when reflectors on posts were installed, compared to no reflectors. They observed that the most mitigated risk-taking behaviour was observed when the reflectors were covered with white canvas bags, a difference that also occurred in comparison with regular reflectors. In a similar manner to Benten et al. (2019), these changes were observed during the first period of the study after installation. However, given the other literature observations, animal habituation (meaning a decreased response to the stimuli from the reflectors) is to be expected. Table 1 provides an overview of some studies and their outcome on animal behaviour.

Table 1. Studies reporting outcomes of reflectors aiming to scare animals away from the road. Green indicates improvement in the outcome, yellow indicates no change, and red colour indicates worsening.

Study	Country	Colour	Animal	Wildlife-vehicle collisions (WVCs)	Roadkill	Animal road crossing	Animal escape	Animal habituation	Other comments
Benten et al. (2018)	Germany	Dark blue, light blue, multi-coloured. Opto-acoustic device.	E.g. roe deer, red deer, wild boar, red fox, raccoon, etc.	No change					
Benten et al. (2019)	Germany		Ungulates	No change in collision risk		No effect	Initial effect		
Riginos et al. (2018)	USA (Wyoming)	Covered with canvas bags	Deer		Lower	Lower			
Brieger et al. (2016)				No change					Systematic re-analysis without own field experiments, based on 53 references. Tests in Europe and North America
Huijser et al. (2021)				No effect, increase			No effect	Possibly (old ref)	Literature review without own field experiments.
Wildenschild (2022)	Norway	Blue		-	-	-	-	-	Only analysis of hardware management was presented.

2.1.2. Animal deterrents

Animal deterrent systems are enhanced developments based on reflector technology: some of these are listed in Table 2. The intention of these systems is to scare animals away from the road using various combinations of lights and sound. These lights are illuminated, in a similar manner to reflectors, in response to the headlights of approaching vehicles. What sets animal deterrent systems and reflectors apart is that the deterrent systems have an additional light source incorporated which actively emits light, while reflectors mainly redirect the headlights of approaching vehicles. The benefit of these systems is that they can theoretically illuminate the area with greater intensity than conventional reflectors. The other element of these deterrents is that some of them also come equipped with a sound system device that creates noise to scare animals away. These devices are commonly referred to as "virtual fences" and can essentially be described as electrical systems that generate light and sound stimuli. An experiment by Fox et al. (2018) implemented virtual fence devices over a period of three years on a single site in Tasmania, Australia. This study aimed to identify whether virtual fences were an effective way of mitigating roadkill among Tasmanian mammal species. Their results showed a reduction in roadkill of up to 50% for some species. However, the results of this study have been criticised by Coulson & Bender (2019), who claim that virtual fence technology is based on the same misconceptions about animal behaviour as reflectors and wildlife warning whistles, such as the fact that target species may not be able to perceive light stimuli. Wildlife may also respond inappropriately, or simply habituate to it. As for this particular study, Coulson & Bender (2019) argued that the study design and analysis were greatly flawed in many ways, ranging from imprecise measurements, low statistical power, violation of test assumptions and no consideration of habituation. It is therefore argued that these study flaws render this trial incapable of evaluating the effectiveness of the virtual fence system. Englefield et al. (2019) investigated the effect of virtual fences in Tasmania, with a similar experimental design to Fox et al. (2018) but with spatial and temporal replication. The study period lasted for 18 weeks, which is a relatively short time compared to Fox et al. (2018). The study did not show any significant impact of the virtual fence system, and hence did not confirm the reduction in roadkill presented by Fox et al. (2018).

Wildlife warning whistles, auditory deterrents without the combination of the lighting/reflective part of the system, is another form of deterrent investigated. These auditory deterrents are typically mounted on vehicles themselves, but D'Angelo & van der Ree present several reasons as to why these devices tend to be ineffective. These arguments were supported in later literature (Coulson & Bender, 2019; Englefield et al., 2019). The shortcomings noted by D'Angelo & van der Ree (2015) involve the effectiveness of the high-frequency noises generated by the whistles. Sound attenuates depending on factors such as distance from the source of the sound, environmental conditions (such as weather, topography and vegetation) and road design (such as bends and cuttings). The reduction of the actual performance of the devices could be problematic, therefore, as they are developed on the basis of the concept of giving animals time to react and flee the scene, rather than being startled by a sudden noise and possibly moving onto the road instead as a result. Other factors mentioned that may possibly reduce the effectiveness of these devices is that the designed frequency spectra of the generated noise could be drowned out by the noise from vehicle engines, along with the risk of habituation to the noise. These shortcomings may not merely be ineffective in scaring wildlife away from the road: in the long run, they may also give drivers a false sense of security on account of the detection system (D'Angelo & van der Ree, 2015).

Table 2. Studies reporting outcomes of animal deterrent systems aiming to scare animals away from the road. Green indicates improvement in the outcome, yellow indicates no change, and red colour indicates worsening.

Study	**Country**	**Technique**	**Animal**	**Wildlife-vehicle collisions (WVCs)**	**Roadkill**	**Animal escape**	**Animal habituation**	**Other comments**
Wildenschild (2022)	Norway	High frequency sound and lights	Elk	No change				Trials terminated
Englefield (2019)	Australia (Tasmania)	Acoustic sound and flashing lights	Bennett's wallaby, pademelon, common brushtail possum		No significant reduction			"Virtual fence"
Babińska-Werka (2015)	Poland	Acoustic sound	Roe deer			More, faster	No sign	Trains
Fox et al. (2019)	Australia (Tasmania)	Acoustic sound and lights	Mammals		Reduction			Information taken from the abstract, and from Coulson & Bender (2019) "Virtual fence"
Sørensen (2017)	Norway	High-frequency sound and flashing lights		No change				

In general, audio deterrents, or a combination of light and audio deterrents, have not been found to be effective in reducing WVCs (Höye, 2019; Huijser et al., 2021).

2.2. Systems affecting driver behaviour

2.2.1. Detector systems

The category of systems used to detect wildlife is important, influencing driver behaviour with some sort of warning or in-vehicle-based system. Some methods have commonly been presented in the literature, and these are summarised below.

Area-cover systems

Animal detection systems are designed to detect approaching animals. The general function of such a system involves a device scanning a detection zone to detect animals, including a scanning system (hardware) and the software processing the information. Finally, a warning sign communicates with drivers in a manner designed to gain attention and allow drivers to respond. Systems like these have the advantage of covering a larger area but often report false positive detections. These false positive detections often come about due to the environmental conditions of the area covered (such as forest vs. open landscape), light conditions (day vs. night) and the size of the animals.

Huijser et al. (2017) reported on a field experiment in which they tried to use a Doppler radar system to detect large mammals (such as deer and elk) approaching the road. The system was applied on a road section 113 m long in Idaho in the USA for a year between 2014 and 2015. The report compared the measured reliability and effectiveness of the detection system against another animal detection system. Huijser at al. found that the Doppler system met the minimum norm for false negative detections at 2.5%; while false positive detections failed to meet the settled criterion, with almost one-quarter of all detections being falsely positive. The reliability of the Doppler system was tested using a thermal camera. The report states that large ungulates (such as elk and deer) crossed the road successfully in about 15 seconds. They found that deer and elk spend several minutes on the road, especially when there is no traffic.

Early detection of wildlife near the road is also of importance. To detect large mammals earlier, Huijser et al. (2017) suggested either making sensors more sensitive and/or to widening the detection zone. However, lowering the sensor threshold could lead to an increase in the number of false positives, as smaller animals in the zone could also trigger the warning system (Huijser et al., 2017). Whether or not smaller animals are of interest for detection, lowering the sensitivity threshold could lead to drivers ceasing to trust the system and thereby not responding to warning signs that they interpret as being incorrect. The authors conclude that widening the detection zone is of interest only if the vegetation is short and there are no livestock adjacent to the area of interest. With regard to detection of smaller animals, another field experiment in a particular province in Japan tested a wildlife detection system for a particular rabbit species with the view to reducing roadkill. This system also warned drivers when animals were detected and instructed them to reduce their speed (Asari et al., 2020). The warning signs lit up with flashing lights when animals were detected.

Other studies were conducted with the purpose of detecting animals near the road and attempting to modify driver behaviour by detecting the animals and warning drivers by means of various warning signs. Gagnon et al. (2019) and Bhardwaj et al. (2022) integrated an animal detection system into a wildlife at-grade crossing on a two-lane road. The system described by Gagnon et al. (2019) consisted of tower-mounted infrared camera detection aimed at detecting wildlife on the crossing. The connected software was sensitive to animal body heat, movement and size. Detection of an animal activated the connected warning signs. The system detected 97% of all approaching animals and had a false negative detection rate of less than 4%. The authors stated that one factor contributing to the accomplishments of their custom system was the fact that system components were installed in a narrow, two-lane section of a road (to reduce the complexity of the infrastructure), thereby allowing them to increase the reliability of the system. However, Gagnon et al. did not indicate false positive detections, which are also important aspects in the reliability of the system, and possibly later as elements in driver habituation.

While the emphasis in Gagnon et al. (2019) was on evaluating the detection capabilities of the roadside system and driver response to the automated warnings, Bhardwaj et al. (2022) aimed to evaluate the crossing behaviour of large ungulates at one at-grade fauna passage. In general, the observations showed that wildlife in groups was never divided; either the entire group crossed the road, or the entire group stayed on one side of the road. They spent little time on the road when crossing it. The presence of vehicles did not affect the amount of time the animals spent on the road; however, the time they spent on the roadside verge was affected when vehicles were present on the road, compared to when there were no vehicles present. The time spent on the roadside verge approaching the at-grade fauna passage dominated the whole road crossing event. The authors demonstrated a 66% reduction in WVCs during the one year of the pilot study. In a review by Höye et al. (2019), the at-grade wildlife passage has also been reported as being effective in reducing collisions and vehicle speeds.

Break-the-beam

Break-the-beam is another form of animal detection deployed along roads. The concept of this system involves detecting an animal as it breaks an infrared beam while crossing the road. A study in southern Florida (Smith et al., 2016; Grace et al., 2017) aimed to assess the reliability of target animal detection with a break-the-beam system. This study took place over almost 2.5 years starting in 2013, the system being installed on a road section 2.1 km in length that was identified as a critical hotspot for WVC-related deaths. The system function was similar to the above description; a continuous infrared beam was projected between multiple integrated transmitters and receivers. A broken beam triggered the flashing lights on warning signs to alert drivers to the presence of wildlife. The sensors and receivers were about 150 m apart, and the beam, running in parallel to the road surface, was positioned about 20 cm above the ground to capture the movement of target species. Infrared camera data were used to evaluate system performance. Overall, they found that the break-the-beam system offered poor to fair performance in detecting the target species. The recorded average success rate (true positives) ranged from 11 to 66% between the five monitored sections, only two of them having a success rate above 50%. They also found that 34 to 89% of the target species were not detected (false negatives), and that over 90% of detections were classified as false positives. Most of the false positive detections were found to occur during the day, which the authors stated could increase the risk of driver habituation as the warning signs were constantly flashing.

Electromagnetic detection

Electromagnetic detection of animals uses a technique whereby the source of the electromagnetic field is generated from cables buried in the ground. This system has previously been tested in a controlled environment at the Virginia Smart Road facility in Blacksburg (Druta & Alden, 2015). In a collaboration between Virginia Department of Transportation and the Virginia Tech Transportation Institute, this system was implemented and evaluated in a real-world situation in order to determine its ability to detect deer and other animals (Druta & Alden, 2020). The system was implemented adjacent to a public road in Virginia. Two sensor cables were buried 23 cm into the ground and 30 cm apart: see Figure 3. One cable distributed the radio frequency signals along the cable route, while the other acted as a receiver and provided the signals to the processor. The electromagnetic detection field surrounding the cables was about 125 m in length and 1 to 1.5 m in both height and width. Animal detection and location was triggered when an animal passed through and broke the electromagnetic field. The reliability of the system when detecting larger animals (such as deer or larger animals) was found to be about 99% (true positives). The false positives, however, were not taken into consideration in the reliability calculations, which other studies have indicated to be an important factor in preventing driver habituation (Huijser et al., 2017; Gagnon et al., 2019). The false positive detections were considered to be temporary issues when heavy construction equipment parked near the detection system (Druta & Alden, 2019). Water flow during heavy rain was also found to have caused false positive detections, while the system is reported not to have been affected by up to 60 cm of snowfall. Furthermore, it was stated that the system could be triggered if a vehicle disturbs the electromagnetic field. However, the signal magnitude differs between animals (5–12 dB), humans (15–22 dB) and vehicles (40 dB) (Druta & Alden, 2015), and the system is therefore deemed to perform well under all traffic conditions, irrespective of vehicle size (Druta & Alden, 2019, 2020). Finally, warning signs were implemented to alert drivers in the event of detection, but the authors insinuate that in-vehicle alerts may also be possible.

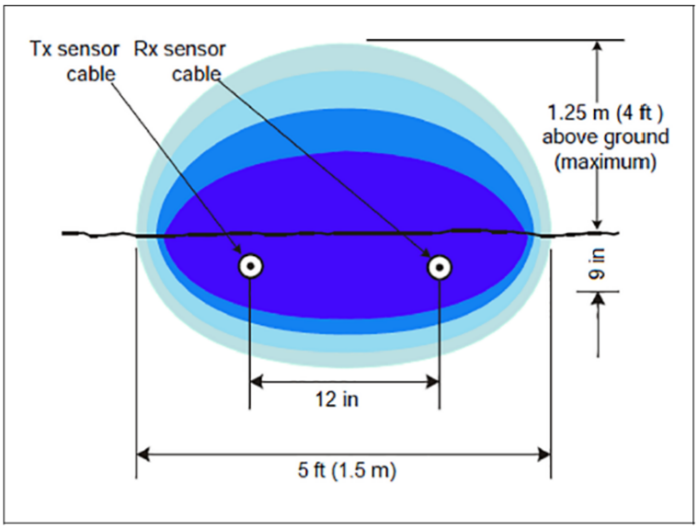


Figure 3. Buried electromagnetic cable system for animal detection purposes. Two sensor cables, one transmitter (Tx) and one receiver (Rx), are buried 23 cm (9 in) below ground and 30 cm (12 in) apart. The electromagnetic field generated extends to up to 1.25 m.

2.2.2. Warning signs

Until now, warning signs have been the main method used to alert drivers for the possible presence of wildlife. Stationary warning signs were found to be ineffective in reducing WVCs, partly due – it is suggested – to drivers not trusting the actual alert and driver habituation to the signs (Höye, 2019).

Variable warning/message signs, as opposed to the fixed variety, are activated only at certain times. These signs can be activated manually; remotely from a central control unit, or automatically on detection of an animal, for example. Variable warning signs are mainly designed either as stationary signs with flashing LEDs when activated, or as variable message signs (with or without LEDs) with displaying urgent messages that aim to alert drivers to the potential hazard. Besides the sensitivity and reliability of such systems for animal detection, one important question with regard to animal detection systems that warn drivers about wildlife on the road is just how effective they are at preventing collisions. The measurement of effectiveness has been based on a number of factors. The goal is to reduce the number of WVCs, which has been one of the measured factors. Another important factor involves measuring the change in roadkill or change in carcass removal. It is essential to reduce vehicle speeds in order to prevent collisions from happening. Vehicle speed and braking responses are two other factors that were measured in order to indicate driver actions and alertness, respectively, in response to the warning signs. Table 3 provides an overview of studies and measured outcomes in respect of driver responses to warning signs.

Table 3. Studies reporting outcomes of animal detection systems using variable warning signs to alert drivers. Green indicates improvement of measured outcome, while yellow indicates no change. VMS: Variable message sign. StaticLED: Static warnings sign with attached LED lights.

Study	Country	Warning sign (VMS/ StaticLED)	Detection system	Animal detections	Wildlife-vehicle collisions (WVCs)	Change in roadkill/ carcass removal	Vehicle speed	Braking	Other comments
Wildenschild (2022)	Norway (North)	StaticLED	Activated manually by text from observations.	Elk and deer	Lower	No change	No change		AVC: random chance not excluded
Donaldson & Kweon (2019)	USA (Virginia)	VMS	Seasonal (Oct–Nov) and 9–17	Deer		Lower	Lower		Greater speed reductions in low traffic volumes
Huijser et al. (2017)	USA (Idaho)	StaticLED	Doppler RADS	Large mammals	Lower				Effective in challenging road conditions
Druta & Alden (2020)	USA (Virginia)	StaticLED	Buried cable		Lower		Lower	Increased	Diff dusk and dawn. Lower WVCs in first year
Gagnon et al. (2019)	USA (Arizona)	VMS & StaticLED	Infrared camera	Animals bigger than rabbits			Lower	Increased	Animal-activated road crossing
Sielecki (2017)	Canada (British Columbia)	Integrated: VSM & StaticLED	Radar & infrared camera	Animals of wolf to elk size	Lower		Lower		Initial results
Grace et al. (2017)	USA (Florida)	StaticLED	Break-the-beam	E.g. deer, black bear, coyote, bobcat			Lower		Lower-speed tourist season, not off-season
Asari et al. (2020)	Japan (Amami Oshima Island)	StaticLED	Infrared sensor (break-the-beam?)	Middle-sized wildlife (Amami rabbits)			Lower		

Spatio-temporal warnings aim to alerting drivers to a specific location with increased numbers of vehicle collisions, as well as specific times at which animal activities increase in the area. Time-induced warnings may vary depending on both the season of the year and the time of day. Variable message signs with animal detection aim to warn drivers only when an animal is present and detected. The main goal is to increase system reliability and driver awareness by warning them only when a risk of collision is present, and *not* warning them when animal activity is low.

Donaldson and Kweon (2019) conducted a study in which variable message signs were activated on the basis of both season (October–November) and time of day (5pm–9am). The evaluations were based on up to six years of deer carcass removal data and four months of vehicle speed data. They found that there were 51% fewer carcass removals when deer advisories were posted, compared to when they were not posted. Vehicle speeds were found to be reduced by 1.9 km/h on average, and by up to 4.5 km/h at individual sensor sites. However, these speed reductions were not observed during high traffic volumes, only during lower traffic volumes. The higher the traffic volumes, the smaller the differences in speeds when comparing activated to non-activated variable message signs. Grace et al. (2017), on the other hand, found that collisions increased during tourist season (November–March), which they believed could have been caused by the observed increase in traffic volume, higher travelling speeds and the fact that the tourist season coincides with the panther breeding season. Although the break-the-beam system in the study malfunctioned, Grace et al. (2017) found the warning signs to be effective in reducing travelling speeds by 3.8 km/h during the tourist season. Travelling speeds during the tourist season were generally higher compared to speeds during the off-season at the study's control sites. The speed reduction was therefore believed to have been caused mainly by local drivers slowing down, forcing tourists to reduce their travelling speeds as well.

Apart from temporal differences, environmental conditions could have an impact on the drivers' response tendencies (Höye, 2019). Huijser et al. (2017) found the warning signs mainly to be effective for reducing vehicle speeds in challenging road conditions, such as at cold temperatures and when roads were covered in snow and ice, as well as during periods of decreased visibility at night. In terms of reduced vehicle speeds, they found the warning signs to be the least effective in summer when driving conditions were at their most optimal. The researchers suggest incorporation of advisory or mandatory speed limits in the warning signs for animal detection purposes in order to force drivers to reduce their speeds. Huijser et al. (2017) also suggested that there may be a need for multiple warning signs for each direction of travel in the detected area. Huijser et al. found in their field experiment that drivers may need time and distance to the detection zone to both interpret an activated warning sign and reduce the speed of their vehicles. They suggested that the arrangement of multiple warning signs should be such that drivers can pass a warning sign and still be able to see and interpret the next warning sign until the end of the detection zone. The warning signs need to be a sufficient distance from the closest edge of the detection zone so that drivers have enough time to reduce their vehicle speeds. This is because drivers should be warned even though they have already passed a warning sign before an animal was detected. Multiple warning signs allow drivers to be warned further into the detection zone, too.

2.2.3. Vehicle-based warnings and interactions

Attempts to alter driver behaviour have traditionally been made by providing information directly to drivers via signs in the infrastructure. However, some of the emerging methods are now being addressed in order to alter vehicle response, either by providing warnings to drivers via in-vehicle systems or by communicating directly with vehicles without attracting the driver's attention. Sensors on vehicles calculate the distance between vehicles and other objects detected on the road. The vehicle itself can then send a warning (audible and/or visible) so that the driver can recognise and act on the object in front of the vehicle. If the reaction from the driver is absent or too slow, the vehicle could intervene and automatically apply the brakes to prevent a collision.

Possibilities for AEB systems to intervene if a collision is imminent

Decker et al. (2021) analysed the potential benefits of automatic emergency braking (AEB) systems with regard to wildlife-vehicle collisions involving light passenger vehicles by studying conditions under which AEB systems were found to be effective for various groups of collision types. A total of six collision groups was defined, ranging from inclusion of all collisions to only taking into account frontal collisions or only collisions that took place during daytime. The analysis was based on database information of wildlife-vehicle collisions, as well as on naturalistic data from 3,000 cars instrumented and recorded over a three-year period in the USA. The analysis found that AEB systems were most effective in situations where the animal is struck in a frontal collision, when the weather is good and conditions are bright. In those optimal conditions, AEB systems were found to potentially mitigate 4 to 38% of fatal collisions and 22 to 94% of collisions reported to the police. Similar numbers were reported in an earlier study by Ydenius et al. (2017), which investigated elk-vehicle collisions in a Swedish database, stating that AEB systems could have prevented 40% of the collisions leading to fatalities. Decker et al. (2021) later found AEB systems to be less effective on bends and in turns, and concluded that current AEB systems are not able to avoid all collisions, and possibly only frontal collisions where there is no loss of control of the vehicle. Decker et al. (2021) also predicted that even more collisions could potentially be mitigated in the future by further developing AEB systems to operate in dim conditions and darkness, for instance.

Erbsmehl et al. (2017) and Decker et al. (2021) found that in the majority of collisions or near misses, drivers were given an average of about 1.5 seconds to react from the time the animal entered the road to when the collision occurred. Erbsmehl et al. (2017) estimated the time from braking to the collision from in-situ infrared video recordings based on the first distance spotted between the vehicle and the animal (about 30 m) and the vehicle speed (about 80 km/h). Decker et al. (2021) observed that most drivers did react in one way or another in an attempt to avoid a collision: 84% of drivers braked before a collision, of whom 40% both braked and steered, while 15% showed no reaction at all. Also, AEB-initiated crash mitigation activated at 1 second could potentially reduce severity, or even avoid a collision, for 50% of the WVCs when observed time from the animal enter the road to the time of impact was larger than 1 second and up to 2.25 seconds.

Communication between vehicles

Alerting of drivers to the potential presence of wildlife by means other than via warning signs in infrastructure were tested in field trials. Finding solutions for in-vehicle warnings is one of the current priorities, either by developing a communication strategy between ITSs in infrastructure and approaching vehicles, or by sharing information between vehicles via vehicle-based detection systems. These solutions require development of a cloud system to store information such as wildlife detections, locations, speeds and braking of approaching vehicles. Apart from both technical and legal aspects of wireless animal detection and information sharing, static warning signs in infrastructure present other challenges. One of these challenges involves finding a way to make drivers comply with the warning messages; in other words, to make drivers trust that warnings are correlated to an elevated risk of WVCs and thus eliminate habituation.

A recent project, Drive Sweden (Jaldemark, 2020), investigated the potential for communication between vehicles on the roads. The main aim was to demonstrate how to use central cloud platforms to record and utilise critical traffic data before sharing it safely with automotive stakeholders. Test vehicles were equipped with a sensor platform to detect and classify potential risk objects while driving, in this case an elk. The platform was also configured to transmit the GPS position in real time together with a video recording to the central cloud system for analysis. The project showed that the cloud system could send instructions from the detection-equipped test vehicle to another receiving test vehicle if the system deemed the situation to be dangerous. The information communicated to the vehicle could include recommended speed limit inside a geofence to be used by the vehicle's adaptive cruise control, or search requests for symbols or texts (such as numberplate information). The cloud-enhanced elk detection system was tested as a proof-of-concept study at the AstaZero test environment park. The vehicle sensors were tested to determine whether they could detect a decoy elk. A message was sent to the central cloud system, and the on-board cameras on the vehicles were activated so that they could send live video sequences to the cloud system. The position of the animal was automatically matched with wildlife fence data from a Swedish state-owned database. If data analysed in the cloud system detected the animal inside the wildlife fence, an automatic message was sent to the test vehicles and the manufacturer's own cloud so that a warning message could be communicated to the connected vehicle fleet and other approaching vehicles. If the vehicles were equipped with adaptive cruise control (ACC), their speeds could be reduced automatically as they passed the critical detection zone.

Warning drivers via navigation systems

Other forms of in-vehicle communication with drivers were investigated by means of map-spotting and selecting driving routes based on various registered hotspots (Huijser et al., 2021). These solutions could be applied as a preventive measure, but possibly also as real-time updates similar to the notifications received regarding roadworks or collisions. Llagostera & Lopez (2022) and Mayer et al. (2021) investigated the possibilities of interacting with drivers via the map or navigation system by developing mathematical tools that predict potential wildlife collision hotspots based on historic collision data and other variables such as seasonal variations, traffic activity and animal population density.

Llagostera & Lopez (2022) focused on finding the safest route between two points by avoiding the most dangerous of the roads available. They developed an algorithm that selected the closest route between two points based on levels of roadkill, daily average traffic volume, speed limits and vegetation density along roads. This was done by weighting different traffic system routes with the above variables. This approach was illustrated using real data sets involving WVCs in a region in Spain. The authors emphasised that this work was mainly designed to analyse traffic safety from a vehicle perspective. This work could be extended by defining and including other relevant variables and functions, as well as optimising the algorithm. One suggestion involved developing an algorithm to avoid collisions based on the animal perspective, such as by incorporating wildlife crossings. The algorithms from the study are available in an open access app designed to interact with other researchers by reproducing the current results and the complete dataset, for example.

Mayer et al. (2021) used historic information about deer-vehicle collisions (DVCs) in Denmark (> 85,000 collisions) over a period of seventeen years to improve awareness of spatio-temporal patterns among these collisions. They found that DVCs were highly predictable in time and space. Their study showed, for instance, that DVCs increased initially with increasing traffic density, but decreased again for the highest traffic densities. They found that DVCs were higher in areas close to woodlands, heathland and water bodies, and for some species the probability increased further in areas with a high proportion of agricultural land. The temporal patterns were affected by the time of day as well as seasonal variations. The risk of DVCs was found to be higher at dusk and dawn and in late spring (May) and autumn (October–November), which coincided with higher levels of deer activity. Mayer et al. (2021) stated that the variables they addressed are already in use in various navigation system services such as Google Maps and built-in navigation systems in vehicles. They also stated that these variables (time of day, date, land cover, road type and road density) could be used to calculate the relative risk of DVCs on the basis of current vehicle location. Mayer et al. further emphasised that the relative risk of DVCs is not equal to the relative risk for drivers; driver risk could be estimated by accounting for fluctuational differences in traffic volume during the day, for example. Incorporating driver risk could provide an opportunity for more intensity levels in warning systems instead of the binary mean of the Waring application, where drivers are either warned or not warned of the risk of collision with animals (Mayer et al., 2021). As exemplified by Mayer et al., a general warning can be provided in situations when there is a greater risk of DVCs at a specific time and in a specific place, and a more intense warning could be provided only when there is a high risk of drivers colliding with animals. Mayer et al. also concluded that existing mapping devices have the potential to improve the estimated predictions and accuracy by means of feedback mechanisms to improve accuracy via direct reporting by vehicle drivers and identification of DVC hotspots.

Mohammadi et al. (2022) conducted a proof-of-concept study investigating the potential of providing various degrees of warning depending on the real-time level of threat based on activity detections from roadside animal detection systems in infrastructure. The level of threat was estimated in a similar manner to Mayer et al. (2021) above; by developing an algorithm with integrated variables. As this prediction algorithm, unlike the above, aims to predict the risk of collision in real time, the variables that were incorporated into the system were the perpendicular distance between the animal and the roadway, the magnitude of the vehicle speed, the stopping sight distance and, finally, the physical distance between the vehicle and the animal. Risk estimates based on these variables would require a great deal of reliability in roadside animal detection systems in terms of true detection and classification of wildlife at any given moment.

Another type of navigation-based warning system is based on source data reported by road users, specifically by drivers. Waze (Huijser et al., 2021; Waze, 2023) and Porokello (Kotituomi et al., 2019) are two mobile device apps that have been developed, the former being used in Israel and the latter being used in experiments in Finland. Road users report either dead or live animals along the road. Based on all the reports collected, the Waze app presents the most dangerous road segments in a map based on reported animal vehicle collisions, while the Porokello app saves reports of wildlife (particularly reindeer) in a cloud system and alerts other drivers entering the reported location (with a radius of 750 m) within 30 minutes.

3. Results from dialogues with stakeholders

The purpose of the dialogues with relevant stakeholders was to identify both the status of preventive work and future research needs for WVC mitigation. Identification of stakeholders providing various knowledge and data sources could be useful when it comes to understanding the overall picture and the extent of the problem, as well as describing the current issues and development needs. Therefore, communication and cooperation between stakeholders with different knowledge backgrounds tend to enhance the understanding of a problem and assist with identification of useful and beneficial solutions that will receive acceptance in a wider perspective and among a larger audience. Stakeholders are listed in Appendix B.

The findings are summarised on a broad level in this chapter, concluding the main areas in need of further development and the main enablers for the future development of systems and tools to resolve issues related to WVCs. Furthermore, some of the crucial stakeholders for these developments have been identified and potential cooperations on different research directions are suggested.

3.1. Stakeholders in respect of WVCs and ITSs

Many stakeholders are involved in, and affected by, WVCs on the roads. This includes industry, interest organisations, authorities and research bodies. The main stakeholders are described in Table 4–Table 8 and sorted according to operating field area.

Table 4. Summary of stakeholders that ***use and develop systems*** *in vehicles and infrastructure.*

Stakeholder (Domain)	Description
Vehicle manufacturers (industry)	Develop safety systems to mitigate the effects of or avoid collisions with animals. Both passenger cars and heavy goods vehicles are included and may offer different perspectives.
System providers (industry)	Include development of aftermarket systems that can be used as add-ons to in-vehicle systems, such as equipment installed in vehicles (such as navigation and information systems), handheld units (such as smartphone applications) and roadside ITSs (such as variable messages signs showing warnings and regulatory information).
Data collection and detection system developers (industry)	Develop systems that can detect and/or collect data from animals and the surrounding traffic, infrastructure and vehicle conditions to ensure that roadside and in-vehicle systems are trustworthy and precise. Sensors for collection and detection of vehicle-based data and roadside sensors for collection and detection of data along a stretch of road are of importance. Additional sensors for collection of data such as weather conditions, road conditions and so forth may also be of importance.
Digital infrastructure providers (industry)	Enable communication of information to and from the road infrastructure and vehicles for further processing locally or via direct access to a cloud service where data can be processed and stored for different purposes. The advantage of a cloud-based solution is that information from different data sources (vehicles and infrastructure) can be merged to increase the information space and knowledge space to ultimately provide more accurate information for end-users, drivers and/or vehicles.
National regulatory bodies (authority)	Responsible for type approvals of vehicles and systems and approval of the introduction of new in-vehicle systems. These approvals can take place in accordance with both national and international rules and regulations. Responsible for roadside equipment.
National transport administration (authority)	Responsible for communication and dialogue with Euro NCAP from a Swedish perspective. Opportunities to influence the framework for the testing and rating of vehicle safety and to include new in-vehicle system types in the rating.

The industry plays a key role in the development of new and improved systems, services and applications to increase safety and reduce the number of WVCs on the roads. Infrastructural systems, in-vehicle systems and aftermarket systems could help to reduce WVCs. Furthermore, the digital infrastructure plays an important role in the provision of knowledge using different data sources. This is why development of communication solutions, sensors and platforms for storage and processing of data are of importance in the development of systems. Industry can also be an important data provider. However, the amount of available vehicle data that can be shared is often restricted by customer or end-user approval, and the purpose of data sharing must be stated clearly to customers or end-users. One example is data sharing for development purposes, where data are not communicated to parties other than vehicle manufacturers. Some data connected to the certification can be made available more readily.

*Table 5. Summary of stakeholders that **provide data** related to wildlife, road infrastructure, vehicles and collisions.*

Stakeholder (Domain)	Description
Insurance companies (industry)	Provide statistics relating to collisions involving wildlife, and sometimes detailed descriptions of the cause of the collision, the severity of injuries and the damage to vehicles. Furthermore, it is sometimes possible to access detailed vehicle diagnostic data, such as speed, systems activation and so forth.
Vehicle manufacturers (industry)	Possess vehicle data from collisions, such as data from wildlife collisions, thanks to in-vehicle systems and event recorders. Information such as speed, acceleration, steering and airbag activations seconds before and during the collision can be obtained.
National transport agency	Provides statistics relating to collisions with wildlife resulting in injuries.
National transport administration (authority)	Provides wildlife collision maps for identification of collision hotspots. Equips the transport system with infrastructural ITSs, where stationary sensors typically collect and provide traffic data such as speed, traffic flow and gaps between vehicles. Specific ITSs designed for wildlife detection are available for some locations which detect passing animals and interactions between vehicles and animals.
National Wildlife Accident Council (interest organisation)	Provides data on wildlife involved in collisions (based on reports to people responsible for searching for injured animals following collisions). Information is available about the type of animal, location, time, and so forth.

Authorities act as data providers, problem owners and solution providers, and play an important and key role when it comes to resolving issues related to the transport system. They bear responsibility for the infrastructure and the roadside environment, and also for how it aligns with the surrounding environment. That includes ensuring that biodiversity is not neglected during road construction and maintenance and when implementing preventive measures in respect of the transport system.

Table 6. Stakeholders responsible for or with knowledge of ***biodiversity and animal habitats*** *in Sweden.*

Stakeholder (Domain)	Description
Hunters' organisations (interest organisation)	Knowledge of wildlife behaviour and current conditions, problems and so forth for different species at specific locations. Responsible for providing trained individuals to take charge of searches for injured animals in the event of a WVC.
County administrative boards (*Länsstyrelser*)	Responsible for approving elk and red deer management plans. This also includes consideration/analysis of trends in reported wildlife collisions. Represented by landowners, hunters and county administrative board employees.
Swedish Transport Administration (authority)	Works actively to secure the transport system and ensure that it is safe for road users and animals and that impact on biodiversity is minimised when building new roads. Works to reduce WVCs and implement measures to reduce the number of collision hotspots in areas where many collisions occur, prioritising roads with high traffic flows and when road users are at high risk of being severely injured. The priorities are in accordance with budget restrictions set out by the government.
Swedish Environmental Protection Agency (authority)	Works to promote biodiversity and supports sustainable national environmental efforts. Specifies rules and regulations for hunters searching for animals injured in road traffic collisions.
National Wildlife Accident Council (interest organisation)	Assists in searches for injured animals to reduce suffering following a WVC. Organisations also included are the Swedish Police Authority, the Swedish Transport Administration, the Swedish Environmental Protection Agency and the hunting organisations *Svenska Jägareförbundet* and *Jägarnas Riksförbund*.

Interest organisations are another important stakeholder that are able to influence their members and the general public in different ways, such as by means of campaigns, publishing statistics, conducting their own research and assigning important work to members of the organisations. These organisations usually focus extensively on the safety of their members.

Table 7. Stakeholders responsible for ***road infrastructure or transport system activities*** *related to WVCs.*

Stakeholder (Domain)	Description
Police (authority)	Responsible for collisions involving wildlife. All WVCs should be reported on the emergency number, 112. Collaborate actively with trained hunters and can delegate some of the work to them. Able to close lanes/roads and redirect traffic as part of the management initiative following a collision.
Swedish Environmental Protection Agency (authority)	Responsible for regulations governing how searches for injured wildlife are to be carried out on Swedish roads, skills requirements, requirements for search dogs, the compensation levels received by search personnel for different types of traffic search, and handling of the state's wildlife.
Swedish Transport Administration (authority)	Responsible for infrastructure on national roads and ensuring that transportation goals are aligned with the rest of the environment and surroundings in Sweden. Is able to provide temporary signs and install roadside ITSs and is responsible for removing dead animals from the road during maintenance work and implementation of preventive measures (such as fences, aqueducts or overpasses) for wildlife, and so forth.

Universities and research institutes are important elements in the development of systems and solutions and for gaining new knowledge of WVCs. This includes identifying causes of collisions and understanding the important underlying factors, but also suggesting solutions and measures to resolve issues and evaluate how road user and animal behaviour is affected by different systems and solutions, and so forth.

Table 8. Stakeholders involved in ***research*** *related to wildlife and collisions.*

Stakeholder (Domain)	Description
Universities/research institutes (authority)	Conduct research within various fields related to wildlife and the transport system in order to acquire new knowledge and provide new methods and tools for implementation of measures to support the reduction of WVCs. Examples of research fields include development of statistical methods applied to data to increase knowledge and suggest preventive measures. Methods for processing data from images, video and sensors to improve wildlife detection, user behaviour studies to gain expertise on how to influence driver behaviour in the event of collision risks involving wildlife by means of warning systems, for example.
Expert organisations (industry, interest organisations, authorities)	Companies, authorities and organisations that provide expert knowledge to help other companies, authorities and private individuals to gain expertise on how measures can be implemented to prevent WVCs. Interest organisations may perform their own research or make use of existing expertise in order to enhance their own skills so as to implement new measures and influence their members in the right direction.

3.2. Findings from the dialogues

This section summarises the findings from the dialogues. No individual responses are presented, but important conclusions are sometimes based on responses by individual stakeholders.

3.2.1. Potential intelligent transport systems to prevent WVCs

A number of aspects and systems were highlighted in the dialogues with stakeholders. These are presented below.

In-vehicle systems

The dialogues with the various stakeholders reveal that a few systems are viewed as promising when it comes to reducing WVCs. In-vehicle systems can be divided into different categories depending on whether they are advanced driver assistance (ADAS) systems or passive safety systems. Automated Driving (AD) is another category which is not dealt with within the scope of this report. See Figure 4 for an overview of promising in-vehicle systems highlighted by the various stakeholders. Note that the systems include both existing systems that may (or may not) need further development and more futuristic systems that require new sources of information and/or development of the applications.

During normal driving, systems that provide information and instruct drivers to take appropriate actions could help to reduce the number of WVCs. However, both background and knowledge about high-risk areas, as well as dynamic information about recent WVCs at specific locations, are important in order to provide the right type of information. Statistical methods and applied mathematics can be used to combine data sources and align static/historical and dynamic information so that more accurate predictions can be made. Predictions and knowledge of recent collisions can then be used to inform drivers about upcoming risks and collisions that have taken place on their planned route. This can help to make them more aware and observant of their surroundings and, where possible, they can also plan to take a different, less risky route, or a route where there is no risk of them getting caught in a traffic jam due to dealing with a collision that has already happened. Furthermore, speed recommendations and intensified warnings about exceeding speed limits can be given in high-risk areas. However, user behaviour, the design of the applications and systems and the choice of information to be communicated are highly important as a means of encouraging the appropriate and desired user behaviour. Furthermore, the information can be communicated directly to the in-vehicle system with no driver interaction. This can therefore alert the in-vehicle animal detection system to high-risk areas, ensuring greater accuracy and precision in the detection systems. This is also useful as a way of improving AI-based learning methods. It may even be possible to flag high risks of certain species, thereby refining the detection algorithms even more extensively.

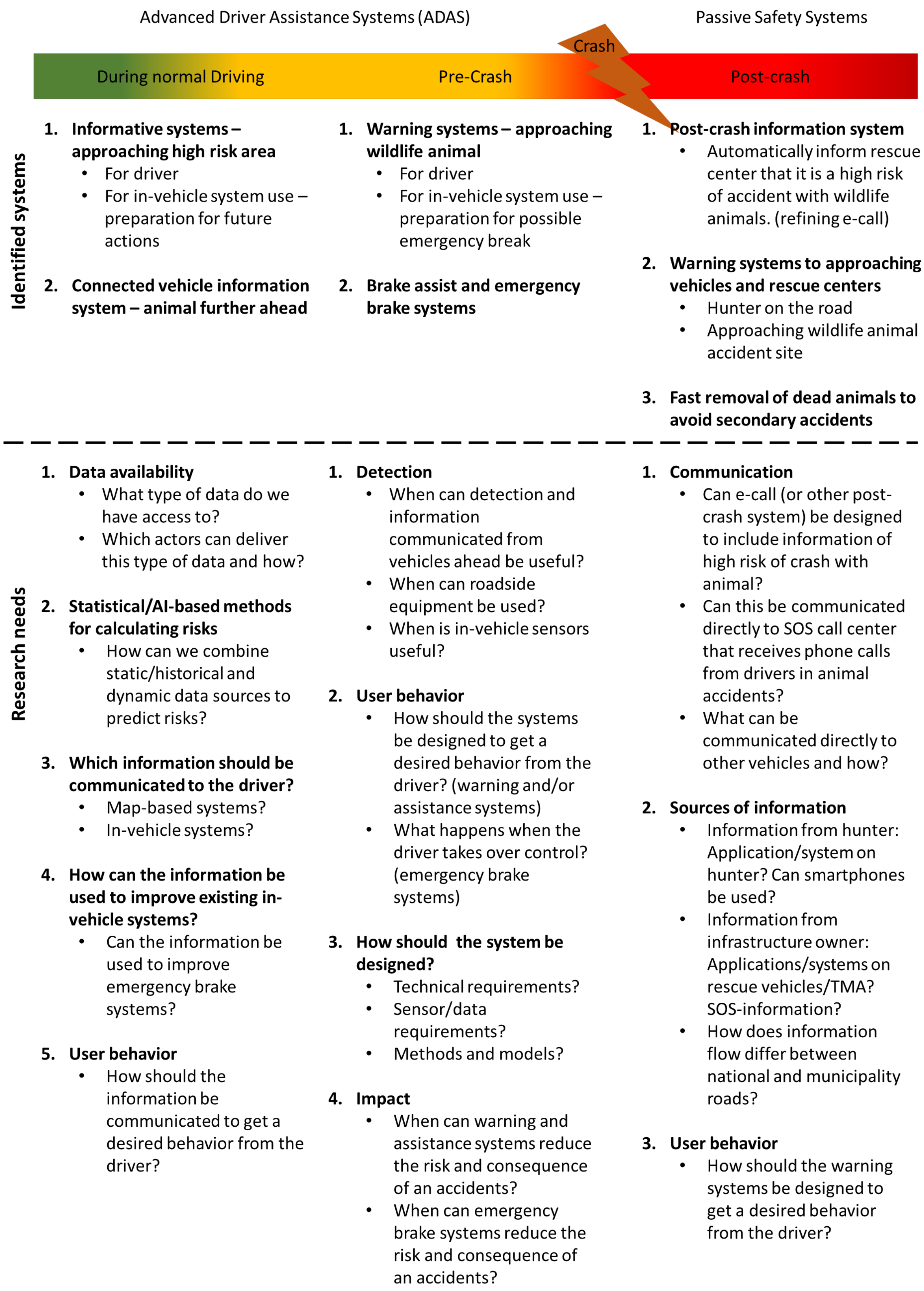


Figure 4. In-vehicle systems identified and related research needs.

Warning systems and collision avoidance and mitigation are of great importance under **pre-collision conditions**, when the collision probability is higher than during normal driving. As vehicle speed is an important influencing factor in respect of the severity of a collision, reducing speed (by means of the driver or a system) is desirable even if the collision cannot be avoided. In-vehicle systems can either warn the driver or take control of the vehicle with no interaction from the driver. If the systems communicate with or assist the driver by means of on-board road user interfaces, namely how the information is communicated and displayed to the user, driver behaviour is again of high importance. Furthermore, the detection equipment, algorithms and external data providers are of importance in terms of the accuracy and correctness of the systems. Large volumes of high-quality training data are required to develop good in-vehicle systems, and in particular good detection algorithms. This is currently an issue that needs to be addressed further. Detection equipment commonly includes video-based sensors or IR sensors that detect heat from bodies on the road. A combination of IR and video-based systems could be an option worth investigating further. Other detection equipment includes LiDAR and radar, detecting objects by means of light or radio waves.

When a collision has occurred, **post-collision**, the vehicle calls the SOS emergency services. In future, vehicles may have the option of providing objective information about the collision in terms of data. If such information is able to include detailed collision data, rescue crews can then act on the basis of a wildlife collision procedure. Furthermore, information about ongoing initiatives at the collision site and information about people on the road could potentially – in future applications –be communicated to approaching drivers, or to traffic information centres so that it can be communicated to road users. It is important to consider the road safety risks for people involved in searching for injured animals and rescue crews at the site, and to include the risk of secondary collisions due to dead animals lying on the road and traffic queues forming at a collision site. In this case, the information sources, the opportunities to communicate, the way in which information is displayed to users and, of course, how users act on the warnings and information provided are all important aspects. Personal GPS trackers that provide information about the position of hunters or other rescue crews on the road are one type of application that may be useful: see, for example, the '*smart vest*' currently being tested by NCC and Swanholm Technology at roadworks (Byggvärlden, 2023). This information can then be used to warn drivers about people on the road. Similar applications may be useful for all types of work on roads, such as construction workers on roads, people involved in moving vehicles following a collision, and so forth. Furthermore, secondary collisions may occur if dead animals are left on the road and not removed. In this case, vehicles equipped with sensors can help to improve the flow and timing of information to contractors or landowners responsible for removing dead animals. Dead animals can be removed quickly if information about dead animals on the road is reported as soon as they are detected.

Note that the Swedish Transport Administration (Trafikverket, 2021) has recently made a statement indicating that the authority should focus on infrastructural solutions, and that intelligence should mainly be part of vehicles when it comes to connected and automated vehicles. This means that the Swedish Transport Administration should not provide roadside units communicating directly with the vehicles. Hence, systems that build upon detection and communication from roadside units to vehicles are viewed as less likely to be implementable.

Infrastructural ITS solutions

According to dialogues with stakeholders working with WVCs, some infrastructural ITS solutions have already been implemented on the roads. ITSs are used to warn approaching drivers of animals crossing at specific locations in Sweden. Messages are displayed on variable message signs (VMSs) before a crossing point when an animal is detected. The detector may use a break-the-beam system, for example. Trials are ongoing to evaluate the effects of such systems, but preliminary results indicate that the number of collisions has declined since the introduction of ITSs. In Norway, an ITS solution has been installed on roads that alerts drivers to elk and deer by means of flashing lights. These lights are installed on stationary retroreflective warning signs indicating the presence of elk or deer. In the current version, the lights are actuated when vehicles pass. The ITS is installed on roads where there is a high risk of collisions involving wildlife. It is activated only at times when there is a high risk of collisions. The risk is calculated on the basis of historical data relating to collisions, weather, time of day and so forth. Studies show that these systems were effective when they were first installed, with slower speed and fewer collisions being recorded, but the positive effects decreased over time. Nowadays, warnings can also be communicated to drivers via their smartphones.

As speed is a crucial factor in the severity of collisions, variable speed limits (VSLs) that are adjusted depending on the risk of a WVC can be considered as an enabler for resolving issues with collisions involving wildlife. In this case, VSLs should only be deployed on high-risk roads with high speed limits, and at times when the risk is increased. It is important to consider compliance with speed limits, which is why speed cameras may be beneficial in connection with VSLs. The display period should also be considered: for instance, it may be a good idea to deploy VSLs at dawn and dusk when animals are more active, or during months when the risk of animals being active in specific locations is higher. Data and statistics can be used to identify these high-risk areas and periods.

In Sweden, there is a great deal of emphasis on infrastructural ITSs that do not communicate information directly to vehicles. However, infrastructural ITSs can be used to display information on VMSs to passing drivers. The Swedish Transport Administration is also open to the notion of ITSs that require digital infrastructure, such as network provision for communication of information to cloud services, vehicles and roadside equipment, but in this case the Swedish Transport Administration is of the opinion that solutions should be provided by commercial stakeholders (Trafikverket, 2021). The Swedish Transport Administration should facilitate the physical infrastructure in a manner supporting the implementation of new technical solutions that may be beneficial for the transport system and that, in this case, shows positive effects on the number of WVCs. ITS solutions already implemented, such as speed cameras, could be considered for new purposes in order to find out whether multiple uses of such solutions are possible on some road types.

As regards infrastructural ITS solutions, it is also important to consider user behaviour and how information should be communicated in order to achieve high levels of compliance with the system when the information is displayed on VMSs and when it is communicated to in-vehicle systems or handheld units. In this case, it is important to consider how frequently the information should be displayed and the format or design of information displayed on roadside units, in-vehicle systems or handheld units and so forth.

Another option could be to use dynamic closure of wildlife passages when they are on the same level as the road. Wildlife can be directed towards specific passages where they can access and cross the road. Passages could be closed by means of electronic gateways during high-risk periods. However, this should only be considered if it can be achieved without compromising too extensively in terms of biodiversity and habitats. Additionally, information on when gateways are closed could also be communicated to vehicles and risk levels could be updated on the basis of the probability of collisions at closed gateways. The risk level communicated must be based on empirical evidence of the mitigation of collision risk at closed gateways.

3.2.2. Data availability for prevention of wildlife collisions

Data on wildlife interactions on and adjacent to roads can be used to calculate the risk of collisions involving wildlife and to identify the underlying factors that have the greatest influence on these risks. Ultimately, this information can be used to identify the correct measures and provide the best solutions for reducing the number of WVCs, taking into consideration both infrastructural and in-vehicle solutions. Vehicle data, traffic data and collision data can be used, but wildlife data is another way of gaining knowledge of animal behaviour and identifying events involving interaction between animals and vehicles in order to learn more about these situations. A number of stakeholders are important providers of statistics and data, with various items of information that can help to provide a more detailed and precise view of collisions. Figure 5 provides an overview of data sources and the types of data that are available in Sweden; an example of typical data that may be useful, and why data providers and types of data are not limited to those shown. The data are divided into three levels:

global, vehicle surroundings and vehicle data. The data may contribute to different purposes and solutions depending on the level and type.

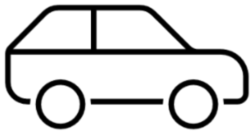
		Data sources	Type of data
Global	 Source: https://bransch.trafikverket.se/contentassets/3ac794bfc13f4f50ae244c5cb17c17ea/ostergotland_viltolyckor.pdf	Data-bases – road authorities Data-bases – private actors/insurance companies Data-bases – police	Accident data – personal injuries Accident data – Location Accident data – Type of animal Accident data – Date and time Machine-readable data of traffic rules Machine-readable data of current status of national infrastructure, including locations and roads
Surroundings	 Source: Ellen Grumert	Detection systems in the infrastructure Digital warnings and mandatory information on VMS Communication between vehicles and infrastructure	Interactions vehicles-animals (detector) Behavior of animals at passages (detector) Traffic conditions Road conditions
Vehicle		Advanced driver assistance systems – detection-based Advanced driver assistance systems – external data	Detection of animals Speed at interaction vehicle-animal Acceleration/deceleration vehicle-animal Vehicle status at accidents

Figure 5. Data sources and type of data available. Note that the amount of vehicle data available is often restricted by customer/end-user approval, and the purpose of data sharing must be clearly indicated to customers/end-users. Some data linked with certification can be made available more easily.

3.2.3. Factors impacting on vehicles and drivers

A number of important factors impact the risk of WVCs and the usefulness of different systems, and the environment surrounding the roads has been identified in the dialogues. These aspects are summarised in this section.

Appropriate speed limits

If we are to believe that we should coexist with other species in the ecosystem on the roads and the surrounding area, we need to minimise the risk of collisions involving wildlife and the consequences of the same. Time of day, time of year, road type, weather conditions, surroundings and so forth are all factors that greatly influence the risk of collision. However, speed is one of the primary factors referred to as crucial by several stakeholders as regards the risk of collision injuring animals and people and how severe such injuries are when a collision cannot be avoided. Hence, systems that prevent drivers from speeding, make drivers more alert to high wildlife risks and provide drivers with proper speed limit warnings and recommendations are viewed as promising tools that could be used to reduce collisions involving wildlife. These systems can be both vehicle-based and infrastructural. Furthermore, dynamic adaptation of speed limits on roads has the potential to reduce the risk and severity of collisions involving wildlife. The decision on whether to incorporate dynamic speed limit adaptations in infrastructure is based on consideration of whether a stretch of road poses a high risk of animals crossing, or if specific sections detect animals crossing. Drivers can adapt their speed accordingly in such cases. Intelligent speed adaption (ISA) and geofencing systems that act by limiting vehicle speeds in certain areas are examples of in-vehicle systems used to reduce speed. Also, in Norway, speed reductions have been identified as one of the most promising solutions when it comes to reducing the number of WVCs.

A recent study by Rizzi et al. (2023) shows that an appropriate speed limit on unfenced roads would be 60 km/h: this would also prevent severe injuries as a result of WVCs and take large animals into consideration. According to the authors, this is because AEB is expected to reduce speeds by 20 km/h at most, since many collisions involving large animals occur in difficult lightning conditions and when there is little time to react before a collision. Furthermore, Rizzi et al. (2023) state that the speed limit can be increased to 80 km/h if the roadside area is free from obstructions. As regards increasing the chances of both survival and fewer injuries following a collision with a large animal, Ydenius et al. (2017) and Krafft et al. (2011) highlighted the need for both a sufficient reduction in vehicle speed and appropriate vehicle design, such as the need for a sufficiently large distance between the heads of car occupants and the internal structures inside the vehicle.

Road user behaviour

Road users have to understand and accept the communicated warnings, recommendations and mandatory traffic rules in a traffic system if the desired and anticipated effects are to be achieved. Therefore, systems both in vehicles and outside vehicles must be self-explanatory and easy for road users/drivers to understand. As regards wildlife systems, this means **understanding** that there is an increased risk of a collision involving wildlife, **accepting** that the measure/system provides appropriate and correct advice/recommendations/actions to prevent collisions involving the specific road user in question and not just road users in general, and **behaving** according to the advice/recommendations/actions in order to achieve desirable effects.

Transport system barriers

Roads divide animals' natural habitats into areas where they are safe and areas where they are at greater risk of being injured or killed. Roads can be viewed as barriers for wildlife at certain high traffic flow levels, and they will not cross. However, there may be an increased risk of collisions when the traffic flow is decreased because of a moderate traffic flow, when animals think the road is safe to cross. There may be less of a risk of collision at low traffic flows, again due to low traffic volumes on the road, but there may also be an elevated risk due to the high number of animals moving in close proximity to the road. It is important to consider these aspects when designing warning systems. For instance, there may be no reason to lower the speed limit at high traffic flows, but there may be a good reason to lower the speed limit at lower traffic flows and at specific points in time, since the lowering of speed limits has to be weighted in terms of traffic system efficiency and the potential increase in journey times. Only lowering speed limits at moderate to lower traffic flows may be justified as a measure to increase traffic safety at high-risk periods while also limiting impact on traffic efficiency.

Roadside areas, biodiversity and animal behaviour

Areas close to roads are important from the perspectives of both animals and drivers and other road users. Maintenance of roadside areas is important in order to reduce vegetation and improve detection system visibility at these locations. However, frequent maintenance may cause vegetation to grow more quickly and become more nutritious and tastier to animals, thereby attracting wildlife to roadside areas. Furthermore, landowners and farmers placing wildlife feeding stations close to roads may also attract animals. However, restricting efficient land use by both farmers and landowners is problematic as loss of income may have an enormous impact on the farmer's or landowner's situation.

Animals of all sizes move on roads. Large animals pose a danger to human road users as they could potentially lead to injuries and deaths. However, it is also important to bear in mind that positive impact on biodiversity is desirable. Hence, it may be beneficial to have roadside meadows, for example, which in turn could have an adverse on detector system visibility.

Wildlife does, to varying extents, adapt and habituate to common situations that alter their environment. The possibility to adapt is species-dependent. This is important to bear in mind if systems aiming to influence animals are introduced. Furthermore, wildlife move depending on season and the surrounding environment. In agriculture, a change in the environment may be observable from one day to another and attract or repel animals, moving them to or away from specific locations, whereas forestry involves slow changes and gradual adaptations of wildlife behaviour. Climate change has also been addressed as an important factor by stakeholders, as it may impact animal movement and behaviour, as well as the use of salt on the roads. This is why the possibility of moving and adapting ITSs to suit the surrounding environment and animal movements are of great importance if the systems are to be implemented successfully.

Fauna screens designed to reduce visual disturbance and noise from traffic on roads that are installed at crossing points are a new type of physical measure that has been proven to be useful in reducing the impact of barriers. Such measures could potentially be used to reduce "noise" perceived by wildlife from ITSs in infrastructure (Elfström, 2023).

Local vs. national representation of the problem

The dialogues have revealed that some problems can be viewed as very local, whereas many of the studies and analyses performed consider statistics and solutions that are homogeneous for the road network as a whole. Different measures could potentially be useful for different parts of Sweden, and on different roads. This includes not only ITS measures, but also physical measures such as fences with at-grade fauna passages, retroreflective warning signs, speed limit adjustments, and so forth. Furthermore, it is also important to prioritise road safety and reduction of suffering for animals in sparsely populated areas where collision numbers are high in relation to the population.

3.2.4. Nordic outlook

Problems with WVCs are global, and many countries are greatly in need of solutions to resolve a growing issue with WVCs. However, as shown in the literature, the issues and types of solutions suggested and implemented are based on the existing species, the design of road infrastructure and the topology in the country under consideration. The Norwegian Public Roads Administration and the Danish Road Directorate were specifically addressed in this study by means of a written questionnaire (as for other stakeholders – see Appendix A) sent by email. The main conclusions from the written answers to these questions are summarised below.

Norway

Norway is seeing a significant increase in the number of WVCs, mostly involving roe deer. Accidents involving elk remain relatively stable. This increase is due mainly to the increase in the deer population. Even so, there is a decrease in the number of personal injuries. Fences are by far the most commonly used wildlife safety measure in Norway, particularly when building new roads in areas where there is plenty of wildlife. Fences in combination with passages and maintenance of roadside areas have proven to be useful in Norway. However, implementation of such measures is sometimes difficult due to limited space, buildings and agriculture along the road. New and other measures are also requested in Norway in order to reduce the number of WVCs still further. This indicates that cooperations involving the Nordic countries would be beneficial.

ITSs were tested, such as detection of wildlife and “yellow flash” warnings to indicate to drivers that there is a risk of wildlife nearby (Solberg et al., 2021). The “yellow flash” has shown no significant impact on WVCs. Warnings issued by means of text messages were trialled, but these had limited impact and there were found to be no significant reductions in speed (Wildenschild, 2022). In 2024–2025, VMSs with speed limit reductions are to be tested when there is a high risk for elk and different types of deer. Furthermore, a major research proposal totalling NOK 10 million has been submitted to SINTEF for trials involving wildlife detection and warnings. ITSs for scaring animals have not been proven to have any effect in Norway.

ITS measures with the aim of reducing the number of WVCs in Norway involve a number of challenges. Power supply is one, as many locations where wildlife are highly likely to occur have no power supply nearby, thereby resulting in enormous installation costs. Moreover, roadside-based ITSs often require installation of both detection equipment and signs/visual equipment over wide areas, which often attracts huge installation and maintenance costs.

Denmark

Denmark has a different topology to Sweden and Norway, with fewer forests, which probably has a favourable impact on the number of WVCs. No numbers were provided via the questionnaire, and further investigations should be performed in order to draw conclusions on the extent of WVCs in Denmark. Furthermore, Denmark has no wild boar population. In addition, responsibility for roads in Denmark is divided differently compared to Sweden and Norway. National roads are only a small proportion of all roads in Denmark, which means that municipalities often bear responsibility for roads. Fences and fauna passages, as well as effective planning when designing new roads, have proven to be effective in Denmark. The Danish Road Directorate works mostly with stationary signs to provide warnings about wildlife, and no ITS measures are referred to as a measure for reducing WVCs.

4. Conclusions

It can be concluded from the literature study that systems that aim to alter animal behaviour in order to prevent WVCs have not been successful historically. Moreover, the habituation of animals reduces the impact of such systems over time.

In-vehicle systems, specifically Autonomous Emergency Braking (AEB), were proven to be beneficial under certain road conditions. Studies have shown that it takes 1.5 seconds on average from the time an animal enters the road to when a collision occurs. It takes the average driver about 1.3 seconds to react, thereby leaving just 0.2 second to brake or steer, whereas AEB can be activated at just 1 second. Hence, many collisions can be avoided if AEB is deployed. One study from the literature found that AEB systems were most effective in situations where the driver strikes an animal in a frontal collision, in good weather and bright conditions, and least effective on bends and in turns. This indicates that AEB can be useful in some situations, but that other solutions should be considered as well. One factor that influences the usefulness of AEB systems is how well they can operate at dawn or dusk, when the sun is low, and in other dark conditions such as at night. This shows that development of detection systems that can operate in low light or dark conditions would be useful for preventing WVCs by means of AEB.

Other in-vehicle systems emphasised as promising in the literature are map-based warnings indicating to drivers where there is a high risk of collisions, and where collisions and roadkill are currently located. This can help drivers to make informed decisions on choice of route, speed and so forth. Furthermore, more urgent warnings are suggested when the risk of collision with animals is high: warnings could be gradual depending on the risk level, for instance.

Infrastructural ITSs have proven to be useful under some road conditions and on some stretches of road. One study from the literature review showed that warning signs were found to be effective only for reducing vehicle speeds in challenging road conditions, such as at cold temperatures and when roads were covered in snow and ice, as well as during periods of decreased visibility at night. This shows that the interpretability of system warnings is important. If drivers understand why warnings are being given, it is easier for them to make appropriate adaptations based on those warnings. Furthermore, speed reductions and braking responses are highlighted in the literature as a means to prevent WVCs and mitigate the consequences. One study showed that reduced speed limits were not observed at times with high traffic volumes, but that they were observed with lower traffic volumes. This shows that drivers tend to follow the speed of the traffic flow rather than the speed indicated on the signs at high traffic flow. Note that roads often present barriers for wildlife at high traffic flows, so there may be less need for speed reductions at these points in time. One study found that collisions initially increased as traffic density increased but decreased again for the highest traffic densities, thereby indicating that the road becomes a barrier at high densities. Remarkably, it is at times with high traffic flows/densities that traffic efficiency is highly affected by reduced speeds, as many vehicles increase their journey times. Hence, it may be necessary to investigate whether speed limits can be kept high at these times, particularly if such periods coincide with a low risk of WVCs.

The false detection rate is an important factor to consider for both in-vehicle-based systems and infrastructural ITSs. This has been addressed in many studies in the literature. The false alarm rate is highly relevant if the system is to be trustworthy and increase the usefulness of warnings for end-users, and this should be carefully evaluated for the system in use. Furthermore, messages, warnings and information to drivers should be designed in such a manner high levels of compliance (or acceptance) with the system can be guaranteed. Drivers should find it intuitive to act on warnings, messages and information communicated so as to encourage the desired behaviour.

In conclusion, the requirements in respect of system coverage are highly dependent on the purpose of the system. This is why it is necessary to investigate when, and whether, different systems would be useful so that appropriate solutions can be deployed in different parts of the road network. Both in-vehicle systems and infrastructural ITSs are to be considered in efforts to reduce the number of WVCs.

5. Future research needs

Five areas in need of further development were identified in this study. These are listed below.

5.1. Improved detection – training data for in-vehicle systems

Correct detection of animals is crucial for system performance. In-vehicle detection systems need to identify animals correctly and quickly, as the time between an animal entering the road and a collision occurring is often a matter of seconds. Furthermore, animals often move rapidly and the behaviour of animals when they have entered the road differs both between species and compared to pedestrians and cyclists for which comparable detection systems have been developed. The problem with animal data is that such data are not easy to collect. Driving along roads with the sole purpose of collecting such data presents a risk of collisions in itself and requires many hours of driving to obtain relevant detections of wildlife and interaction between animals and the vehicle. Apart from vehicle sensors, other sensors for other purposes may be used; such as infrastructural sensors or video recordings, and so forth. However, sensor data must be of sufficient quality to be used as training data. Table 9 provides a summary of sensor data that we would like to investigate further in order to conclude whether it can be used as training data for in-vehicle systems, and if so, to what extent.

Maintenance to reduce vegetation along roadsides is viewed as a solution to increase the visibility of wildlife for drivers, but also as a way of making these areas less attractive to animals. Another important factor that was addressed in the dialogues was the potential positive effect of such maintenance as regards increasing detection system visibility. One interesting research direction would therefore be to investigate the relationship between the width of the roadside area and vehicles' sensor visibility, and hence the chances of detecting wildlife at roadsides.

Finally, different types of vehicle-based sensors have different pros and cons. A review of pros and cons for existing sensors is needed, alongside an investigation of the benefits and disadvantages of new sensors. For instance, it would be desirable to investigate whether new systems such as LiDAR that are becoming more common can reduce wildlife detection times. In the future, when systems include AD functionalities to a grater extent, use of sensors will become more important for detection of wildlife as well. Sensor requirements for future needs should also be included in any such investigation. Furthermore, methods for detecting objects and sensors for other AD functionalities may be useful for wildlife detection as well, which is why identification of synergies with other systems/sensors may be beneficial.

Table 9. Description of different data sources with the potential to be used as training data for in-vehicle detection systems.

Sensor/system	Type of data	Status	Data provider
Video recordings from trains (collected as part of the research project *Wildlife-safe railways*, Seiler et al. (2022b))	Videos of animals along the railway.	Historical	- Swedish Transport Administration - SJ
Detection and video recordings of animals at crossings on roads	Video recordings that include animals when they cross a road, interactions between animals and vehicles and animal behaviour before they cross the road.	Historical	- EnviroPlanning - Swedish Transport Administration - Norwegian Public Roads Administration
In-vehicle black box data immediately before a collision, during the collision and immediately after the collision	Images from the vehicle may exist when AEB is activated. This data can be used internally by manufacturers to enhance their systems. However, such data are only available to the manufacturer if the end-user consents.	Historical	- Volvo Cars - Volvo Trucks? - Other car manufacturer?
IT platform for recognition of wildlife – Capture, Seiler et al. (2022b)	Combines manual metadata management with automatic image analysis through artificial intelligence (AI) / machine learning (ML) and automated depersonalisation of images that may potentially infringe privacy.	Historical, and in ongoing projects	Developed through collaboration between the Swedish University of Agricultural Sciences, Sweco, Nina and a reference group made up of the Swedish Environmental Protection Agency, county administrative boards, the Species Database and hunters' associations.
Video recordings from landowners (from a project conducted by Svenska Jägareförbundet and the Swedish University of Agricultural Sciences)	Video recordings at various forest locations to obtain an inventory of wild animal species in Sweden (machine learning from video). Behavioural data of animals in their natural habitat – does it differ much from near-road behaviour?	Ongoing project	- Swedish University of Agricultural Sciences - Svenska Jägareförbundet
Dashboard cameras from companies with vehicles that frequently drive in areas where wildlife is abundant	Video recordings of animals in their natural habitat. Behavioural data.	Data collection within the project, or historical data	- Univrses Home care companies - Hunters - Securitas
GPS trackers on elk and deer in Norway	Tracking of animal movements.		-

5.2. Effectiveness of different systems – based on knowledge and historical data

Some systems are only able to contribute to positive impact on WVCs when a collision is imminent, and so it is important to investigate the instances in which the effects of such systems can be reduced; particularly when it comes to automatic emergency brake systems, where detection and mitigation have to take place in just a few seconds. Others aim to provide information and warnings well in advance to give drivers the opportunity to make more informed decisions on their routes and make them more aware of and attentive to the road and the surrounding area, as well as reducing vehicle speeds. Ydenius (2017) showed that many collisions caused primarily by elk result in secondary collisions with other objects at the roadside. This indicates the importance of reducing vehicle speeds after the primary collision with the elk as well in order to minimise the impact of a secondary collision. Hence, these secondary collisions should also be considered and investigated in order to understand the extent to which such collisions occur and whether other mitigating measures can be applied. Research is suggested into when different systems are useful and capable of contributing to WVC mitigation and prevention. Road type, weather conditions, time of year, time of day and so forth must also be taken into consideration. Prior knowledge about collisions from the road authorities and insurance companies, but also detailed vehicle data and data from stationary roadside sensors can add to this knowledge.

This also includes mapping WVCs in respect of existing ITS solutions in order to conclude the effects of installation of such systems on the number of WVCs. This may also include ITS solutions that do not aim to reduce WVCs, such as speed limit changes, speed cameras and so forth. The aim of this is to conclude whether such systems could be used for multiple purposes. For instance, fewer WVCs on roads classified as high-risk following installation of speed cameras could potentially be a dual effect, in addition to reductions in average speeds. In such instances, it may be strategic to consider locations where collisions occur more frequently when installing new speed cameras. Note that the Swedish Transport Administration focuses mainly on solutions on national roads, which is why it may also be important to investigate how municipalities deal with the same issues.

Cooperation between countries – particularly the Nordic countries, which have similar climates – is viewed as an important measure so that they can learn from one another on the basis of historical data and experiences of different measures implemented.

5.3. Collision prediction – high-risk areas

Historical data from collisions, vehicles, roadside sensors, weather and so forth can be used to create prediction models and calculate collision risks. These models should be dynamic in time: in other words, high risks may be observable at specific times, and low risks at other times. These models can be static, and hence include only historical data, or dynamic to allow for updates from data that can indicate a change in the risk over time. This may be important if changes in risk occur on account of changes in animal behaviour due to climate change, for example. More recent data is more reliable in this case. Furthermore, the models can be made even more dynamic by also considering collisions and risks that vary depending on the time of day. The requirement with regard to how dynamic the prediction model should be is dependent on the final application and the requirements for the system.

Two specific applications should be considered: warnings/information to drivers via map data, and risk maps to improve in-vehicle detection systems by providing more information about the likelihood of collision with animals.

Note that the number of WVCs resulting in injuries is recorded in the Swedish Traffic Accident Data Acquisition database (STRADA), but in some cases the actual cause of the collision is recorded as a single-vehicle collision instead of a WVC. This is what happens when, for example, a driver leaves the road because of an animal and strikes an obstacle at the side of the road or another vehicle approaching from the opposite direction. Similar problems are also experienced in Norway, where non-severe collisions in particular are reported as single-vehicle collisions instead of collisions with animals. On the contrary: insurance companies may find that collisions recorded as WVCs are overrepresented due to a reduction in the excess for WVC-type collisions for a small additional charge added to the cost of policies. Additionally, it may be more beneficial from an ethical standpoint to indicate collision with an animal as the cause of accidents, rather than inattention, looking at a mobile phone and so forth in the case of accidents where the driver is responsible. Furthermore, the healthcare service may provide yet another data source giving information about the long-term effects of WVCs in respect of non-serious injuries such as whiplash and fractures. Hence, multiple data sources may provide a better understanding of the actual statistics.

5.4. User behaviour

User behaviour and the human-machine interface (HMI) are of major importance in respect of system compliance. Research is needed on the design of the HMI, as well as the warnings and information that should be communicated and when. This is applicable for many ADAS systems, but for animal detection and warnings it is important to make drivers aware of the correctness of such detection and warnings as drivers may not always see animals. Hence, drivers may be more responsive to warnings when they are introduced initially and become less responsive over time if there is no confirmation of animals in the vicinity of their vehicles. Driver simulator studies can be used before such systems are implemented in real-life environments in order to investigate how drivers are affected by different HMI designs, warnings, information and so forth, and how to guarantee high levels of compliance with the system.

The emphasis is on warnings/information to drivers via map data, warnings of wildlife ahead and infrastructural ITSs (warnings of wildlife with speed limit reduction, with and without speed cameras). It should also be studied whether early warnings for the risk of animals ahead should be communicated, and if so how, in order to achieve the desired effect.

Financial incentives could be used to alter driver behaviour. For instance, insurance companies charging a lot of money for damage to vehicles on account of WVCs could potentially lead to more careful driving. Other incentives could be provided by reducing the cost of additional lights in high-risk areas: this has actually been implemented by one insurance company in some parts of Sweden. This should be explored further.

5.5. Post-collision mitigation systems

Post-collision mitigation systems are another important type of system that can improve traffic conditions and limit the impact of WVCs when they have happened. Research into post-collision mitigation systems is therefore deemed to be important in work on WVCs to include the whole range of systems. For example, ITS systems that are capable of communicating the positions of hunters and other rescue personnel may be useful for sending warnings to drivers about people in the road, thereby also enhancing hunter safety. Moreover, detection of dead animals and communication of their locations using sensors and communication equipment in vehicles can be used to remove dead animals quickly. However, the extent of the problem relating to secondary collisions on account of dead animals is not known at present, which is why research is needed to examine the number of collisions caused by dead animals. Moreover, the extent and type of incidents involving hunters who are searching for injured animals along the road is unknown, and future research into this area is also deemed to be necessary in order to provide a better understanding of safety issues related to hunters searching for injured animals following collisions. This is clearly linked with all types of work done on roads involving people who are unprotected or outside vehicles, such as construction workers on roads, rescue crews, people removing stationary vehicles following collisions and incidents, and so forth.

References

Asari, Y., Yamaguchi, R. & Hayakawa, Y. (2020). Decreasing road kill of Pentalagus furnessi with a wildlife detection system that warns drivers to reduce vehicle speed. *Journal of JSCE*, *8*(1), p. 1-4. Available at: https://doi.org/10.2208/journalofjsce.8.1_1.

Babińska-Werka, J., Krauze-Gryz, D., Wasilewski, M., & Jasińska, K. (2015). Effectiveness of an acoustic wildlife warning device using natural calls to reduce the risk of train collisions with animals. *Transportation Research Part D: Transport and Environment*, *38*, p. 6-14. Available at: https://doi.org/10.1016/j.trd.2015.04.021.

Benten, A., Hothorn, T., Vor, T., & Ammer, C. (2018). Wildlife warning reflectors do not mitigate wildlife-vehicle collisions on roads. *Accident Analysis & Prevention*, *120*, p. 64-73. Available at: https://doi.org/10.1016/j.aap.2018.08.003.

Benten, A., Balkenhol, N., Vor, T., & Ammer, C. (2019). Wildlife warning reflectors do not alter the behavior of ungulates to reduce the risk of wildlife-vehicle collisions. *European Journal of Wildlife Research*, *65 (76)*, p. 1-12. Available at: https://doi.org/10.1007/s10344-019-1312-4.

Bhardwaj, M., Erixon, F., Holmberg, I., Seiler, A., Håkansson, E., et al. (2022). Ungulate use of an at-grade fauna passage and roadside animal detection system: A pilot study from Southern Sweden. *Frontiers in Environmental Science*, *10*, 991551. Available at: https://www.frontiersin.org/articles/10.3389/fenvs.2022.991551 (Accessed: 9 November 2023).

Brieger, F., Hagen, R., Vetter, D., Dormann, C. F., & Storch, I. (2016). Effectiveness of light-reflecting devices: A systematic reanalysis of animal-vehicle collision data. *Accident Analysis & Prevention*, *97*, p. 242-260.. Available at: https://doi.org/10.1016/j.aap.2016.08.030.

Byggvärlden (2023). *Uppkopplad väst larmar vid fall.* Available at: https://www.byggvarlden.se/uppkopplad-vast-larmar-vid-fall/

Coulson, G., & Bender, H. (2019). Roadkill mitigation is paved with good intentions: a critique of Fox et al.(2019). *Australian Mammalogy*, *42*(1), p. 122-130. Available at: https://doi.org/10.1071/AM19009.

D'Angelo, G., & van der Ree, R. (2015). Use of reflectors and auditory deterrents to prevent wildlife–vehicle collisions. *Handbook of road ecology*, p. 213-218. Available at: https://doi.org/10.1002/9781118568170.ch25.

Decker, J. A., Haus, S. H., Sherony, R., & Gabler, H. C. (2021). Potential benefits of animal-detecting automatic emergency braking systems based on US driving data. *Transportation research record*, *2675*(10), p. 678-688. Available at: https://doi.org/10.1177/03611981211012416.

Donaldson, B. M., & Kweon, Y. J. (2019). Effectiveness of seasonal deer advisories on changeable message signs as a deer crash mitigation tool. *Transportation research record*, *2673*(12), p. 548-557. Available at: https://doi.org/10.1177/0361198118823204.

Druta, C., & Alden, A. S. (2015). *Evaluation of a buried cable roadside animal detection system* (No. FHWA/VCTIR 15-R25). Virginia Center for Transportation Innovation and Research. Available at: https://vtechworks.lib.vt.edu/handle/10919/94364 (Accessed: 27 June 2023).

Druta, C., & Alden, A. S. (2019). Implementation and Evaluation of a Buried Cable Animal Detection System and Deer Warning sign. Available at: https://vtechworks.lib.vt.edu/handle/10919/94377 (Accessed: 27 June 2023).

Druta, C., & Alden, A. S. (2020). Preventing animal-vehicle crashes using a smart detection technology and warning system. *Transportation research record*, *2674*(10), p. 680-689. Available at: https://doi.org/10.1177/0361198120936651.

Elfström, M. (2023). Miljöuppföljning – effekter av faunaskärm utmed väg 11 ovan faunaport Vomb. Available at: https://www.diva-portal.org/smash/get/diva2:1758999/FULLTEXT01.pdf

Englefield, B., Candy, S. G., Starling, M., & McGreevy, P. D. (2019). A trial of a solar-powered, cooperative sensor/actuator, opto-acoustical, virtual road-fence to mitigate roadkill in Tasmania, Australia. *Animals*, *9*(10), p. 752. Available at: https://doi.org/10.3390/ani9100752.

Erbsmehl, C. T., Landgraf, T., & Yuasa, H. (2017). Animal street crossing behavior – an in-depth field study for the identification of animal street crossing behaviour using the AIMATS-methodology. In *25th International Technical Conference on the Enhanced Safety of Vehicles (ESV) National Highway Traffic Safety Administration*. Available at: https://www.semanticscholar.org/paper/Animal-street-crossing-behavior%3A-an-in-depth-field-Erbsmehl-Landgraf/eadc89d4f9c591f4a4a8df5ddb8a0ed46284bc63 (Accessed: 6 July 2023).

Fox, S., Potts, J. M., Pemberton, D., & Crosswell, D. (2018). Roadkill mitigation: trialing virtual fence devices on the west coast of Tasmania. *Australian Mammalogy*, *41*(2), p. 205-211. Available at: https://doi.org/10.1071/AM18012.

Gabrielsson, M., Östman, C., Lundin, U., & Sjölund, A. (2022). Redogörelse för utveckling av viltolyckor. Avaliable at: https://urn.kb.se/resolve?urn=urn:nbn:se:trafikverket:diva-5443

Gagnon, J. W., Dodd, N. L., Sprague, S. C., Ogren, K. S., Loberger, C. D., et al. (2019). Animal-activated highway crosswalk: long-term impact on elk-vehicle collisions, vehicle speeds, and motorist braking response. *Human Dimensions of Wildlife*, *24*(2), p. 132-147. Available at: https://doi.org/10.1080/10871209.2019.1551586.

Grace, M. K., Smith, D. J., & Noss, R. F. (2017). Reducing the threat of wildlife-vehicle collisions during peak tourism periods using a roadside animal detection system. *Accident Analysis & Prevention*, *109*, p. 55-61. Available at: https://doi.org/10.1016/j.aap.2017.10.003.

Høye, A. K. (2019). *Trafikksikkerhetseffekter av tiltak mot viltulykker/Title: Road safety effects of wildlife-vehicle collision mitigation measures.* TØI rapport 1715/2019. Report. The Norwegian Public Roads Administration; Ministry of Transport and Communications. Available at: https://www.toi.no/publications/road-safety-effects-of-wildlife-vehicle-collision-mitigation-measures-article35674-29.html (Accessed: 14 July 2023).

Huijser, M. P., Fairbank, E. R., & Abra, F. D. (2017). *The reliability and effectiveness of a radar-based animal detection system*. FHWA-ID-17-247 Center for Environmentally Sustainable Transportation in Cold Climates. Available at: https://rosap.ntl.bts.gov/view/dot/34943 (Accessed: 27 June 2023).

Huijser, M. P., Ament, R. J., Bell, M., Clevenger, A. P., Fairbank, E. R., et al. (2021). 701-18-803 TO 1 Part 1. Animal vehicle collision reduction and habitat connectivity pooled fund study–Literature review. Available at: https://trid.trb.org/view/2122527 (Accessed: 27 June 2023).

Jaldemark, K. (2020). *CeViSS - Cloud enhanced cooperative traffic safety using vehicle sensor data | Drive Sweden*. Project report, p. 21. Available at: https://www.drivesweden.net/en/project/ceviss-cloud-enhanced-cooperative-traffic-safety-using-vehicle-sensor-data (Accessed: 14 July 2023).

Kotituomi, S., Huju, M., Kulmala, R., Lahtela, A. (2019). *Impact evaluation of the Porokello alert service*. Research Report 9/2019. Finland: Finnish Transport and Communications Agency, p. 156. Available at: https://www.traficom.fi/sites/default/files/media/publication/Porokello_Traficom_tutkimuksia_9_2019_EN_FINAL.pdf (Accessed: 26 June 2023).

Krafft, M., Kullgren, A., Stigson, H., & Ydenius, A. (2011). Bilkollision med älg – utvärdering av verkliga olyckor och krockprov. *Umeå Universitet*, *29*. Available at: https://nyhetsrum.folksam.se/sv/files/2011/10/Folksam-algrapport-2011.pdf

Llagostera, P., Comas, C., & López, N. (2022). Modeling road traffic safety based on point patterns of wildlife-vehicle collisions. *Science of the total environment*, *846*, p. 157237. Available at: https://doi.org/10.1016/j.scitotenv.2022.157237.

Ma, A. (2022). SWWS: A Smart Wildlife Warning Sign System. In *Proceedings of the AAAI Conference on Artificial Intelligence* (Vol. 36, No. 11, pp. 13197-13199). Available at: https://doi.org/10.1609/aaai.v36i11.21726

Mayer, M., Nielsen, J. C., Elmeros, M., & Sunde, P. (2021). Understanding spatio-temporal patterns of deer-vehicle collisions to improve roadkill mitigation. *Journal of environmental management*, *295*, p. 113148. Available at: https://doi.org/10.1016/j.jenvman.2021.113148.

Mohammadi, A., Park, P. Y., Mukherjee, A., & Liu, X. (2022). Developing a situation and threat assessment framework for a next generation roadside animal detection system. *IET Intelligent Transport Systems*, *16*(1), p. 71-84. Available at: https://doi.org/10.1049/itr2.12129.

Morrison, M. L., Block, W. M., Strickland, M. D., Collier, B. A., & Peterson, M. J. (2008). *Wildlife study design*. Springer Science & Business Media. Available at: https://doi.org/10.1007/978-0-387-75528-1

Riginos, C., Graham, M. W., Davis, M. J., Johnson, A. B., May, A. B., et al. (2018). Wildlife warning reflectors and white canvas reduce deer-vehicle collisions and risky road-crossing behavior. *Wildlife Society Bulletin*, *42*(1), p. 119-130. Available at: https://doi.org/10.1002/wsb.862.

Rizzi, M., Boström, O., Fredriksson, R., Kullgren, A., Lubbe, N., et al. C. (2023). Proposed Speed Limits for the 2030 Motor Vehicle. In *27th International Technical Conference on the Enhanced Safety of Vehicles (ESV) National Highway Traffic Safety Administration* (No. 23-0166). Available at: https://www-nrd.nhtsa.dot.gov/departments/esv/27th/

Rowden, P., Steinhardt, D., & Sheehan, M. (2008). Road crashes involving animals in Australia. *Accident Analysis & Prevention*, *40*(6), p. 1865-1871. Available at: https://doi.org/10.1016/j.aap.2008.08.002.

Seiler, A., Willebrand, S., & Verschuur, L. (2014). Funktion och effekt av blå viltreflektorer – en litteraturstudie och fältexperiment. *Trafikverkets Rapport TRV*, *7617*. Report. Available at: https://res.slu.se/id/publ/103640

Seiler, A., Jäderkvist, P., Dalheimer, J., & Jansson, C. (2022a). Capture: IT-plattform för bildigenkänning och förvaltning. 2022:017. Report. Trafikverket. Available at: https://www.diva-portal.org/smash/get/diva2:1647741/FULLTEXT01.pdf

Seiler, A., Olsson, M., Bhardwaj, M., Håkansson, E., & Söderstöm, P. (2022b). Djur på spår – videoanalys av interaktioner mellan djur och tåg. 2022:036. Report. Trafikverket. Available at: http://trafikverket.diva-portal.org/smash/get/diva2:1660387/FULLTEXT01.pdf

Seiler, A. (2023). Viltolyckskostnader – uppdatering 2022, 2023-01-20. Ref.no. TRV 2019/96127.

Sielecki, L. (2017). Wildlife Detection Systems, Highway 3, British Columbia: Real-time warning systems for protecting wildlife and drivers. In *TAC 2017: Investing in Transportation: Building Canada's Economy--2017 Conference and Exhibition of the Transportation Association of Canada*. Available at: http://www.tac-atc.ca/sites/default/files/conf_papers/bcmoti_-_tac_2017_environmental_achievement_award_submission.pdf

Smith, D., Grace, M., Miller, A., Noss, M., & Noss, R. (2016). Assessing the Effectiveness and Reliability of the Roadside Animal Detection System on US Highway 41 Near the Turner River in Collier County. *Contract No. BDV37, TWO, 2*. Report. Available at: https://www.academia.edu/27986166/Assessing_the_Effectiveness_and_Reliability_of_the_Roadside_Animal_Detection_System_on_US_Highway_41_near_the_Turner_River_in_Collier_County (Accessed: 27 June 2023).

Solberg, E. J., Van Moorter, B., & Rolandsen, C. M. (2021). Skilt med gulblink for varsling av elgfare i trafikken. Effekter på sannsynlighet for påkjørsel og påkjørselsutfall. NINA Rapport 2043. Report. Norsk institutt for naturforskning. Available at: https://brage.nina.no/nina-xmlui/handle/11250/2830074.

Sørensen, J. B. (2017). *Moose-vehicle collisions in Northern Norway: Causes, hotspot detection and mitigation* (Master's thesis, Norwegian University of Life Sciences, Ås). Available at: http://hdl.handle.net/11250/2467077

Trafikverket (2021). Ställningstagande digitalisering väg. Ref.no: TRV 2021/147923

Waze (2023). *Driving Directions, Traffic Reports & Carpool Rideshares by Waze* (no date). Available at: https://www.waze.com/apps/ (Accessed: 14 July 2023).

Wildenschild, H. (2022). *Statens vegvesen sine forsøk for å redusere antallet viltpåkjørsler*. SVV rapport 803. Report. Statens vegvesen. Available at: https://vegvesen.brage.unit.no/vegvesen-xmlui/handle/11250/2985804 (Accessed: 16 June 2023).

Ydenius, A., Kullgren, A., Rizzi, M., Engström, E., Stigson, H. et al. (2017). Fatal car to moose collisions: Real-world in-depth data, crash tests and potential of different countermeasures. In *25th ESV Conference Proceedings*. *International Technical Conference on the Enhanced Safety of Vehicles (ESV)*, Detroit, Michigan USA. Available at: https://www-esv.nhtsa.dot.gov/Proceedings/25/25ESV-000294.pdf (Accessed: 31 October 2023).

Appendix A – The invitation to participate and the list of questions presented to stakeholders in different areas

An email was sent to stakeholders prior to the dialogue, asking whether they would participate in one-to-one dialogues. This invitation took the following format:

*Hej **[namn]**,*

*Vi kontaktar er då vi (VTI, Trafikverket och Volvo Cars) just nu håller på med en förstudie om viltolyckor. Studien ämnar att kartlägga system i fordon och infrastruktur som detekterar vilt längs med vägnätet och varnar för vilt med syfte att förhindra en olycka från att ske. Inom arbetet vill vi intervjua relevanta aktörer som kan bistå med information och insikter. Vi skulle gärna vilja ha ett samtal med er på **[organisation]** för att höra om och på vilket sätt ni jobbar med viltolyckor och/eller åtgärder och system för att minska antalet viltolyckor.*

Vi tänker oss ett teamsmöte på 1.5 h där vi kort presenterar projektet och sedan har vi en dialog utifrån ett antal frågor som vi skickar till er i förväg.

Förstudien är finansierad av Vinnova via det Strategiska innovationsprogrammet Drive Sweden. En kort sammanfattning finns nedanför och på Drive Swedens hemsida hittar ni projektinfo - ITS åtgärder i fordon och infrastruktur som en lösning för minskade viltolyckor | Drive Sweden.

Vi vore mycket tacksamma om ni har möjlighet att hjälpa oss med detta (eller skicka vidare till kollegor inom er organisation som ni tror kan bidra). Jag bifogar förslag på tider. Meddela gärna så snart ni har möjlighet ifall ni kan bidra och vilka tider ni föredrar så att vi kan pussla ihop det med övriga aktörer. Återkom också om ni vill delta men ingen av tiderna funkar så försöker vi hitta en annan tid.

Med vänlig hälsning

XX

The questions used are listed below. These questions were adapted depending on the stakeholder. A few stakeholders are active in more than one area, which is why questions from multiple areas were included in such instances. The invitation and questions are in Swedish as the stakeholders considered for participation operate in Sweden or other Nordic countries, and hence the Swedish language was used for the dialogues.

Stakeholders within the field of in-vehicle system and service development

Inledande fråga: Använder ni system för att detektera vilt idag? Isåfall vilket/vilka?

Om JA - Teknik och utveckling

- *Vilken typ av detektering används? Lidar/Radar/video…*
- *Vad skulle ni säga är de största utmaningarna vid detektering av vilt?*
- *Vad är de största möjliggörarna?*
- *Är kommunikation mellan fordon en lösning? Och vad behövs iså fall?*

- *Hur ser ni att system i infrastrukturen kan samverka med system i fordon?*
- *Ser ni skillnader i behov av systemfunktionalitet kopplat till vägtyp?*

Om JA - Användarperspektivet

- *Hur kommuniceras information till användaren?*
- *Är systemen rådgivande eller automatiserade? Eller både och?*
- *Utvärderas systemets användarvänlighet?*
- *Vad är största utmaningen ur ett användarperspektiv?*

Om JA - Biologisk mångfald

- *Tas hänsyn till biologisk mångfald och djurens habitat eller hamnar det utanför ert påverkansområde?*

Om NEJ - Teknik och utveckling

- *Vilka möjligheter har ni att idag utveckla system och tjänster för varning och detektering av vilt?*
- *Använder ni er utav kommunikation mellan fordon idag?*
- *Använder ni er utav kommunikation mellan fordon och infrastruktur*
- *Ser ni att system för detektering och varning av vilt skulle kunna vara en del av er verksamhet/ligga inom ramen för framtida utveckling eller hamnar det utanför ert utvecklingsområde?*
    - *Om ja – tror ni detta skulle vara ett efterfrågat system/tjänst hos era kunder?*

Om nej – vem tror ni bör ansvara för att reducera viltolyckor? Har ni funderat på hur?

Stakeholders within the field of infrastructure

Teknik och utveckling

- *Hur jobbar ni med detektering och varning för vilt idag?*
- *Fysiska åtgärder*
- *Vad fungerar och vad fungerar inte?*
- *Behöver fysiska åtgärder vara stora och kostsamma eller finns det exempel på mindre kostsamma fysiska åtgärder som har lyckats?*
- *Hur ser ni att ITS i infrastruktur skulle kunna bidra? Är det er roll att tillhandaha sådana system?*
- *Hur påverkar vägtyp behoven? Och finns det exempel på åtgärder som riktar in sig på det glesare vägnätet?*
- *Vad skulle ni säga är de största utmaningarna vid utveckling av åtgärder för att minska viltolyckor?*
- *Vad är de största möjliggörarna?*
- *Är kommunikation mellan fordon en lösning? Och vad behövs iså fall?*
- *Hur ser ni att system i infrastrukturen kan samverka med system i fordon?*

Användarperspektivet

- *Hur stor roll har användaren av systemet för att reducera viltolyckor?*
- *Vet ni hur efterlevnaden ser ut av ITS lösningar?*
- *Använder ni andra metoder för att kommunicera risk för viltolyckor?*

Biologisk mångfald

- *Hur tar ni hänsyn till biologisk mångfald och djurens habitat när ni implementerar fysiska åtgärder?*
- *Hur tar ni hänsyn till biologisk mångfald och djurens habitat när ni implementerar ITS åtgärder?*

Övrigt

- *(Kan vi lära oss något om projekt kring viltolyckor och järnväg?)*

Stakeholders within the field of biodiversity, animal behaviour and habitat

Biologisk mångfald

- *Hur anser ni att biologisk mångfald och djurens habitat påverkas vid implementering fysiska åtgärder?*
- *Hur anser ni att biologisk mångfald och djurens habitat påverkas vid implementering ITS åtgärder i infrastruktur?*
- *Hur anser ni att biologisk mångfald och djurens habitat påverkas av förarstödssystem?*
- *Vad anser ni är den/de viktigaste aspekterna för att minska antalet viltolyckor?*
- *Tror ni att ny teknik kan bidra till att minska viltolyckor? Hur?*
- *Hur kan vi lära oss mer om djurens beteende och rörelsemönster?*
- *Använder ni någon typ av detektering för att lära mer om djurens beteenden?*

Övrigt

- *(Kan vi lära oss något om projekt kring viltolyckor och järnväg?)*

Stakeholders within the field of statistics and information on wildlife collisions

- *Hur ser antalet viltolyckor ut över vägnätet?*
- *När och var förekommer flest olyckor?*
- *Kan man kategorisera olyckorna?*
- *Finns det några studier som undersöker orsaken till olyckorna? För hög hastighet, dålig sikt, etc…*
- *Vilka typer av personskador förekommer vid viltolyckor? (Ofta lindriga skador – vilka är dessa?, övergående eller invalidiserande över en längre tidsperiod?)*
- *Kan vi lära oss mer från statistiken för att förstå vilka typer av åtgärder som har högst potential att minska antalet viltolyckor?*
- *Och ifall olika typer av åtgärder behövs för olika delar av vägnätet?*

Appendix B – List of stakeholders

We would like to extend our warmest thanks to the following individuals and organisations who contributed with an open mind and shared their views on and knowledge of wildlife and collisions involving wildlife.

Organisation	Persons in attendance
EnviroPlanning	Marcus Elfström Mattias Ohlsson
Folksam	Anders Kullgren Anders Ydenius
If P&C Insurance	Magdalena Lindman
IMSA Knowledge Company AS (Norway)	Stein Bie Lars Rød-Eriksen
Länsförsäkringar	Kajsa Aminder Pers Jenny Norén Anders Wallstenius
Swedish Environmental Protection Agency	Lars Plahn
Swedish Police Authority/Nationella viltolycksrådet	Lena Britz Kenneth Kronberg Daniel Blad
Norwegian Public Roads Administration (Norway)	Henrik Wildenschild
Svenska Jägareförbundet	Jesper Einarsson
Swedish University of Agricultural Sciences (SLU)	Andreas Seiler
Swedish Transport Administration (road safety, biodiversity/environment, ITS)	Richard Fredriksson Ulrika Lundin Johan Rydlöv Peter Smeds
Swedish Transport Agency	Khabat Amin Omar Bagdadi Robert Ståhl
Danish Road Directorate (Denmark)	Anne Eriksson
Volvo Cars	Christian Applehult Anders Axelson Annelie Wyholt
Volvo Trucks	Anna Wrige Berling Lennart Cider Torbjörn Gustafsson Peter Wells
Zenseact	Andrew Backstone

The Swedish National Road and Transport Research Institute (VTI) is an independent and internationally prominent research institute in the transport sector. We conduct research and development to advance the state of knowledge within infrastructure, traffic, and transport. Through our work we contribute to the attainment of Sweden's transport policy goals related to accessibility, safety, environment, and health.

We conduct commissioned research within all modes of transport and work in an interdisciplinary organisation. Knowledge that we develop provides important information for stakeholders in the transport sector and in many cases leads to direct applications within both national and international transport policies.

As well as research we also undertake investigations, provide counselling, and perform various services related to measurement and testing. At VTI we have a wide range of advanced research equipment along with world-class driving simulators. We also have accredited laboratories for road material testing and crash safety testing.

The library at VTI is a national resource that collects and disseminates information in the field of Swedish transport research. As well as answering queries and lending publications the library also offers services such as information searches, monitoring developments within the field, and maintaining a website with a structured catalogue of publications and projects.

In Sweden, VTI collaborates with universities that conduct related research and education. We participate regularly in international research projects, primarily in Europe, and are active within international networks and alliances. We have about 240 employees and are located in Linköping, Stockholm, Gothenburg and Lund.

vti

Swedish National Road and Transport Research institute • www.vti.se • vti@vti.se • +46 (0)13–20 40 00