Modelling the impact of highways on impedance of movement and mortality locations of Badger *(Meles meles)* and Roe Deer *(Capreolus capreolus)*: A Case Study of the A73 in The Netherlands

Parag Prasad Khatavkar
March, 2009

Course Title:	Geo-Information Science and Earth Observation for Environmental Modelling and Management
Level:	Master of Science (M.Sc.)
Course Duration:	September 2007 - March 2009
Consortium partners:	University of Southampton (UK) Lund University (Sweden) University of Warsaw (Poland) International Institute for Geo-Information Science and Earth Observation (ITC) (The Netherlands)
GEM thesis number:	2007-12

Modelling the impact of highways on impedance of movement and mortality locations of Badger *(Meles meles)* and Roe Deer *(Capreolus capreolus)* , A Case Study of the A73 in The Netherlands

by

Parag Prasad Khatavkar

Thesis submitted to the International Institute for Geo-information Science and Earth Observation in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation for Environmental Modelling and Management

Thesis Assessment Board

Chairperson: Associate Prof. Dr. Yousif Hussin
Internal Examiner: Dr. A.G. Toxopeus
External Examiner: Associate Prof. Dr. Petter Pilesjö
Primary Supervisor: M.Sc. Andre Kooiman
Secondary Supervisor: Drs. Joan Looijen
Study Adviser: Sukhad Keshkamat (PhD student)

ITC International Institute for Geo-Information Science and Earth Observation
Enschede, The Netherlands

Disclaimer

Abstract

Wildlife mortality due to vehicular collision is one of the most important threats of road development and operation. Though sufficient research has been conducted on factors affecting road kill, the identification of mortality locations as a key to developing mitigation measures such as wildlife crossings has largely been ignored. Studies to identify the locations of wildlife crossings need extensive wildlife datasets and collection of such data is not always possible. On the other hand road development is a continuously growing process worldwide. Hence it is important to develop and validate a model which can identify relative mortality locations for wildlife using limited wildlife data. The A73 highway in The Netherlands was selected to develop a model using badger *(Meles meles)* and roe deer *(Capreolus capreolus)* as indicator species. Data on wildlife mortality and developed mitigation measures such as wildlife overpass/underpass was used for validation

The first step to identify relative mortality along the A73 highway was the creation of an impedance map for the two species, based on analysis of expert knowledge. Impedance is the resistance offered by different landuse and landcover types to animal movements. The impedance map was rasterised and circular buffers of 250 meter radius were developed. Using zonal statistics the circular buffers were divided into four categories – no, low, medium and high impedance. Secondly, a traversability equation from Jaarsma *et al.,* (2006) was used to estimate the probability of road kill for the indicator species. The A73 highway was divided into mortality threat zones of low, medium and high probability. Overlay analysis of the impedance map and the mortality threat map was performed using two scenarios.

The impedance model showed high impedance values for human settlements and industrial areas and only medium impedance for the A73 highway itself for both species. High probability of road kill was estimated in four continuous lanes of roads while relatively low probability was estimated if four lanes were divided in 2x2 lanes. In case of badger *(Meles meles),* scenario 2 identified 77 high mortality circular buffers. Likewise for roe deer *(Capreolus capreolus),* scenario 2 identified 71 high mortality circular buffers. Validation showed that scenario 2 predicted results better than scenario 1. The developed model is able to predict relative wildlife mortality locations using only species presence data. Validation of the model has shown satisfactory results. Using the output from current model, a separate functional model has been developed in STELLA for first time to estimate animal mortality. Future focus should be on applying and validating the model in other locations for other species

Acknowledgements

First of all, I am thankful to European Union Erasmus Mundus scholarship program. I would also like to thank the GEM panel for selecting me for this prestigious GEM program.

I would also like to express my gratitude to the academic team involved in this research. I would like to thank Andre Kooiman, Joan Looijen and Sukhad Keshkamat for their help, support, guidance, patience and constructive criticism. This research would not have been possible without your encouraging words and support.

I would like to thank all my GEM classmates for this wonderful eighteen months of journey in four different countries. Special thanks to Mandar, Anupam and Shijo for helping me in my life and studies.

I would like to thank Zoogdiervereniging Vzz, Society for the study and conservation of mammals for providing me badger and roe deer presence and mortality data. I would also like to thank Jasja Dekker, Projectleider for sharing his expert knowledge in this field.

I would also like to thank Dr. C.F. Jaarsma (University of Wageningen), Gerard Muskens (ALTERRA), J.M. Krisp (Helsinki University of Technology), Hans Bekker (Senior Adviser, Coordinator Meeriarenprgramma Ontsnippering), Dr Hien van Gills (ITC), Drs, E.H. Kloosterman (ITC), A.K. Brouwer (Local wildlife observer) for sharing their experiences, expert knowledge and helping me in making this research a success.

I would also like to thank my family for encouraging me all the time during this eighteen months of ups and down. I would also like to thank Mr. Prasanna Kolte for continuous encouragement during my thesis work. I would also like to thank Ms. Amruta M More for her support during my thesis work.

Finally, I would like to thank the entire faculty involved in GEM program for the help and knowledge they offered for last eighteen months.

Table of contents

List of figures

List of tables

1. Introduction

Roads are critical components of human life(Demir, 2007). They play a vital role for economic development of any country. This is well supported as 1% to 2% of the land in industrial countries is allocated for roads thus rapidly reaping the economic benefits of this outlay (Geneletti, 2003, Forman *et al.*, 1998). Also transportation geographers have successfully proved the link between road network expansion and economic development (Coffin, 2007). Being such a critical component for economic growth and development it has triggered pressure on the governments to extend their existing road networks (Keshkamat *et al.*, 2008).

However, recently the road developments have become controversial due to their short term and long term environmental impacts. They are now viewed critically by NGOs and the public thus challenging political interests (Keshkamat *et al.*, 2008, Demir, 2007).

1.1. Road development and its impact on environment

Development of roads and transport systems has modified the natural landscape and is responsible for changes in the landuse patterns (Demirel *et al.*, 2008). The effects of roads on environment can be grouped into two categories namely abiotic and biotic impacts (Forman *et al.*, 1998). Abiotic impacts include changes in the hydrological structure, slope and others while biotic impacts include effects on floral and faunal populations (Affum, 1997, Reijnen *et al.*, 1996). Construction of a road generally has abiotic impact on the environment making permanent changes (Forman *et al.*, 1998). On the other hand biotic impacts such as road kill and invasion of exotic species takes place during construction and operational phase of a road (EPA, 1994).

1.1.1. Road development and its impact on fauna

An alteration in ecology affects the habitat of fauna thus affecting the faunal populations. Well documented effects of the roads on faunal populations are habitat fragmentation, habitat degradation, habitat loss, loss of ecological corridors, edge effects, resistance for animal movements, noise disturbance and faunal mortality from vehicular collisions (See fig. 1.1). (EPA, 1994, Jaarsma *et al.*, 2006, Geneletti, 2003, Geneletti, 2006, Jones *et al.*, 2008, Demir, 2007),(Jorritsma, 1995). Hence wildlife scientists refer to roads as "*sleeping giants of conversation ecology"* (Coffin, 2007)..

Van Langevelde *et al.,* (2008) stated that the most immediate concerns are from habitat fragmentation, resistance for animal movements and the faunal mortality due to vehicular collisions. Habitat fragmentation and resistance for the animal movements creates a barrier effect, restricting the animal movements in small pockets of isolated populations leading to inbreeding and loss of genetic variability (Speziale *et al.*, 2008, Spooner *et al.*, 2008, Verboom *et al.*, 2007). The loss of corridor and resulting fragmentation further leads to inaccessibility of the resources such as feeding grounds, water and breeding areas thus severely affecting faunal populations (Jaeger *et al.*, 2005, Tanner *et al.*, 2007). The effects of habitat fragmentation and resource inaccessibility is so severe that they pose a risk for local extinction of species (Mata *et al.*, 2008).

Further risks arise from mortality of the fauna by collision with vehicles during road crossing for accessing resource or during seasonal migration (Olsson *et al.*, 2008). Coffin (2007) & Forman *et al.,* (1998) reviewed different effects of road on the fauna and found that road kill is responsible for depletion of the local faunal populations.

1.2. Vehicular disurbance, road aviodance and Impedance effect

Vehicular disturbance and road avoidance is developed due to increasing traffic volume and noise pollution reducing faunal mortality (Affum, 1997). Avoidance effect on animal movements is complicated to study and is seen as the cumulative effects of road development (Krisp, 2004). Coulon *et al.,* (2008) radio-collared 20 roe deer in south-western France to study avoidance behaviour of roe deer in different landscapes. GPS reading were recorded 2 to 4 hours every day and showed that roe deer tend to avoid human settlements, valleys and roads. But road avoidance was based on type of road and traffic intensity. Road avoidance was also based upon the placement of the road. If the road cuts home ranges, migratory corridors then use of it was observed in a particular season only with avoidance in rest of the year.

Jaeger *et al.,* (2005) developed a model for avoidance behaviour of animals towards roads. The model considered avoidance behaviour from noise, road surface, traffic density and road size. However, the output of this model is questionable as it uses the weights defined from 1 to 3 based on low avoidance, moderate avoidance and high avoidance. However actual results may vary as avoidance affects animal movements which is not a reality and faunal mortality numbers in vehicular collisions suggest another story (Madsen *et al.*, 2002, Rokorny, 2006).

Impedance is the resistance offered by different landuse and landcover types to animal movements. Literature reviews shows that roads and habitat fragmentation act as barrier for animal movements (Demirel *et al.*, 2008). while the traffic density, road side development and noise pollution causes road avoidance behaviour (Jaeger *et al.*, 2005). According to sources, barrier effect and road avoidance should reduce the road kill numbers for roe deer and badger. However studies conducted on roe deer and badger in Sweden, Denmark, The Netherlands, England and France indicate an increase in road kill numbers (Aaris-Sorensen, 1995, Bekker *et al.*, 2003, Clarke *et al.*, 1998, Danielson *et al.*, 1998, Madsen *et al.*, 2002). Similarly telemetry data showed roe deer avoidance towards human settlements (Coulon *et al.*, 2008). Movement along the road during breeding season and for foraging were recorded on many occasions. Similarly roe deer mortality increased in mixed areas of agriculture and forest. The roe deer mortality also increased during peak traffic hours in Denmark, thus opposing road avoidance behaviour to traffic density (Coulon *et al.*, 2008). Also studies conducted on badger showed road crossing behaviour for foraging and breeding (Clarke *et al.*, 1998).

This suggests that animal movements are dependent on the landcover type along the road and not solely on the road itself. Each animal species will have its own interaction with every landcover. Human settlements may be avoided by most of the species indicating higher resistance while agriculture and forest have lower resistance. This resistance developed by a particular landcover type will give rise to impedance effect. The higher the impedance effect the lower will be the chances for an animal passing through that landcover. On the other hand, the lower the impedance the higher will be the chance of an animal using a particular landcover for its passage. Literature review shows that predicting animal movements is complex. However impedance effect will help to select and visualize the areas available for species movements and can be further used for identifying possible mortality areas.

1.3. Road Effect Zone

Forman *et al.,* (1998) studied and reviewed the impacts of roads on environment in The Netherland, Australia, United Kingdom and United States with special focus on habitat fragmentation, animal movement barriers and road kill. The result showed that "road–effect distance is an area which is affected extending outward from the road and is several times wider than road and roadsides". The effect of road development on ecology extends upto 1 km outward from either side of the road affecting the potential wildlife habitats (Forman *et al.*, 1998). This effect extending outward from 100m upto 1.5 km from either side of the road is well supported in literature (Rajvanshi A *et al.*, 2001, Alexander *et al.*, 2000, Krisp, 2004, Treweek, 1996, Eigenbrod *et al.*, 2008, Forman *et al.*, 1995, Roever *et al.*, 2008a, Carr *et al.*, 2002, Reijnen *et al.*, 1994, Reijnen *et al.*, 1996). The impacts on ecology extending outwards from the road generally bring changes in hydrological structure, habitat fragmentation, habitat destruction and others. Hence for studying effect of single road it is important to consider area of 100 meters to 1500 meters outward from road to avoid interference of other road effects.

1.4. Factors causing faunal mortality due to vehicular collisions

Road kill is one the major factor for faunal depletion and has exceeded the poaching rates (Coffin, 2007). Road kill also pose a major risk for local extinction of the faunal species (Clevenger *et al.*, 2005). Studies conducted in last two decades record nearly 1,59000 faunal mortality in The Netherlands, while 3000 moose, 2500 white tailed deer and reindeer accidents in Finland, (Forman *et al.*, 1998, Krisp, 2004, Alexander *et al.*, 2000). Small mammals are attracted towards roadside vegetation; spilled grains and waste food thrown away by tourists and are thus frequently killed by the vehicular collisions (Rajvanshi A *et al.*, 2001). While large herbivores are generally attracted towards roadside grass and there are a few interesting studies showing that they are also attracted towards the road salt increasing the possibility of road kill (Alexander *et al.*, 2000). Predators are generally attracted towards the road in search of prey. The mortality of faunal species is dependent on its mobility, migratory distances and migratory corridors with the road density (Vos, 1995, Orlowski, 2008).

1.4.1. Risk of badger mortality due to vehicular collision

Badgers are endangered species and widely studied for their mortality along the roads in the Netherlands, Denmark and England (Jaarsma *et al.*, 2006, Aaris-Sorensen, 1995, Clarke *et al.*, 1998). Badgers are predominantly nocturnal animals with territories extending from 40 to 180 hectares (Hughes *et al.*, 1996, Kruuk, 1978). They are social animals with 3 to 12 individuals in each colony (Rogers *et al.*, 1997). They burrow the soil to form underground network of tunnels knows as “setts” (Woodroffe *et al.*, 1995). The food habits differ widely from insects, to small vertebrates, reptiles, other plant matter and earthworms forming critical component of their diet (Roper, 1994). Dispersal behaviour of badger is generally observed in males during breeding seasons (Woodroffe *et al.*, 1995).

From 1990-1995 nearly 1850 badger deaths along the roads have been recorded in the Netherlands (Bekker *et al.*, 1995). Van Landgevelde *et al.,* (2008) compared the traffic mortality of badgers on major roads and minor roads in the Netherlands. The results of their research showed that minor roads have more road kills due to area covered by them. Couple of other studies has been conducted on badger mortalities in South England and Netherlands have shown that badger have fixed route of travel for foraging and pose a major risk if roads fall within its range (Aaris-Sorensen, 1995, Bekker et al., 1995). Clarke *et al.,* (1998) studied badger mortality in South England and results showed that mortality of badgers is directly linked with traffic intensity. Surprisingly the mortality rate on different roads was nearly the same for per unit length of road in kilometre. Bekker *et al.,* (1995) showed that major risk for badger mortality is in the areas where the habitat is present on both sides of roads. Similarly the mortality ratio was dependent on breeding seasons where males migrated to nearby badger colonies. The study in Denmark showed that the empty "setts" of dead badgers along the roads were occupied by sub-adult male populations posing continuous threat for vehicular collisions (Aaris-Sorensen, 1995).

1.4.2. Risk of roe deer mortality due to vehicular collision

The roe deer are widely distributed in European continent but are now threatened due to habitat fragmentation and mortality by vehicular collisions (Coulon *et al.*, 2004). It is observed as a solitary animal as well as in small groups especially in winter (Cornelis *et al.*, 1999). It has specific territorial boundaries with average home range of about 95 hectares (Danielson *et al.*, 1998). The roe deer mainly occupy woodland and forested areas but are commonly visible in fields and grazing grounds (Said *et al.*, 2006). Frequent invasion of roe deer in agricultural fields and grazing lands is leading to conflict issues with local farmers (Putman *et al.*, 2002). Roe deer movements are not only restricted to day but also show some effective movements at night (Rokorny, 2006). It also shows seasonal migratory behaviour in both males and females ranging from 2 to 5 kms (Wahlstroem *et al.*, 1995, Said *et al.*, 2006).

One of the major threats posed to roe deer populations is from the roads (Rokorny, 2006). A study conducted in Denmark showed 115 fatalities constituting young and old roe deer due to vehicular collisions in one year (Madsen *et al.*, 2002). One of the interesting finding from this study was that high number of roe deer mortality was observed where agriculture fields and forest patches were close to roads providing food resources. A similar study conducted in Slovenia showed that mortality of roe deer is directly dependent on the vehicular intensity as most of the accidents occurred during peak hours (9 – 10am and 5 – 7 pm) (Rokorny, 2006). Another study conducted in the Netherlands showed increase in vehicular intensity by 1.5% shooting up the road kill rate of roe deer by 10% (Danielson *et al.*, 1998). Similar results of increased mortality of roe deer were observed in Cumbria with increasing traffic intensity (Lurz *et al.*, 2005). The roe deer collisions with vehicles not only kills the animal but there are also humans injuries and fatalities as have been reported from Sweden (Seiler, 2003).

1.5. Use of Geo - infomation for identifying impacts of roads on fuana for developing mitigation meaures

The studies conducted for identifying impacts of road on fauna are categorised as direct such as habitat fragmentation and road kill and indirect impacts such as depletion of water quality. However, current research considers direct impacts only. Alexander (2008) studied the effects of road on fauna due to construction of the Trans-Canada Highway (TCH) in Banff National Park. They studied faunal movement across TCH with effect to annual traffic intensity, barrier effect and animal mortality. Using Geo-information technologies, they converted point data into raster map through interpolation and the analysis for barrier effect was carried out using observation made on animal movements, traffic density, slope and topography. Treweek (1996) developed an approach for ecological assessment using Geo-information sciences. The research considered the impact zone of road development to be 1 km on either side of the road. Cumulative effects of habitat fragmentation were considered through changes from road development.

For understanding animal movements along the roads and determining the probability of road kill, wildlife movement algorithms have been developed (Jaarsma *et al.*, 2007, Forman *et al.*, 1998, Coffin, 2007). Jaarsma *et al.,* (2007) used simulation for analyzing and predicting the badger *(Meles meles)* mortality by 2015 due to traffic and infrastructure development. During research they used two different models namely Traversability model for successful animal crossing and small step model for simulating animal movements along the road.

Austin (2005) developed a model using Geo-information sciences for placement of wildlife crossings. The model constitutes of LULC, developmental plans, telemetry data, wildlife movements data and habitat fragmentation data. Though identification of the locations for developing wildlife crossings was achieved it required extensive wildlife datasets collected over 4 years. Krisp (2004) developed an ecological barrier model of moose for the Vantaa city in Finland using expert's knowledge. For evaluating the effects of the roads on fauna, studies suggest that ecosystem mapping should be carried within 1:5000 to 1:25000 scales (Jha *et al.*, 2005, Liu *et al.*, 2008).

1.6. Effectiveness of wildlife crossings developed as mitigation measures against faunal mortality and habitat fragmentation

For preventing habitat fragmentation and reducing the mortality of faunal populations mitigation measures are being adopted in Europe, US and Australia (Forman *et al.*, 1998). The mitigation measures include development of the wildlife overpasses, underpass, ecoduct, fencing and green bridges (Keller *et al.*, 1995, Olsson *et al.*, 2008). Placement of these wildlife crossing has always been a point of debate (Mata *et al.*, 2008).

A study conducted in Sweden along E4 highway showed that underpass and overpass constructed for wildlife to reduce the moose accidents was used only by stationary moose and not by migratory moose population (Helldin, 2003). This reduced road accidents as stationary moose populations could adapt to the underpass and overpass. Mata *et al.,* (2008) assessed the wildlife crossing developed along A-52 in Spain and indicated efficient use of wildlife crossing by animals but the crossing intensity differed for each species with respect to wildlife crossing structure (Underpass, overpass and ecoducts). The results suggested having mixture of wildlife crossing structures will increase the probability of animal crossings. Olsson *et al.,* (2008) used infrared camera, tracks counts, GPS and telemetry data to track animal movements across wildlife crossing structures for moose and roe deer in Sweden. But the results were not up to expectations as their study found only 6 to 7 moose using the overpass who had their home ranges around the wildlife crossings.

Cachon (2003) studied 82 wildlife passages in Spain and found its effective use by small rodent, mammals, amphibians and reptiles. Bekker *et al.,* (1995) studied badger tunnels in the Netherlands which showed effective use, if the tunnels were properly constructed and well guided by fencing and vegetation cover. Janssen *et al.,* (1995) carried out a similar study involving in the Netherlands and showed that 25% of the wildlife structures did not meet the required expectations. The major reasons were improper placement of the crossing structure, inadequate lengths of fencing and unguided routes towards the crossing structures.

Clevenger *et al.,* (2005) used performance indices to study the effectiveness of the wildlife crossing. The results showed that structure of overpass is not so important as compared to its placement. The literature shows the mixed results for effective and ineffective use of wildlife crossing. Predicting the exact location of wildlife crossing is a difficult but is most important for its efficient use.

2. Research Proposal

2.1. Research Proposal

The effect of road development and operation on fauna is in focus since 1980's (Forman *et al.*, 1998). Literature review shows that ample of research has been conducted on habitat fragmentation, loss of corridors, road avoidance behaviour and barrier effect due to road development (Bekker *et al.*, 2003, Demirel *et al.*, 2008, Helldin, 2003, Jaeger *et al.*, 2005). Also research has been undertaken to identify factors affecting the road kill and wildlife mortality on different types of roads (van Langevelde *et al.*, 2009). However none of them focused to prioritise locations of mitigation measures for reducing the faunal road mortality. Though recent research has focused to develop models for predicting faunal mortality, they require extensive wildlife datasets, complex simulation models such as "small step" and are oriented for single species (Jaarsma *et al.*, 2007). Most of the developed models are not tested with the ground data. However it is not always possible to acquire such extensive wildlife data sets to use the present models. Even if required wildlife data is provided, present models will only predict mortality risk posed by a road and will not prioritise wildlife mortality locations. When dealing with limited datasets it is important to study the interaction of species with different landcover types to identify the areas available for species movements. Hence, the impedance effect plays a vital role for estimating the areas available for species movements.

Very few attempts have been made to identify the mortality locations along a road. One of such attempt has been on the A50 highway in The Netherlands (Muskens *et al.*, 2008). Where as another is the Trans-Canada highway in Banff National Park (Alexander, 2008). For both studies extensive wildlife datasets have been used with more than 6 years of telemetry data on animal movements. However, road development is a continuous process and has gained pace in rapidly developing countries like India. It is not always possible to acquire such datasets everytime because of cost and time (Rajvanshi A *et al.*, 2001). Also due to increasing traffic congestion the existing roads have to be widened. Depending upon space either two separate lanes or 4 continuous lanes are constructed and they may have different mortality impacts. Hence road kill poses the most important threat of rapid road development in developing countries with hardly any mitigation measures. Thus predicting faunal mortality zones on their optimum locations will be a priority. Similarly developing mitigation measures is expensive and proper knowledge is necessary (Mata *et al.*, 2008).

Considering these issues it is important to develop a model which can predict the wildlife mortality locations with limited (available) wildlife datasets in order to prioritise the mitigation measures such as wildlife overpass / underpass. It is also important to validate the developed model to assure its reliability. This study chose to develop the model in the Netherlands, where wildlife mortality has been monitored and developed mitigation measures such as wildlife overpass / underpass which can be used for validation have been constructed. Such a validated model requiring limited wildlife datasets should enable its use in developing countries for constructing wildlife mitigation measures such as underpass / overpass.

2.2. General Objective

The general objective of this study is to develop a model that prioritizes locations for mitigation measures by comparing impedance and mortality risk posed by A73 highway using badger *(Meles meles)* and roe deer *(Capreolus capreolus)* mammal species.

2.3. Specific Objective

1. To estimate the impedance on movements of badger *(Meles meles)* and roe deer *(Capreolus capreolus)* due to operation of the A73 highway in The Netherlands.
2. To model the mortality risk posed by the A73 highway for badger *(Meles meles)* and roe deer *(Capreolus capreolus).*
3. To identify priority locations for mortality of badger *(Meles meles)* and roe deer *(Capreolus capreolus)* so as to develop wildlife mitigation measures such wildlife underpass / overpass or ecoducts.
4. To validate model output of identified mortality locations with available wildlife datasets.

2.4. Research Questions

1.1 What is the effect of impedance on badger *(Meles meles)* and roe deer *(Capreolus capreolus)* movements across the A73 highway?

1.2 How can impedance be visualised on badger *(Meles meles)* and roe deer *(Capreolus capreolus)* movements across the A73 highways?

2.1 What is the risk posed by the A73 highway on mortality of badger *(Meles meles)* and roe deer *(Capreolus capreolus)?*

2.2 What is the impact of two road widening scenarios of 4 continuous lanes and 2 separated lanes on mortality risk of badger *(Meles meles)* and roe deer *(Capreolus capreolus)* along the A73 highway

3.1 What is the relative mortality of badger *(Meles meles)* and roe deer *(Capreolus capreolus)* along the A73 highway?

4.1 How reliable is the model to predict the mortality?

2.5. Expected Outcome

1.1 Impedance values and the impedance map produced for movements of badger *(Meles meles)* and roe deer *(Capreolus capreolus)* along the A73 highway.

1.2 3 – Dimensional visualisation map for the impedance of badger *(Meles meles)* and roe deer *(Capreolus capreolus)* movements along the A73 highway.

2.1 Estimation of mortality risk posed by the operation of the A73 highway.

2.2 Estimation of mortality risk on 4 continuous lanes and 2 separated lanes of the A73 highway.

3.1 Tabular and map output for relative mortality locations of badger *(Meles meles)* and roe deer *(Capreolus capreolus).*

4.1 Tabular output and map output for validation of relative mortality locations with available validation data.

3. Methodology

3.1. Description of the study area

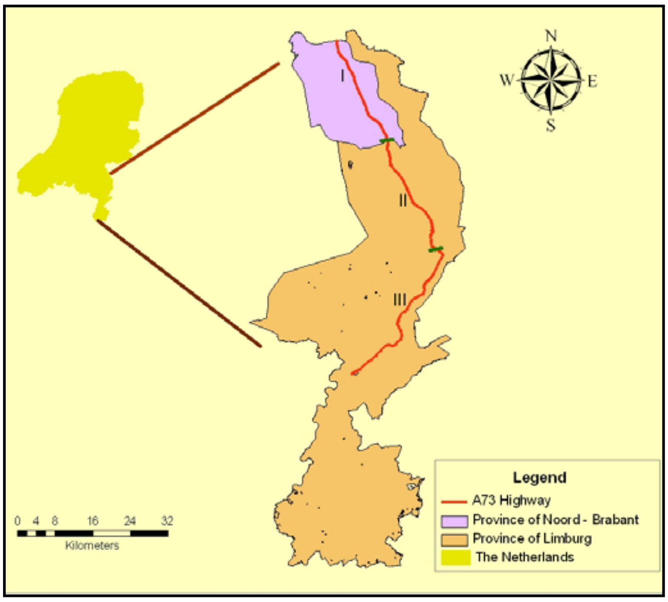


Figure 3.1 The A73 highway I) Northern section, II) Central Section and III) Southern section passing through the Province of Limburg and the Province of Noord – Brabant, The Netherlands.

For this research the study area is along the A73 highway in The Netherlands. The A73 highway passes through the Province of Limburg and the Province of Noord Brabant. It stretches 110 km from Ewijk to Echt. The A73 highway was constructed in 1985, at the time connecting the Province of Brabant and the northern part of the Province of Limburg. Recently (2003 – 2008) new construction of 40 kms has been done in the southern part of the Province of Limburg due constant traffic congestion (Oene, 2004). The southern part of the A73 Highway came in operation since January 2008 (Rijkswaterstaat, Province of Limburg, 2008). The A73 highway is a 4 lane highway divided by a grass strip of 5 meter width in some of the areas making it 2x2 and continuous 4 lanes in other parts. The complete stretch of highway consists of 41 mixed structures of viaducts, bridges and tunnel to the local roads. The A73 highway passes mainly through urban areas, woodland, shrub-land, heath-land, fine landscape and corn fields (Cuperus *et al.*, 2002) .

The A73 highway also passes through ecologically important areas consisting of endangered species such as Badger (*Meles meles*), Pine Martens (*Martes martes*) and Roe Deer (*Capreolus capreolus*) (Cuperus *et al.*, 2002). The widening and development of the A73 highway was in debate since 1995 and questions had been raised in the European Parliament as it passes through important natural areas along the river Maas (European Parliament, 2001). The EIA for the A73 highway widening and development focused mainly on air quality, noise levels, impacts on flora and faunal populations, soil and water (Oene, 2004).

With no major changes for diverting the planned route an ecological compensation plan was developed and implemented. For the compensation plan the Dutch authorities have sanctioned 5.8% of the construction costs which accounts approximately $10 million. The compensation plan involved the development of wire fence, 2 adaptation bridges, 82 small fauna tunnels, 20 ecoculverts, 1 fauna overpass and 2 Fauna underpass (Cuperus *et al.*, 2002).

The A73 highway was selected as a case study area because data was available on the selected species and because of the mitigation measures. This way the model output could be compared with the existing and proposed mitigation measures along the A73 highway after its development.

3.2. Selection of indicator species

The selection of indicator species is critically important as each species has different impact of road development. Also the barrier, effects and mortality rates will differ for each species (Forman *et al.*, 1995, Vos, 1995, Jaarsma *et al.*, 2006, Roever *et al.*, 2008b, Tanner *et al.*, 2007). This research focuses on two mammalian species - one nocturnal and one diurnal species - with different home range, foraging areas and niche requirements. For current research following indicator species were selected. The species were selected whose presence was confirmed by species presence data.

1. Badger *(Meles meles)*
2. Roe Deer (*Capreolus capreolus)*

3.2.1. Reasons for selection of badger as an indicator species

Couple of studies have been conducted on badger mortalities in the Netherlands. Jaarsma *et al,* (2006) and Jaarsma *et al.,* (2007) developed Traversability equations for animal movements using badger as indicator species. For current work badger was selected considering three aspects. It’s a nocturnal animal and studying it will cover mammalian species with similar behaviour such as mongoose *(Herpestes javanicus)*, civet cat *(Viverricula Indica)* and porcupines *(Hystrix indica)*. As past research has been conducted on badgers in the Netherlands data of species presence and mortality is available. Similarly mitigation measures developed for reducing the mortality can be used for comparing the model's output results.

3.2.2. Reasons for selection of roe deer as an indicator species

In past studies in the Netherlands roe deer has been used as an indicator species for developing the wildlife crossings (Cuperus et al., 1996). Also use of Roe deer is made for assessing the impact of minor roads on the large mammals (van Langevelde et al., 2009). It has been used for assessing the genetic flow in fragmented landscapes (Wang *et al.*, 2002, Coulon *et al.*, 2006). It also meets the requirement for large mammal category. Therefore as past research on Roe deer has been conducted in the Netherlands, the availability of species presence and mortality data is a positive point for selecting it as an indicator species.

3.3. Data collection and data description

Data collection has been done from various organisations, governmental agencies and governmental web databases in the Netherlands.

3.3.1. Data collection for developing impedance

Landuse Landcover (LULC) classified shape files

As each landcover class will contain different impedance values for animal movements, landcover classification is important. As pre-classified landcover vector files for the Province of Limburg and the Province of Noord – Brabant were available, land cover classification using satellite imageries was avoided.

The classified landcover data for the Province of Limburg was downloaded from Geo Dataportaal for year 2008
http://portal.prvlimburg.nl/geo_dataportaal/viewer.do (Accessed on 10/10/2008).

While classified landcover data the Province of Noord – Brabant was downloaded in vector format from CD-ROM developed by Province of Noord Brabant for year 2005 – 2006.

All downloaded data was combined together to form a complete landcover map. All vector layers were projected in RD_new Projection system with datum D_Amersfoort which is specific for the Netherlands (GeoData portal, Province of Limburg, 2008)

Landcover extraction for developing impedance map

For the current research, landcover map is clipped for 1.5 km distance on either side of the A73 highway. As according to literature the impact zone of the road development or operation varies from 100 meter to 1.5 km on either sides of the road having different effects on fauna. (Rajvanshi A *et al.*, 2001, Alexander *et al.*, 2000, Treweek, 1996, Eigenbrod *et al.*, 2008, Forman *et al.*, 1998, Coffin, 2007). A buffer of 1.5 km was developed on either side of the A73 highway and clip operation was used to extract the 1.5 km strip of landcover on either side of the A73 highway.

The A73 highways passing through the Province of Limburg and the Province of Noord – Brabant encompassed 17 landcover classes. Total area consumed by all 17 landcover classes is estimated to 365 sq. km. Of all the classes in the Province of Limburg, the 1.5 km clip on either side of the A73 highway constitutes 28% of its area as urban and rural settlements followed by agriculture, 25%; industrial, 19%; and Forest, 19%. While the 1.5 km clip on either side of the A73 highway in the Province of Noord – Brabant constitutes 48% of its land as agriculture, 29% for forest and 13% for human settlement (See fig. 3.2)

3.3.2. Expert knowledge

For developing the impedance map expert knowledge for the animal barriers have been used. Individual observations and telemetry data are two other options for impedance values. But in the available time span individual observation were not feasible while telemetry data was not available. In past studies, expert knowledge has been successfully used for identifying mitigation measures (Clevenger *et al.*, 2002, Krisp, 2004).

The Landcover classes classified in paragraph 3.3.1 were used to evaluate impedance values for animal movements through expert weights. Every expert was requested to assign an impedance value between 0 to 10 for each indicator species to each landcover type where value of 0 represents no impedance and value of 10 represents absolute barrier for the animal movements. Experts were selected considering their knowledge on species, species habitat, past work on species movements and experience in developing mitigation measures. The experts were selected from University of Wageningen, ALTERA, Rijkswaterstaat Dienst Verkeer en Scheepvaart, local wildlife observers and ITC. For badger, 6 experts have evaluated the impedance value while for roe deer 4 experts have evaluated the impedance value. Total of 8 experts were used (Some experts have evaluated impedance for both species).

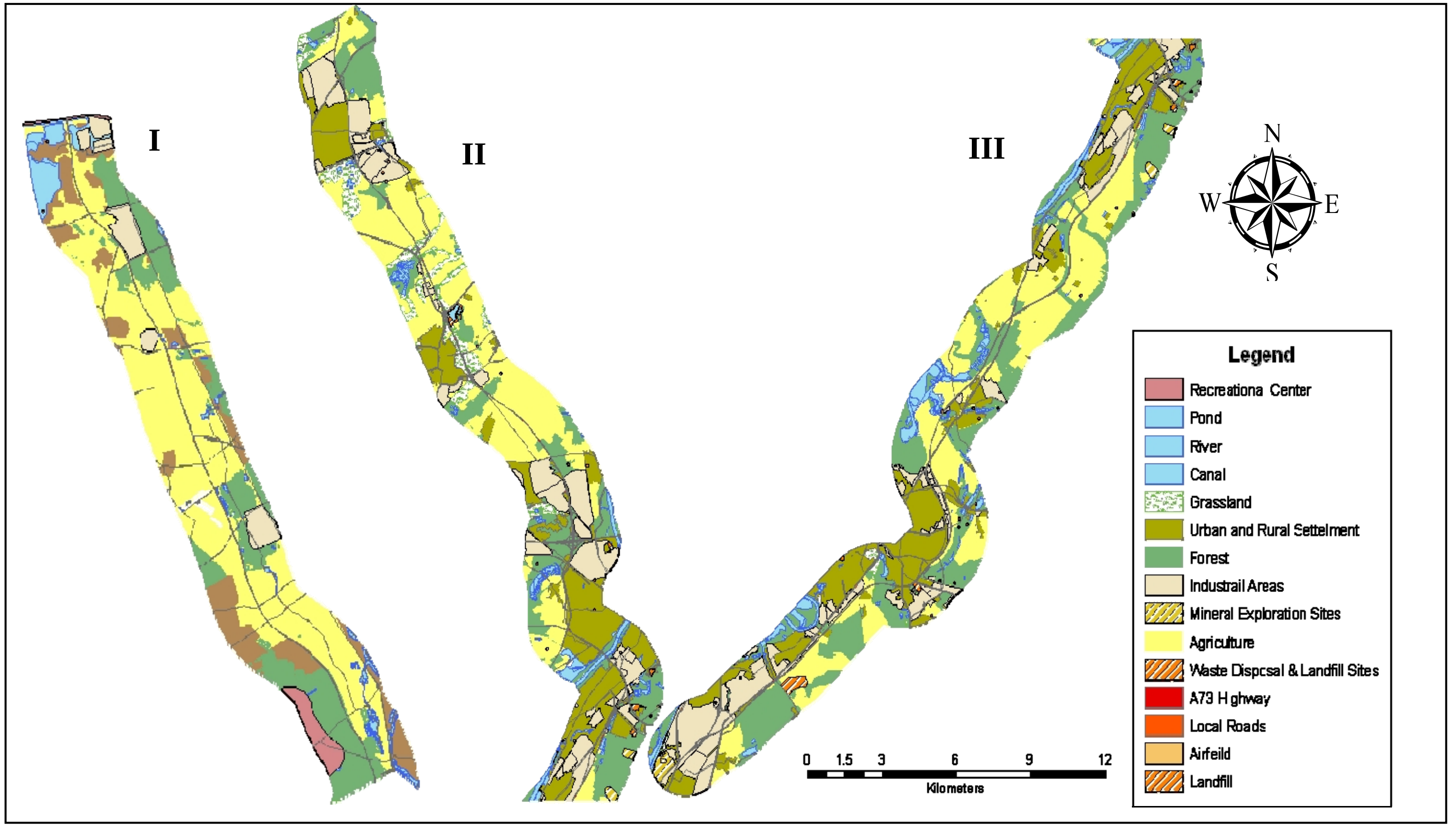


Figure 3.2 Landcover classes in 1.5 km clip on either side of the A73 highway in three sections. I: Northern section, II: Central section and III: Southern section of the A73 highway

3.3.3. Data collection for estimating mortality

Traffic Intensity data & Traffic characteristics

The traffic intensity data at a particular place along the 73 highway was downloaded from the "Ministerie van Verkeer en Waterstaat Rijkswaterstaat" website "Data – ICT – Dienst" http://81.18.1.212/index.html (7th November 2008) using MTR+ open source software (See fig.9.2 in Annexure). Vehicular intensity data along the A73 highway are monitored by Rijkswaterstaat at different locations every year. To cover the complete section of the A73 highway vehicular intensity data from January 2006 to December 2008 was used. The data were downloaded and analysed as follows:

1. Data was downloaded as weekly average number of vehicles.
2. It was converted into monthly average and then into yearly average at vehicle counting points.
3. The traffic intensity data was required for predicting the animal mortality locations using the Traversability equation. The Traversability equation requires traffic intensity per second (Jaarsma *et al.*, 2006). Hence average yearly number was then converted into of average yearly number vehicles per second.

The traffic characteristics included:

Average width of vehicles – 3 meters
Average length of vehicles – 6 meters
Average speed of vehicles – 90 km/hour

Source: Ministerie van Verkeer en Waterstaat Rijkswaterstaat, 2008

Species characteristics

Table 3.1 Characteristics of selected indicator species

	Badger *(Meles meles)*	**Roe Deer *(Capreolus capreolus)***
Average Length	1 meters	1.4 meters
Average Width	0.4 meters	0.4 meters
Average Speed	6.5 m s^{-1}	5.2 m s^{-1}

Source: (Roper, 2008)& (Jaarsma et al., 2006)

3.3.4. Data collection for validation of the model

Species presence data

The species presence data that were obtained from Zoogdiervereniging (VZZ) (Society for the Study and Conservation of Mammals) show presence point in a 1 sq. km. grid. For the study area data has been collected from 1990 to 2008. The species presence has been marked after observation and mentioning the type of observation made. Following types of observation were made, namely, species observed, foot prints, faeces presence, caught and badger dens for marking species presence.

Species Mortality data

Mortality data has been obtained from VZZ and from Waarneming.nl. for the period 1990 to 2008. Most of the mortality data for badger and roe deer due to vehicular collision has been verified by VZZ. Not all the mortality data was collected from the A73 highway itself. At many points the mortality of animals was observed away from the A73 highway. This is because the vehicular collision may not lead to immediate death of the animal. The animal is hit by vehicle and gets injured and may die some distance away from the road or may die after 1 or 2 days at larger distance from the road (Forman et al., 1998). Hence an understanding of the cause of the mortality of the animal away from the road is important. Only data recorded as road kill has been used for the analysis. Hence a 500 meter buffer was developed for roe deer and for badger and only mortality data from within this area was considered as the victim of road kill due to vehicular collision and selected for further analysis (See fig 3.3 & 3.4). It is important to avoid overlays with road kills from other road with the A73 highway. This problem was reduced by selecting mortality data within 500 meter of buffer on either side of the A73 highway.

Wildlife crossing locations

The wildlife crossing locations were downloaded from GeoData portal for the Province of Limburg and from CD-ROM for the Province of Noord – Brabant. Along the A73 highway 40 wildlife crossing locations were available from the above source. Though there more than 40 locations none of the agencies were able to give the wildlife crossings locations.

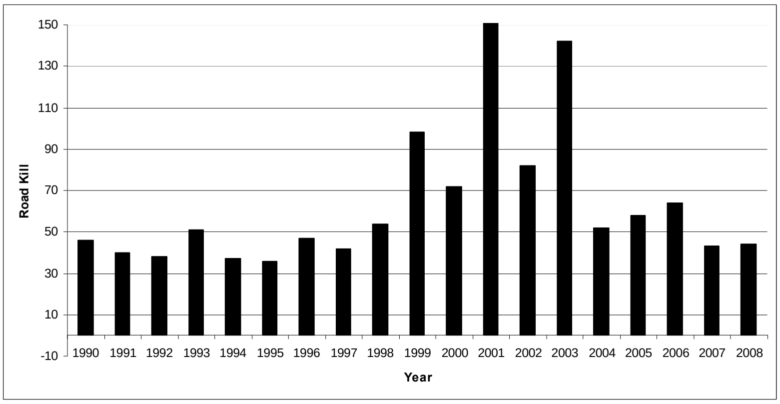


Figure 3.3 Badger road kill data in the 500 m buffer along the A73 highway since 1990 – 2008. (Source: Zoogdiervereniging VZZ)

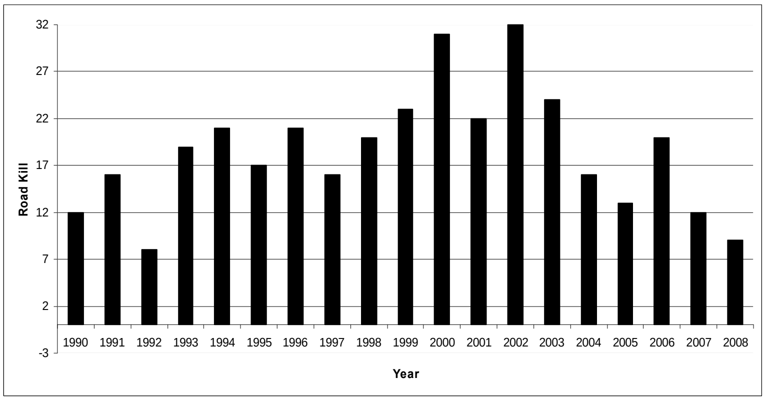


Figure 3.4 Roe deer road kill in the 500 m buffer along the A73 highway data since 1990 – 2008. (Source: Zoogdiervereniging VZZ)

3.4. Developing impedance map

The Impedance map was developed using expert knowledge. Every expert has his own opinion when assigning the weight hence there is difference of opinion for every species and every landcover class (Krisp, 2004). Two different methods were opted for analysing expert knowledge to understand ratings given by experts and difference of opinions.

3.4.1. Assigning equal weight to every expert (Method 1):

Every expert is given equal weight and is considered to have equal knowledge about the species (Krisp, 2004).

Table 3.2 Equal weight assigned to every expert

Name of Indicator Species	Number of Experts	Percentage of weight assigned to every expert	Weight Assigned to each expert (WA)
Badger	6	16.66%	0.166
Roe Deer	4	25%	0.25

The impedance value given to a landcover class by an expert was multiplied by the expert's weight for a respective species and then added up to get a combined weight for an individual landcover class.

Impedance value for Individual Landcover class = Σ (VE_n x WA_n)

Where, VE = Value given by each expert for every landcover category

WA= Weight Assigned to each expert

3.4.2. Assigning different weight to every expert (Method 2):

Every expert is assigned individual weight depending upon their experience and work done on the species. Higher the experience of the expert on indicator species, habitat and behaviour higher is the weight assigned to an expert (Capistrano *et al.*, 2005) (See table No. 3.5).

Table 3.3 Weights assigned to each expert

Number of Experts	**Percentage of weight assigned to each Expert**	**Weight assigned to each expert (W.A)**
Badger *(Meles meles)*		
Expert 1	30%	0.3
Expert 2	20%	0.2
Expert 3	20%	0.2
Expert 4	10%	0.1
Expert 5	10%	0.1
Expert 6	10%	0.1
Roe Deer *(Capreolus capreolus)*		
Expert 1	30%	0.3
Expert 2	30%	0.3
Expert 3	20%	0.2
Expert 4	20%	0.2

Impedance value for Individual Landcover class = Σ (VE_n x WA_n)

Where VE = Value given by each expert for every landcover category

WA= Weight Assigned to each expert.

3.4.3. Developing a 3-Dimensional impedance map for visualisation

For converting the 2 dimensional impedance map into "3-D" we require a "Z' value. This "Z" value will act as an elevation for projecting the impedance map. For visualizing the real barrier for animal movements impedance values assigned by the experts were converted to "Z" using ArcScene extension of ArcGIS.

Following steps were involved in development of 3 – D impedance map:

1. Impedance values were converted into "Z" value which will act as elevations.
2. Vertical exaggeration value of 10 was used.

3.4.4. Classification of the impedance map using expert knowledge

The impedance map was converted into four classes for further analysis to predict relative mortality locations. The classes were decided by the experts and personal communication with J.M. Krisp (2008) who developed barrier effect model for Moose movements in Finland (Krisp, 2004, Krisp *et al.*, 2004).

Table 3.4 : Impedance classes through expert knowledge

Sr No.	Impedance class	Badger	Roe Deer
1	No Impedance	0 – 1	0 – 1
2	Low Impedance	1 – 4	1 – 3
3	Medium Impedance	4 – 7	3 – 6
4	High Impedance	7 – 10	6 – 10

Steps involved in developing impedance classes

1. Classified impedance map with impedance values was converted in to Raster map with 90 meters cells size.
2. Points were placed at a distance of 500 meter along the A73 highway.
3. A circular buffer of 250 meter radius was developed around the points with the A73 highway in the center.
4. Zonal statistics was used to find the mean and standard deviation for the pixels falling under the circular buffer to determine the impedance class.

3.5. Estimating the probability for mortality of badger and roe deer

Not all road length poses a risk to animal mortality. Some parts of the road may pose high risk while others may have low mortality risk. The mortality of the animals is directly dependent on the vehicular intensity and vehicular speed (Danielson et al., 1998, Lurz et al., 2005). To determine the different mortality risk stretches of the A73 highway the "Traversability Equation for Animal Movements" developed by (Jaarsma *et al.*, 2006) was used.

Traversability Equation for Animal movement's assumptions (Jaarsma et al., 2006)

1. The collision between car and animal occurs when car arrives on a spot before the animal evacuates the spot
2. The animal traverses the road at a constant speed
3. Animal dies if the collision occurs with the vehicles

The animal can successfully cross the road between the gaps of two vehicles at a given location. To estimate the probability of animal deaths with relation to traffic intensity Poisson distribution is used. "As in a Poisson distribution, the number of events in sequential time periods of an equal length is independent stochastic drawings" (Jaarsma *et al.*, 2006).

In the traffic modelling the Poisson distribution P(x) is used to estimate the probability of vehicles "x" coming in direction of road in given period of time T (in seconds) with equation

$$P(x) = \frac{(\lambda T)^x e^{-\lambda T}}{X!} \qquad \text{………………………..(Equation 1)}$$

Where λ = traffic volume in vehicles s^{-1}

If the animal has to successfully cross the road without getting killed then x should be equal to "0". Then the equation changes to,

$P(0) = e^{-\lambda T}$

That means P(0) probability of successful animal crossing depends if the front end of next car will not arrive in time period T second considering the traffic flow on average vehicles λ s^{-1}. The probability of animal being hit by a car will depend upon vehicular intensity, average vehicular width, average vehicular length, traffic speed and species characteristics.

If this has to be expressed in the characteristics of animal and car for estimating the probability of animal kills then

$$P_a = e^{-\lambda\left(\frac{\frac{Wc + La}{\cos(\alpha)}}{Va} + \frac{Lc + Wa\cos(\alpha)}{Vc}\right)} \qquad \text{…….. (Equation 2, Jaarsma } \textit{et al. 2006)}$$

Where Wc = average vehicle width in meter

La = average animal length in meter   Va = average animal traverse

Cos (α) = angle of animal traverse   Lc = average vehicular speed

Wa = average animal width   Vc = car length

In the above equation cos (α) = 0 i.e. perpendicular traverse the angle then equation would be

$$P_a = e^{-\lambda\left(\frac{Wc + La}{Va} + \frac{Lc + Wa\cos(\alpha)}{Vc}\right)} \qquad \text{…… (Equation 3, Jaarsma } \textit{et al,. 2006})$$

To estimate risk for animal mortality probability during traversing (D_a)

$D_a = (1 - P_a)$ ……………………………(Euqation 4, Jaarsma *et al.,* 2006)

For current study equation 2 and equation 4 have been used for estimating the probability of animal being hit by the vehicle. If sufficient number of animals are radio collared and enough reliable data is received for number of times road crossed by the animal. Then from equation 4 we can estimate accurate number of animal deaths which can occur due vehicular collision though

$D_a = (1 - P_a)\, K_{a,\,t}$ …………………………(Equation 5, Jaarsma *et al.,* 2006)

Where D_a becomes actual number of road kills due to vehicular collisions

$K_{a,\ t}$ = Number of attempt made by animal to cross the road in time "t" from actual field (telemetry data). But $K_{a,\ t}$ is nearly impossible to predict as conditions will change and the species crossings will depend on various factors.

3.5.1. Road widening in two different ways

A73 highway is widened in two types:

1. Four lanes separated by grass strip converting them into two different roads;
2. Four lanes continuous with no grass strip between.

Hence if the two lanes are joined together and there no gap between the two lanes then traffic should be considered as bidirectional to calculate the combined probability in this case we have two traffic intensities λ1 and λ2 which can be calculated by multiplying the probabilities calculated on each traffic flow (Jaarsma *et al.*, 2006).

$$P_a = e^{-\lambda 1\left(\frac{Wc\ +\ La}{Va} + \frac{Lc\ +\ Wa\cos(\alpha)}{Vc}\right)} \cdot e^{-\lambda 2\left(\frac{Wc\ +\ La}{Va} + \frac{Lc\ +\ Wa\cos(\alpha)}{Vc}\right)}$$

(Equation 6, Jaarsma *et al.,* 2006)

3.5.2. Angle of Traversing (cos (α))

Predicting the angle at which animal can cross the road with respect to vehicle is not possible. Hence probability of animal death at each traverse angle with correspondence to vehicle should be calculated. But as it is not feasible in the current research to calculate mortality at each traverse angle therefore an estimation of animal mortality due to vehicular collision was carried out at traverse angle of 0, 30, 60, 90, 270, 300 and 330 degrees. The mean was calculated from the all the estimated probability values of angle of traversing. This mean has been assigned as the estimated probability value for the given road segment.

3.5.3. Classifications of the road segments using Traversability equation

Using the Traversability equation the probability for animal kills was estimated. It was divided into three classes (Jaarsma et al., 2007) (see table 3.5 below).

Table 3.5 Estimated probability classes for mortality risk along the A73 highway

	Badger	Roe Deer
Low Probability	<0.3	<0.2
Medium Probability	0.3 – 0.6	0.2 – 0.5
High Probability	>0.6	>0.5

3.6. Prediction of mortality risk locations

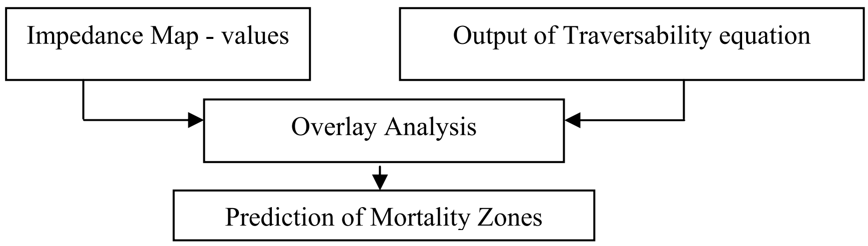


Figure 3.5 Chart showing the overview for prediction of mortality zones

Prediction of animal mortality will depend on impedance map and probability value estimated through Traversability equations. Steps involved in prediction of mortality zones along A73 highway:

1. A map was produced from the results of the Traversability equation from step 3.5.3 and a circular buffer map was overlaid with the impedance raster map.
2. This was done even as if the Traversability equation predicts high mortality of species on a road segment but if the mean impedance values along the road is high then number of animals crossing the road would be less. Hence the number of deaths will also be less. If the Traversability equation has predicted moderate mortality zone along a given part of A73 highway but the impedance is low or zero then the animal crossing will be high increasing the animal mortality by vehicular collisions.

3. Two scenarios using zonal statistics were developed for three types of relative mortality location circles – High mortality risk, medium mortality risk and low mortality risk (See table 1.10).

Table 3.6 Scenario 1: Prediction of Animal Mortality risk zones from Traversability equation and impedance map

Impedance Classes for animal movements	Estimated Probability Classes using Traversability Equation		
	Low Probability	**Medium Probability**	**High Probability**
Low Impedance	Low Risk	High Risk	High Risk
Medium Impedance	Low Risk	Medium Risk	High Risk
High Impedance	Low Risk	Low Risk	Medium Risk

Table 3.7 Scenario 2: Prediction of Animal Mortality risk zones from Traversability equation and impedance map

Impedance Classes for animal movements	Estimated Probability Classes using Traversability Equation		
	Low Probability	**Medium Probability**	**High Probability**
Low Impedance	Low Risk	Medium Risk	High Risk
Medium Impedance	Low Risk	Low Risk	Medium Risk
High Impedance	Low Risk	Low Risk	Low Risk

3.7. Validation of the Model

The comparison of the model output is done with the observed road kills of badger and roe deer from 1990 to 2008. The comparison has been carried out by considering percentage of road kills observed in high, moderate and low mortality risk zones. Similarly present known wildlife crossing have been used to compare their presence in high, medium and low mortality zones. This method is adopted as it is very difficult to say where the road kill will occur as crossing routes will keep on changing. Similarly not all the species will die immediately after collision with vehicles and may die at longer distance from the A73 highway at some other spot. The risk zone comparison also helped to two scenarios for their efficient results.

4. Results

4.1. Results of Expert knoweldge Analysis

The following results show the expert knowledge analysis using two different methods. For impedance values of individual class please see Annexure table 9.2 for badgers and 9.3 for roe deer.

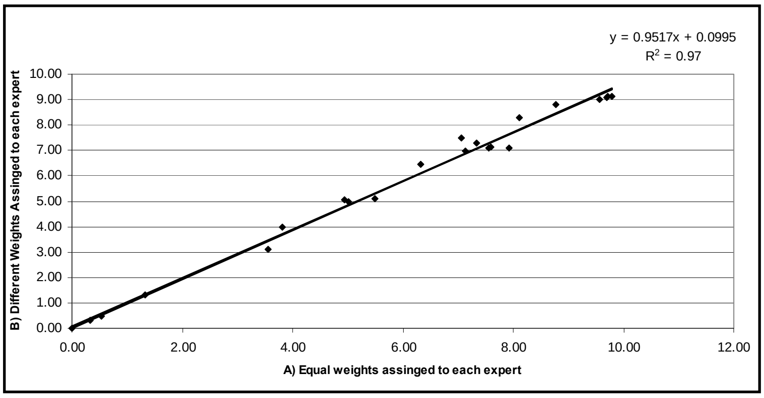


Figure 4.1 Regression analysis, to compare results of expert knowledge using two different methods for badger *(Meles meles)* (p=0.05)
A.) Equal weight to each expert. B) Different weight to each expert

	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6
Expert 1	1.00					
Expert 2	0.90	1.00				
Expert 3	0.88	0.83	1.00			
Expert 4	0.89	0.87	0.86	1.00		
Expert 5	0.90	0.93	0.90	0.94	1.00	
Expert 6	0.86	0.83	0.82	0.86	0.88	1.00

Table 4.1 Correlation analysis results for each of experts view on impedance for badger *(Meles Meles)* movements

The results obtained using regression analysis for badger *(Meles meles)* (See Annexure Table 9.2) showed that method 1 and 2 have 97% correlation at p = 0.05 (See fig 4.1). This shows that there is no significant difference for impedance values between method 1 and method 2. Hence the results obtained by analysis method 2

(Different weights assigned to each expert) was selected as some of the selected experts have worked extensively on badger movements along the roads and have given specific reasons for assigning the impedance values to a particular landcover. High correlation was also observed between every expert for evaluating the impedance effect on badger *(Meles meles)* movements (See table 4.1).

Similar to badger the results obtained for roe deer *(Capreolus capreolus)* using two different methods for expert knowledge did not show significant difference (See table 4.2). The regression analysis showed that analysis method 1 and method 2 have 99% correlation at p=0.05. This suggests no significant difference in results obtained from two methods. In order to assess the expert views correlation analysis was performed which showed high correlation between all the expert views to assign impedance values for the roe deer *(Capreolus capreolus)* (See table 4.2). Hence impedance value obtained from method 2 have been used for further analysis as some of the experts have given comments for assigning the impedance values and also helped in deciding the classification of impedance values.

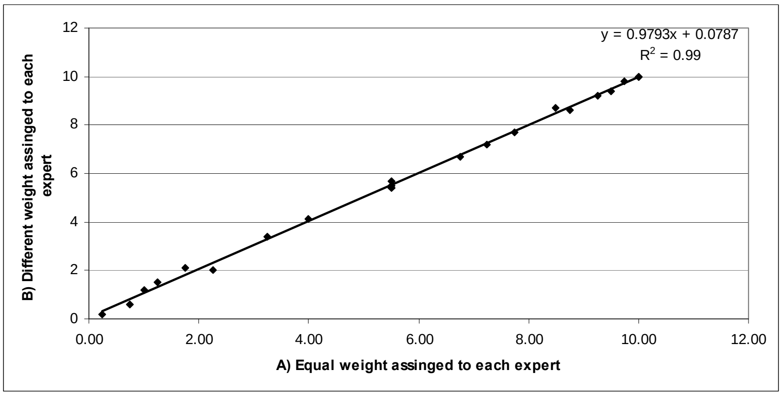


Figure 4.2 Regression analysis, to compare results of expert knowledge using two different methods (p=0.05)
A.) Equal weight to each expert. B) Different weight to each expert

	Expert 1	Expert 2	Expert 3	Expert 4
Expert 1	1.00			
Expert 2	0.92	1.00		
Expert 3	0.91	0.88	1.00	
Expert 4	0.80	0.88	0.93	1.00

Table 4.2 Correlation analysis results for each expert view on impedance for roe deer (Capreolus capreolus) movements

All the experts had nearly same view for high impedance effect on movements of badger and roe deer in landcover classes such as roads with fence, human settlement (rural and urban), and industrial areas. While a slight difference was observed in the landcover types which allow the badger and roe deer movements such agricultural fields, waste disposal sites and roads without fence. According to experts the provincial roads and the highway with fence have high impedance value of 9.56 and 9.79 respectively for badger (For method 2 see annexure table 9.2*)*. While for roe deer provincial roads and highways with fence have high impedance value of 9.20 and 9.50 (See fig. 4.3) (For method 2 see annexure table 9.3).This is followed by human settlement with 0 meter buffer having impedance value of 8.60 and 50 meter buffer having impedance value of 7.06 for badger. While for roe deer human settlement with 0 meter buffer has impedance value of 10 and 50 m buffer has impedance value of 6.7. The industrial areas have higher impedance upto 50 meter buffer and then reduced at 100 meter buffer for both badger and roe deer. The low impedance values were assigned to local roads having less traffic, agriculture, grassland for both badger and roe deer. No impedance (0) was assigned to forest patches for badger while for roe deer 0.25 impedance values for forest was observed due human disturbance.

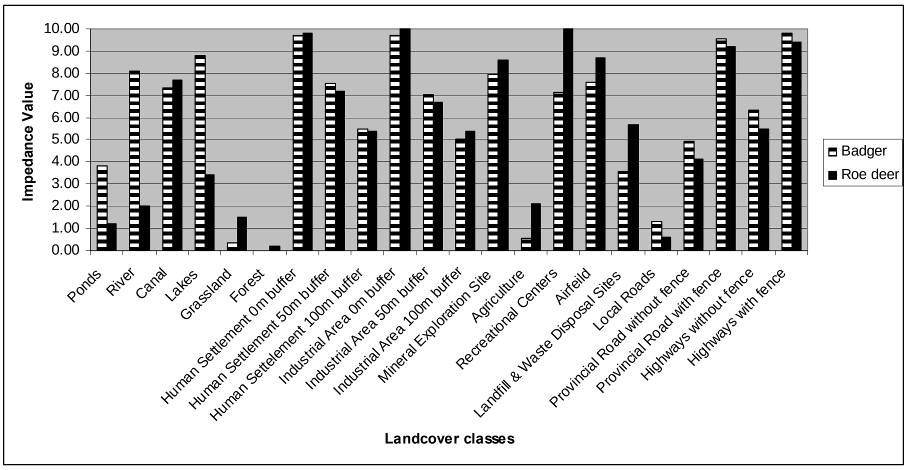


Figure 4.3 Impedance values from method 2 for all landcover classes for badger and roe deer

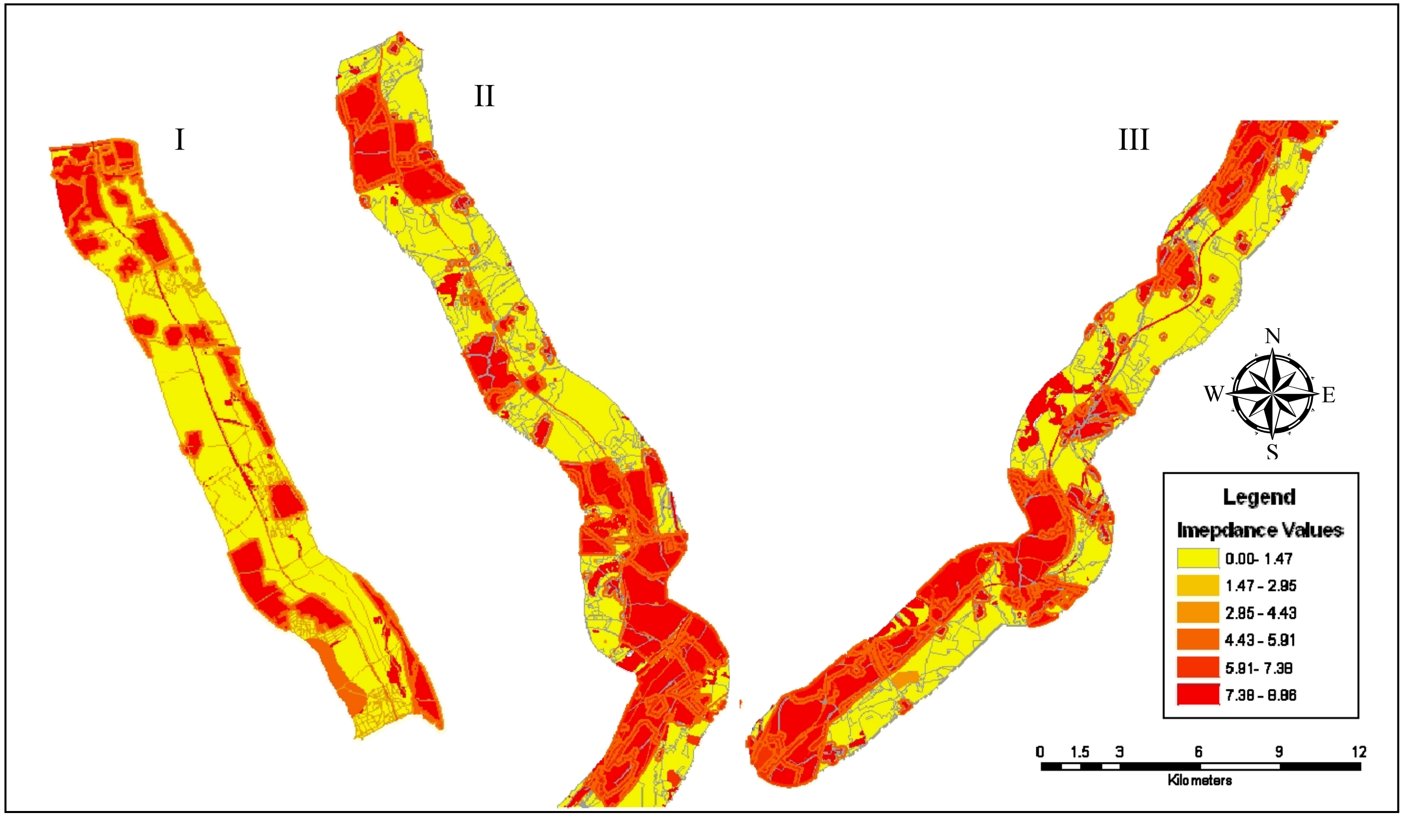


Figure 4.4 Impedance map for badger (Meles meles) using method 2 (Different weight for each expert)
I: Northern section, II: Central section and III: Southern section of the A73 highway

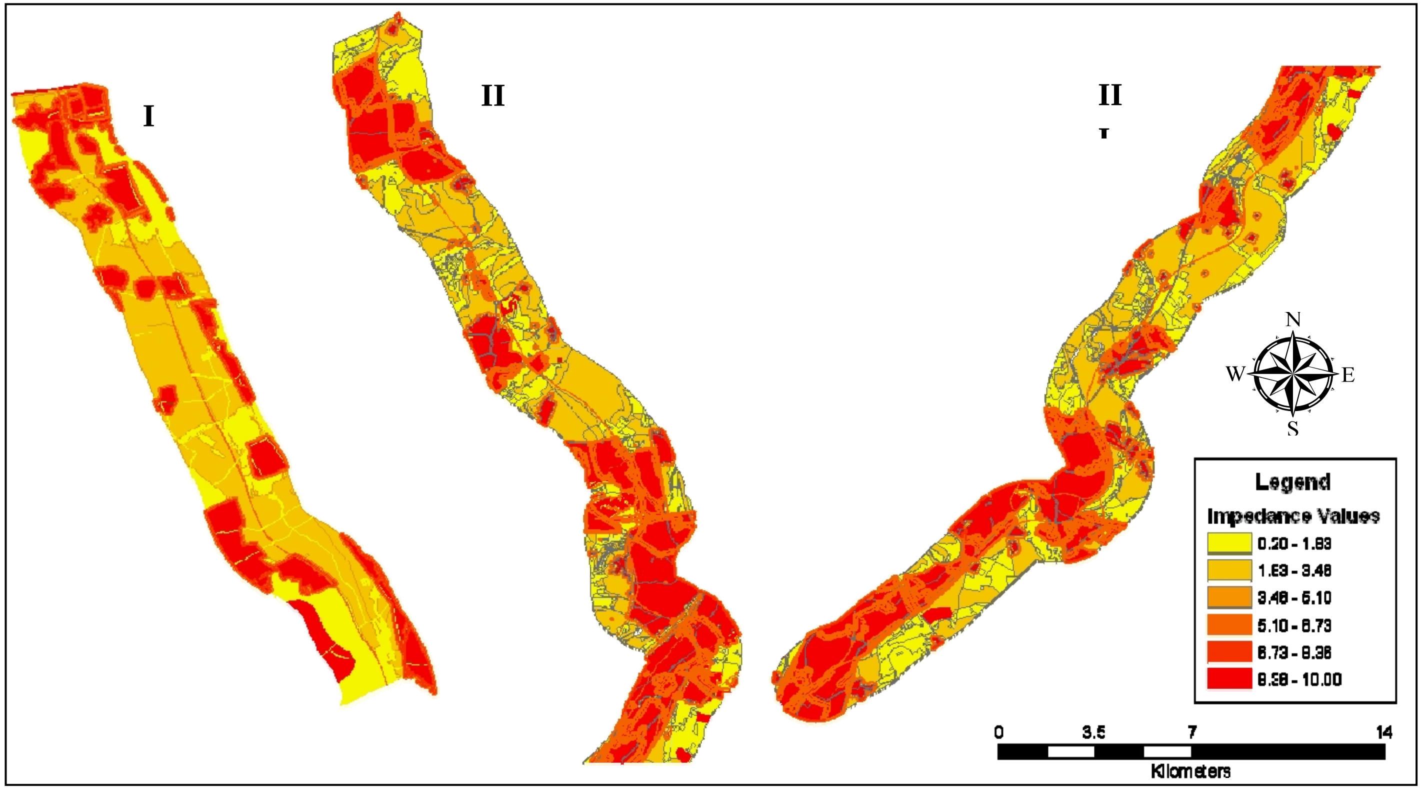


Figure 4.5 Impedance map for roe deer (Capreolus capreolus) using method 2 (Different weight for each expert)
I: Northern section, II: Central section and III: Southern section of the A73 highway

4.1.1. 3 – Dimensional mapping of Impedance effect along the A73 highway

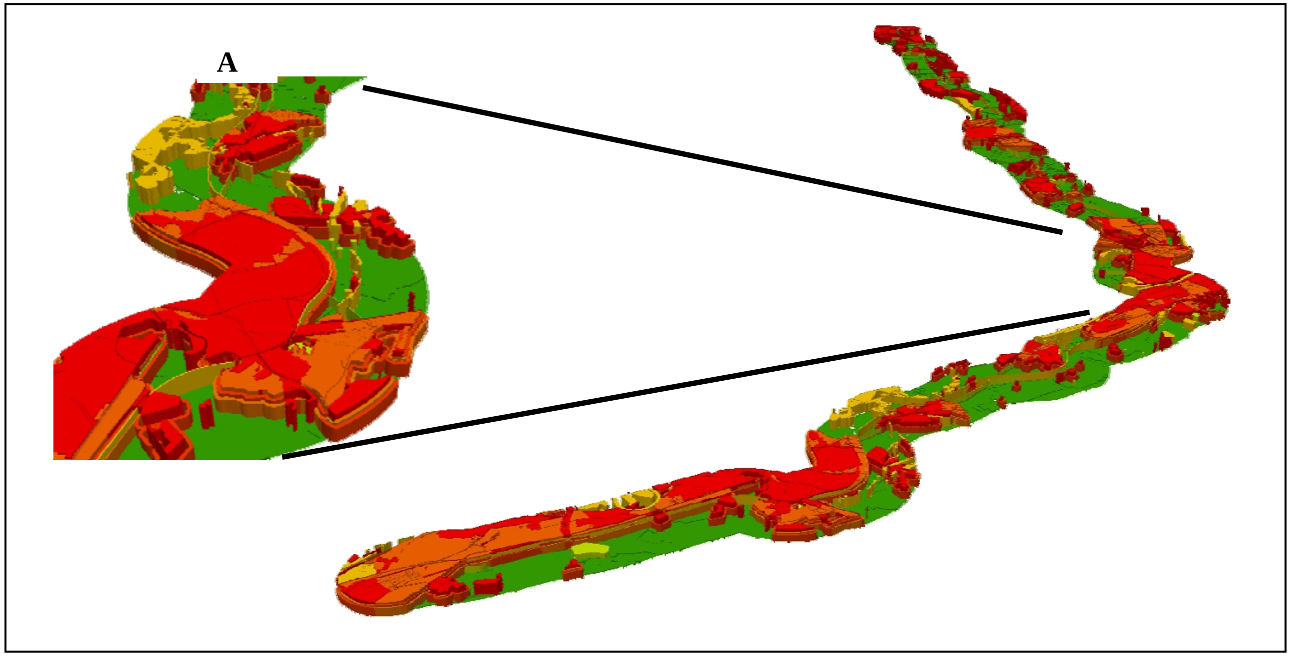


Figure 4.6 3-dimensional Impedance map for badger (Meles meles) using method 2 (Different weight for each expert) A) Close up of the 3D impedance map

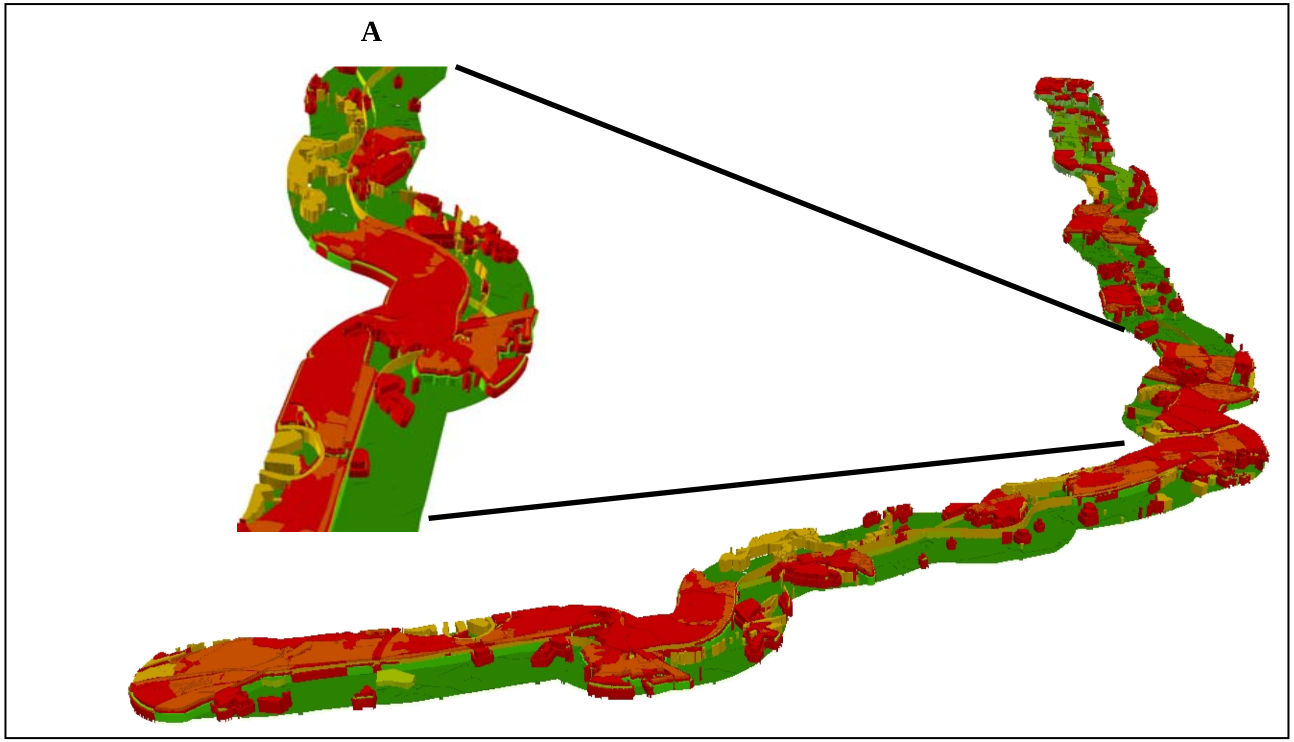


Figure 4.7 3-dimensional Impedance map for roe deer (Capreolus capreolus) using method 2 (Different weight for each expert) A) Close up of the 3D impedance map

4.1.2. Results for impedance classes using zonal statistics

Results for Impedance classes using zonal statistics for badger *(Meles meles)*

Along the A73 highway 11% of the zones (circular buffer of 250m radius) prove to be of high impedance for the badger movement while 48% of zones prove to be of low impedance allowing high mobility. The higher impedance was observed near the zones consisting of water bodies, canal, human settlements and industrial areas. Medium impedance was observed in 23% of zones which mainly covered two or three mixed landcover classes. Nearly 16% of the zones were unpredicted due to standard deviation of more than 3 making it difficult to assign impedance class (As the mean was crossed checked so as to confirm that + or – standard deviation will not affect the impedance classes). The map of circular impedance zone with four different classes is attached in annexure fig 9.4.A and table 4.3

Table 4.3 Showing the results of zonal statistics for badger using Impedance map for prediction of different impedance zones along the A73 highway

Impedance classes	Total
High Impedance	21
Medium Impedance	42
Low Impedance	86
Unpredicted	29
Total Circular Buffers	178

Results for Impedance classes using zonal statistics for roe deer

For roe deer along the A73 highway, 41% of the zones have low impedance allowing high mobility for foraging, migration and breeding. While only 20% of the zones along the A73 highway cover higher impedance, which mainly includes human settlement, industries, canal and recreational centers, 15% of the zones were unpredicted. (See table 4.4 and Annexure fig 9.5 B)

Impedance classes	Total
High Impedance	36
Medium Impedance	41
Low Impedance	74
Unpredicted	27
Total Circular Buffers	178

Table 4.4 Showing the results of zonal statistics for roe deer using Impedance map for prediction of different impedance zones along the A73 highway

4.2. Results of travesability equation

The results of Traversability equation for animal movement's covers traffic intensity flow, estimated probability for mortality at different traverse angle and predicting the probability associated with road segment for mortality of badger and roe deer.

4.2.1. Traffic flow results

The traffic flow along A73 highways varies from maximum of 31475 vehicles per day in year to minimum of 8756 vehicles per day in a year The average traffic intensity per hour was observed to be maximum of 1384 vehicles/ hour and minimum as 525 vehicles / hour vehicles per hour (See fig. 4.8).

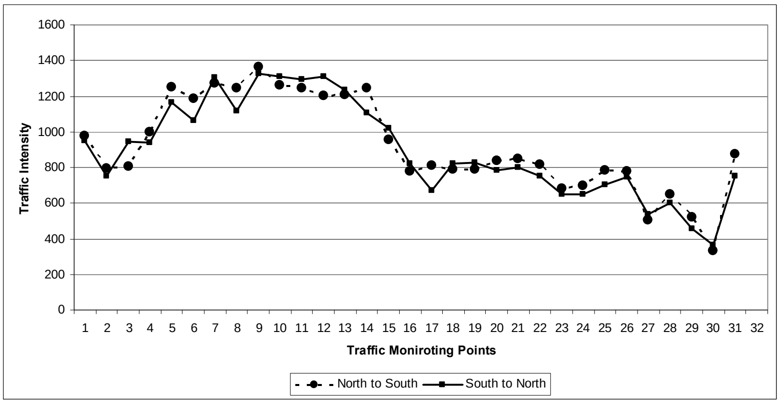


Figure 4.8 Average per hour traffic flow along the A73 highway North – South and South – North Traffic flow.

4.2.2. Results for Traversability angle of species against estimated probability of animal mortality

Maximum estimated probability (Da) for mortality of badger and roe deer was observed if the animal traverses the road at 30 degrees and this was followed by zero degrees which is perpendicular to the vehicle (See Fig 4.9 and 4.10). The least estimated probability of animal mortality was found at 300 degrees. But it is not possible to predict the traverse angle of animal at which it would cross the road. Hence average estimated probability of the all the angles has been considered to predict the threat of mortality posed by a segment of the road. The results were same for South – North as there is not much difference in the vehicular intensity on both the sides of the roads.

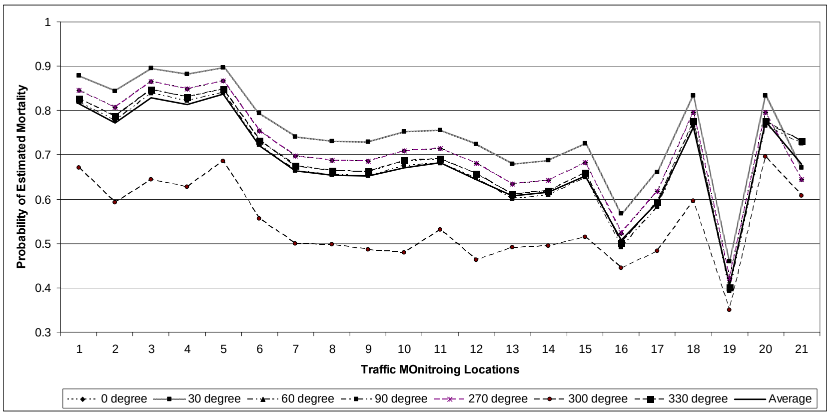


Figure 4.9 Estimated probability for badger (Meles meles) mortality at different traverse angles

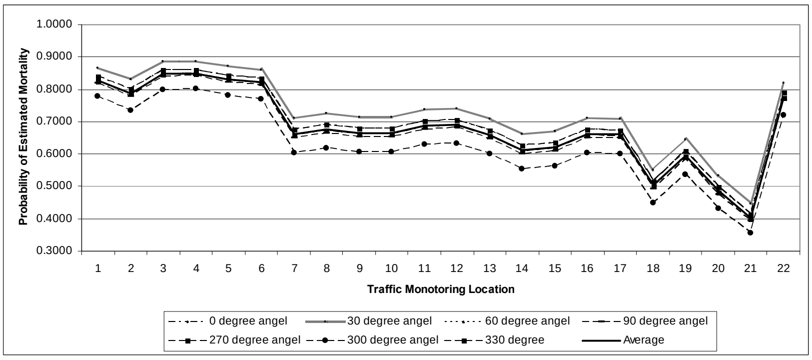


Figure 4.10 Estimated Probability for roe deer (Capreolus capreolus) Mortality at different traverse angels

4.2.3. Results for vehicular intensity against the estimated probability for mortality of badger and roe deer along the A73 highway

It was observed that mortality rate of badger and roe deer increases with increase in the traffic intensity. The estimated probability (Da) for both badger and roe deer shows sharp increase in mortality from 371 to 622 vehicles/ hour (See fig 4.11). From 662 to 850 vehicles/hour the increase in mortality of badger and roe deer was steady and grew slowly. But from 860 to 1120 vehicles /hour mortality of badgers and roe deer increased sharply and then continued to rise steadily there after uptill 1360 vehicles/ hour.

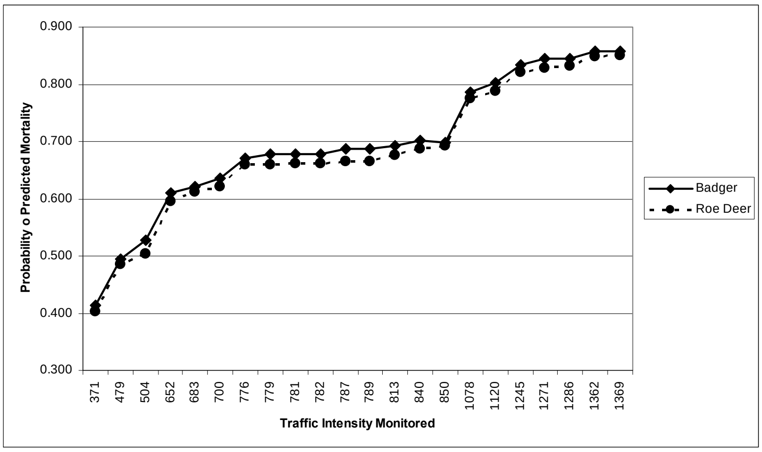


Figure 4.11 Estimated Probability for mortality of Badger & Roe Deer against the traffic intensity data.

4.2.4. Estimated probability for mortality of badger and roe deer considering two road scenarios

Two scenarios are compared for the road widening effects on the mortality of badger and roe deer:

1) 4 lanes continuous;
2) 4 lanes divided by grass strip or by different landcover.

The results showed that continuous 4 lanes poses higher probability for badger and roe deer mortality due to vehicular collision than 4 lanes separated by the other landcover or grass strip. Wherever four lanes were continuous the estimated probability for badger mortality was more than 0.7 and reaching a maximum probability of 0.97. If the road was separated into 2x2 lanes then estimated probability of badger mortality varied between minimum of 0.5 to a maximum of 0.7. Similarly, for roe deer the estimated high probability for mortality on continuous four lanes is rising above 0.8 and with a maximum of 0.98 (See fig 4.12 and 4.13). In case of four lanes separated into 2x2 the estimated probability varied from minimum probability of 0.4 to a maximum of 0.8.

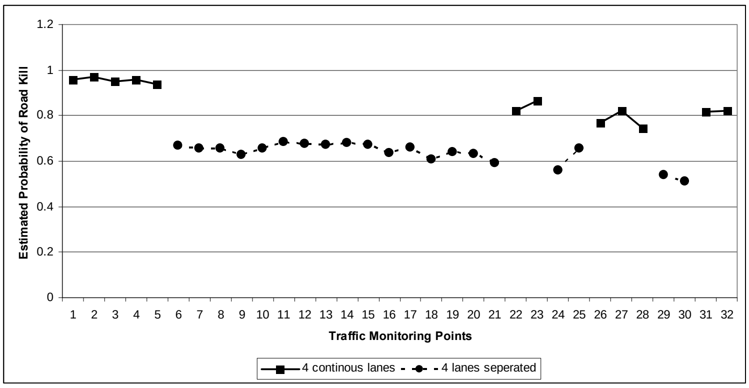


Figure 4.12 Comparison between estimated probabilities for two road widening scenarios for Badger (Meles meles) mortality along the A73 highway.

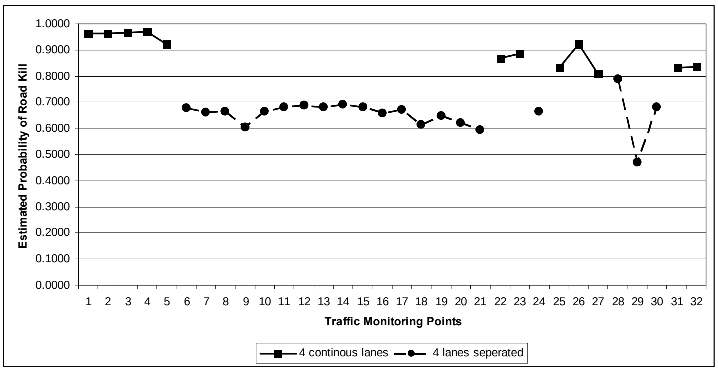


Figure 4.13 Comparison between estimated probabilities for two road widening scenarios for roe deer (Capreolus capreolus) mortality along the A73 highway.

4.2.5. Final output of Traversability equation for mortality of badger and roe deer along the A73 highway

The estimation of probability for mortality of roe deer and badger to both road scenarios has been developed in graphical and map format.

Estimated Probability for mortality of Badger along the A73 highway:

The predicted badger mortality varies from maximum of 0.97 and minimum of 0.57. The maximum predicted rate has increased when we consider two scenarios of roads. Considering the probability rate produced through Traversability equation the A73 highway posses medium and high risk for badger mortality. In the current scenario for badger only 18 kms of road pose medium mortality risk to badger populations while rest 92 kms proves to have high mortality risk (See fig 4.14). As the traffic intensity is high along the A73 highway no low risk segments along A73 highway were present. (See map in Annexure 9.5A)

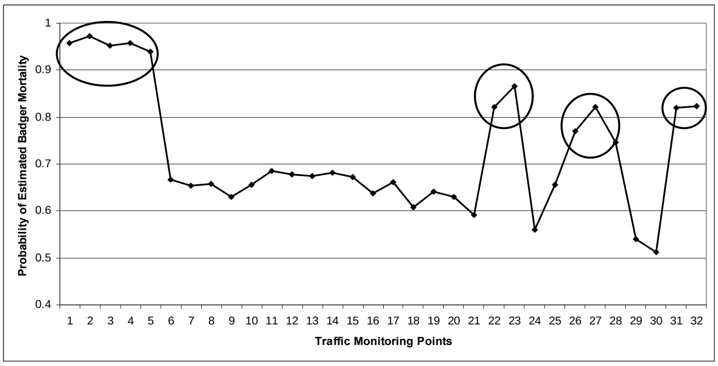


Figure 4.14 Final result of the estimated probability for badger mortality along A73 highway considering two road scenarios. (Circles indicate 4 continuous lanes)

Estimated Probability of Roe Dear mortality along A73 highway:

For roe deer considering two road widening scenarios along the A73 highway, maximum estimated probability of roe deer kill is 0.97 and minimum is 0.46. For current roe deer scenario only 12 kms of the A73 highway proves to be of medium risk for mortality while rest 98 kms of road poses high risk (See fig 4.15). No low risk mortality segments were present for roe deer. (See map in Annexure 9.5B)

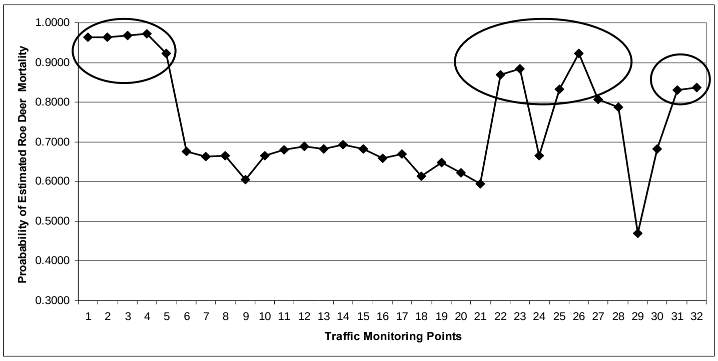


Figure 4.15 Final result of the estimated probability for roe deer mortality along A73 highway considering two road scenarios. (Circles indicate 4 continuous lanes)

Observed mortality data of badger and roe deer for two road scenarios:

The results from analysis of observed mortality data showed that nearly 42% badger mortality and 41% of roe deer mortality occurred along the A73 highway on 4 continuous lanes. Almost 58% of badger road kill and 59% of roe deer road kill was observed on 4 lanes divided by grass strip (2x2). Considering the length of continuous 4 lanes (36 kms) the percentage of the road kill is sufficiently high in comparisons with 2 separate lanes (74 kms) (See table 4.5.).

Table 4.5 Actual mortality numbers observed on the two scenarios of road widening for badger and roe deer species along the A73 highway

	4 continuous Lanes	4 lanes separate (2 x 2)	Total Mortality
Badger Mortality	191	260	451
Roe Deer Mortality	69	98	167

4.3. Predicting the mortality zones

Prediction of the relative mortality locations for badger and roe deer was done using the impedance map and probability values produced through the Traversability equation. Two scenarios were considered for prediction of the mortality zones of badger and roe deer species.

Prediction of Mortality Zones for Badger *(Meles meles)* along A73 highway

Scenario 1 predicted 58%, 19%, 5% as high, medium and low mortality risk zones respectively and 16% unpredicted zones. Scenario 2 predicted 43%, 16%, 24% as high, medium and low mortality risk zones respectively and 16% is in unpredicted zones. Scenario 1 over-estimated 15% of high mortality zones and 3% of medium mortality zones over scenario 2, while scenario 2 over-estimated low mortality zones by 19% over scenario 1 (See Table 4.6 for actual numbers).

Table 4.6 The Predicted Mortality Areas for Badger in circular 250m radius buffer along the A73 highway.

Predicted Zones	Scenario 1	Scenario 2
High Mortality Zone	105	77
Medium Mortality Zone	34	30
Low Mortality Zone	10	42
Unpredicted Circles	29	29
Total	178	178

Prediction of Mortality Zones for roe deer *(capreolus capreolus)* along A73 highway

Scenario 1 predicted 57%, 24%, 2%, as high, medium and low mortality risk zones respectively with 15% unpredicted zones due to high standard deviation. Scenario 2 predicted 39%, 17%, 26% as high, medium and low mortality risk zones respectively with 15% unpredicted zones, which is due to high standard deviation. Scenario 1 over-estimated high mortality zones by 18% and medium mortality risk zones by 7% as compared to Scenario 2. Whereas Scenario 2 over-estimated nearly 24% of low mortality zones as compared to scenario 1 (See Table 4.7).

Table 4.7 The predicted mortality areas for roe deer in circular buffer of 250m radius along the A73 highway.

	Scenario 1	Scenario 2
High Mortality Zone	103	71
Medium Mortality Zone	44	32
Low Mortality Zone	4	48
Unpredicted Circles	27	27

4.4. Validation of predicted relative mortality risk zones

4.4.1 Validation of relative mrotlaity locations for badger *(Meles meles)*

Validation for both scenarios was done using mortality data. Following are the results for the comparative analysis

Scenario 1

Table 4.8 ***Actual mortality data with predicted relative mortality zones***

Predicted Classes	**Number of Predicted Zones**	**Observed Kills**	**Percentage**
High risk of mortality	105	386	84%
Medium risk of mortality	34	25	6
Low risk of mortality	9	2	0.5
Unpredicted	29	44	10
	177	457	

Table 4.9 Mortality of badger per circle in scenario 1 for predicted zones Vs observed badger mortality data

Road kill observed per circle	High Mortality	Medium Mortality	Low Mortality
0	36%	76%	77%
1 to 3	24%	56%	23%
4 to 6	22%	0%	0%
> 6	16%	0%	0%

Scenario 2

Table 4.10 Actual Mortality with predicted mortality zones

Predicted Classes	Number of Predicted Zones	Observed Kills	Percentage
High risk of mortality	78	327	71%
Medium risk of mortality	41	60	13%
Low risk of mortality	29	26	6
Unpredicted	29	44	10
	177	457	

Table 4.11 Mortality of badger per circle in scenario 2 for predicted zones Vs observed badger mortality data

Road kill observed per zone	High Mortality	Medium Mortality	Low Mortality
0	20%	32%	51%
1 to 3	18%	41%	45%
4 to 6	16%	20%	0%
> 6	44%	4%	4%

Both scenarios were able to predict the mortality zones for badgers. Table 4.8 and 4.10 shows that scenario 1 can predict mortality areas more accurately than scenario2. But if we look at table 4.9 and 4.11 then interesting results strikes out. Scenario 1 has predicted 105 high mortality risk circles with 84% observed kills. While on the other side scenario 2 requires only 78 high mortality zones with 71% of its prediction coinciding with mortality data. Also table 4.9 & 4.11 shows that 36% of high mortality risk zones in scenario 1 have reported “0” badger deaths. While scenario2 only 20% predicted high mortality risk zones have reported “0” badger deaths. Both the scenarios have extrapolated the high mortality zones but comparatively scenario 2 has edge over scenario 1. Also if we look at the class intervals scenario 2 has predicted 44% of high mortality zone having atleast 6 dead badgers while scenario 1 was able to able to have only 16% of observed road kill above 6.

4.4.2 Validation for relative mortality locations for roe deer

Scenario 1

Table 4.12 Actual mortality with predicted mortality zones for roe deer

Predicted Classes	Number of Predicted Zones	Observed Kills	Percentage
High risk of mortality	103	83	49%
Medium risk of mortality	44	51	30%
Low risk of mortality	4	14	8%
Unpredicted	27	20	12%
	178	168	

Table 4.13 Mortality of roe deer per circle in scenario 1 for predicted zones vs observed roe deer mortality data

Road kill observed per zone	High Mortality	Medium Mortality	Low Mortality
0	59%	38%	0%
1 to 3	37%	57%	50%
4 to 6	3%	4%	25%
>6	0%	0%	25%

Scenario 2

Table 4.14 Actual mortality with predicted mortality zones for roe deer

Predicted Classes	Number of Predicted Zones	Observed Kills	Percentage
High risk of Mortality	71	73	43%
Medium risk of Mortality	32	43	25%
Low risk of Mortality	48	32	19%
Unpredicted	27	20	11%
	178	168	

Table 4.15 Mortality of roe deer per circle scenario 2 for predicted zones vs observed roe deer mortality data

Road kill observed per zone	High Mortality	Medium Mortality	Low Mortality
0	32%	0.4%	56%
1 to 3	44%	53%	43%
4 to 6	20%	6%	0%
>6	0%	0%	0%

The mortality of roe deer is comparatively less than that of badger. The two scenarios used to predict mortality locations along the A73 highway had slight differences in their results. Although tables 4.12 and 4.14 indicate that scenario 1 gives more adequate results than scenario 2, tables 4.13 and 4.15 show that scenario 1 has over-estimated the high mortality risk zone. This is well proved as nearly 59% of the high mortality risk zones have not yet reported any roe deer mortality from vehicular collision. While scenario 2 has predicted 71 high mortality areas with 43% coinciding with observed mortality data. Also roe deer being more agile its mortality varies widely along the A73 highway. But scenarios 2 has predicted high mortality zones with sufficient evidence as nearly 43% of the badger kills between 1 to 3 are coinciding with the high risk zone.

Hence considering the entire analysis results, scenario 2 is efficient in predicting the mortality risk zones and is able to divide them into appropriate categories of high, medium and low mortality risk zones for badger and roe deer. Hence it is further used for validation with wildlife crossings and mapping (See fig 4.16).

4.5. Validation with Ecological Connections (Networks):

Validation of predicted mortality zones was also done with current and proposed ecological connections such as wildlife overpass, underpass and ecoduct. Most of the ecological connections are coinciding with high risk zones predicted by the model. This suggests that the current model is capable of predicting mortality locations. This will assist in developing mitigation measures such as wildlife crossing (See fig. 4.18). Two ecological passes for roe deer were identified in high risk mortality zone predicted by the model. Similarly one proposed ecological corridor in Province of Brabant also was identified in the high risk zone predicted by the model (See fig 4.18C). Also, by using impedance zones the model predicted those patches of forest which could be fragmented and hence require development of ecological networks.

Table 4.16 Predicted mortality risk zones comparison with number of wildlife crossings for Scenario 2

Mortality risk zones	Number of wildlife crossings
High mortality risk zone	32
Medium mortality risk zone	7
Low mortality risk zone	1

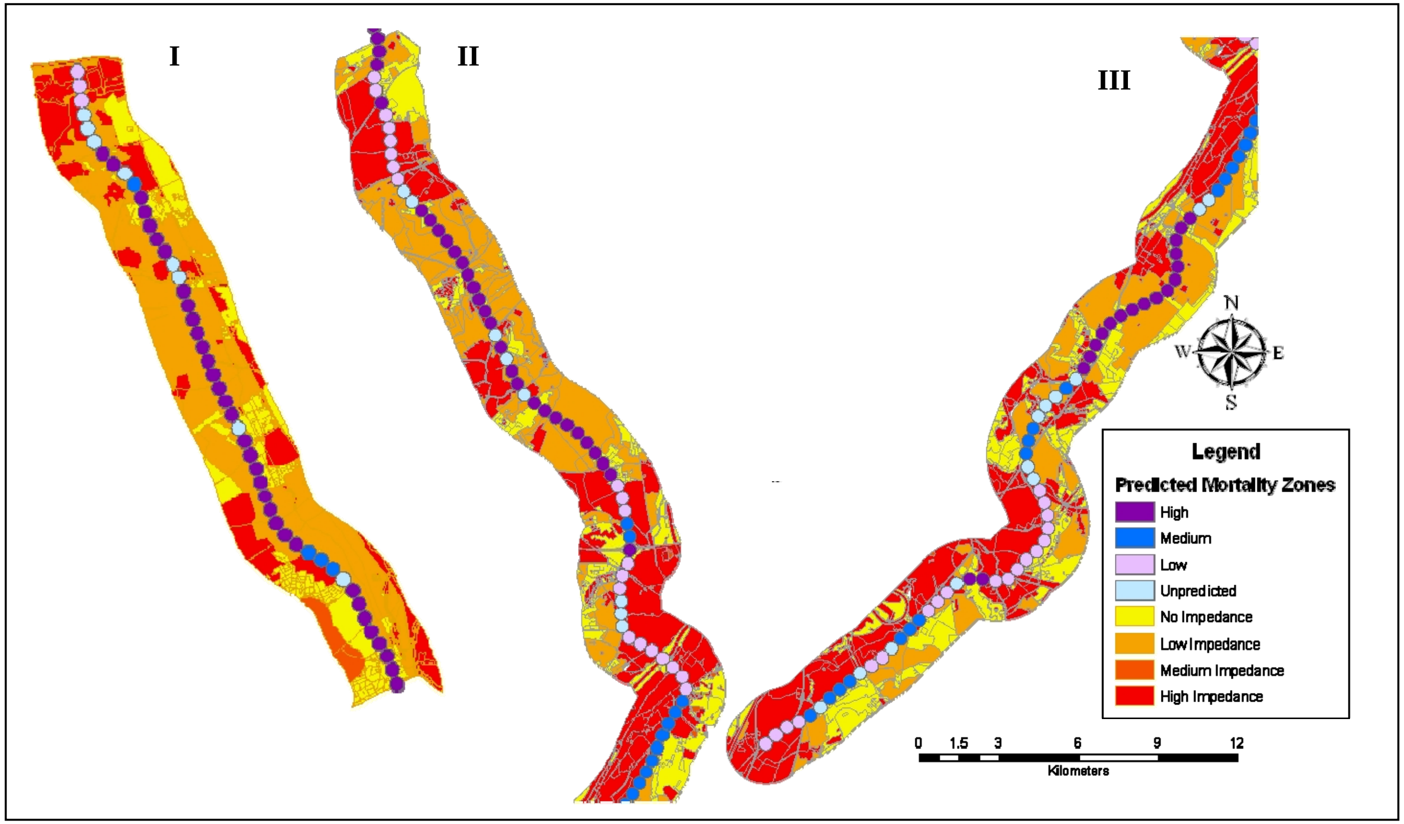


Figure 4.16 Predicted relative mortality risk location along the A73 highway for badger using scenario 2 I) Northern Section II) Central Section III) Southern Section of the A73 highway

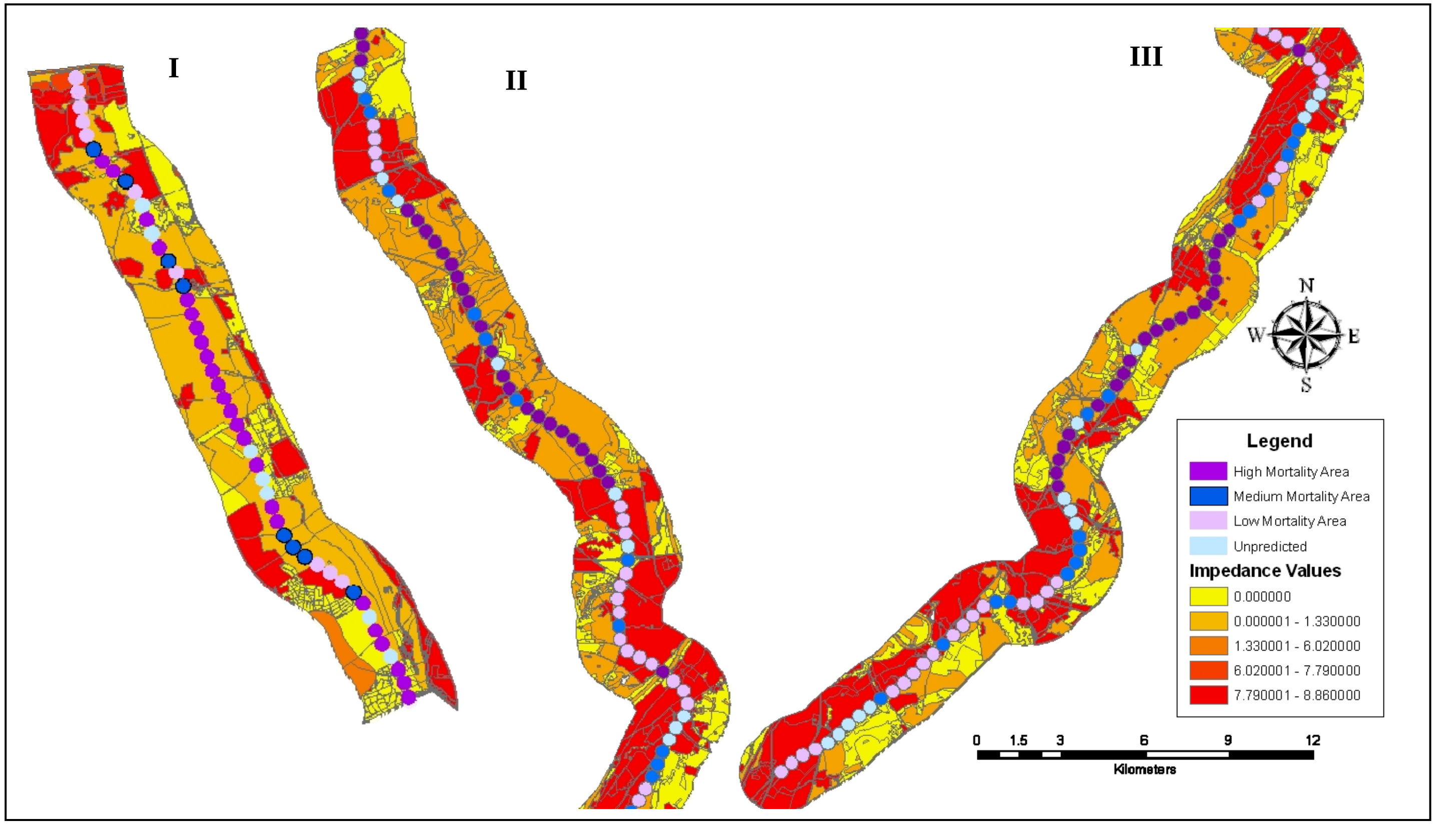
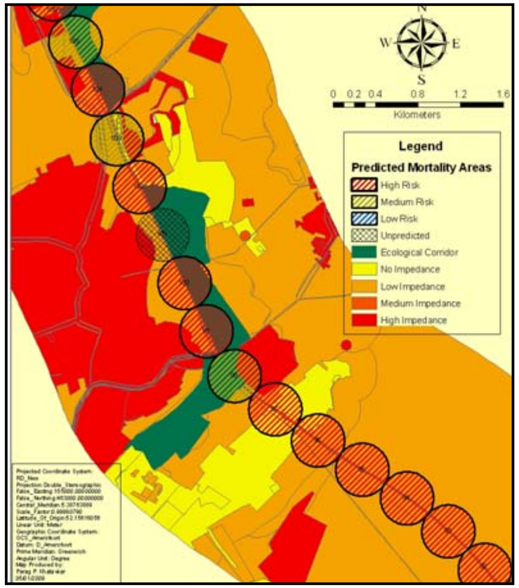


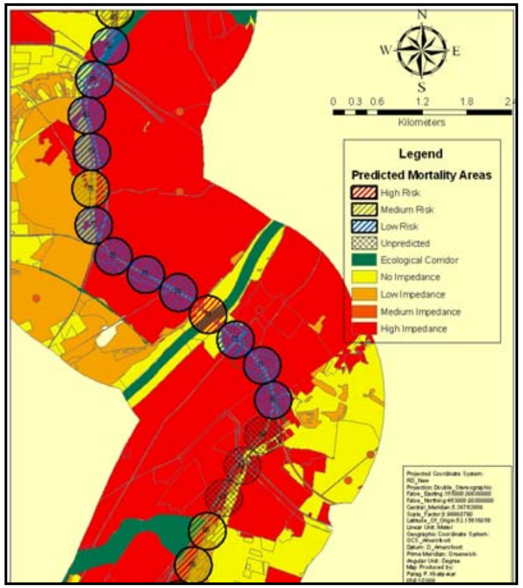
Figure 4.17 Predicted relative mortality risk location along the A73 highway for roe deer using scenario 2 I) Northern Section II) Central Section III) Southern Section of the A73 highway

Figure 4.18 Predicted relative mortality locations with the present wildlife crossings, ecoducts and ecological corridors



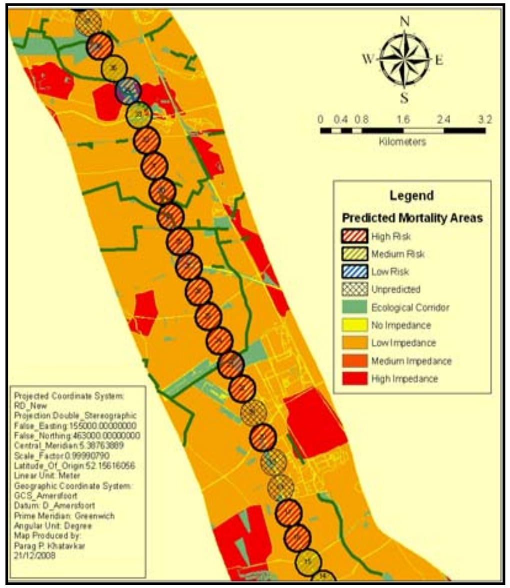
Roe deer over passing through the predicted high mortality risk zone

A



Wildlife crossing passing through the predicted high mortality risk zone

B



Ecological corridors passing through the predicted high mortality risk zone

C

5. Discussuion

5.1. Impedance as a function of landocver on movements of badger *(Meles meles)* and roe deer *(Capreolus capreolus)*

Modelling the impedance effects on movements of badger and roe deer is vital for identifying probable mortality locations along highways. The impedance effect on movements of badger and roe deer differed for certain landcover classes along the A73 highway such as agriculture, rivers, lakes and recreational centers. Each species has a specific interaction with the landcover type thus developing different impedance values. For example, roe deer has an impedance value of 2.3 in agricultural fields while badgers have 0.53 (See figure 4.3 and annexure table 9.2, 9.3). Though roe deer are often observed in the agricultural fields, experts reported that local farmers usually try to scare them away using dogs or by making noise. Similarly, use of the modern machines for ploughing and harvesting the fields affects the free movement of roe deer in the agricultural fields. On the other hand badgers being nocturnal animals are generally not disturbed by human activities such as machines and dogs. However, badgers are threatened as their "setts" may get destroyed by human activities. Lakes and rivers pose higher impedance (8.80 and 8.30 respectively) for badger as they are not known to swim well. For both species higher impedance is observed for industrial area and human settlements including a 50m buffer. The impedance is mainly developed due to human disturbance.

Waste disposal sites prove to have low impedance for badger movements. According to experts waste disposal sites attract badgers for food. However, most of these sites are well managed and have lesser importance as feeding grounds. For roe deer waste disposal sites produces medium impedance as garbage dumping is generally at night and early morning to reduce the traffic congestion, while in fringe areas garbage collection is during day. Hence waste disposal sites have human disturbance for 24 hours but may attract roe deer for food (No expert had observed the roe deer feeding in the waste disposal site).

Impedance modelling proves to be very important in this research. In the past most researchers have vehemently contended that roads and transportation services restrict animal movements (Coffin, 2007, Eigenbrod *et al.*, 2008, Finke *et al.*, 2008, Geneletti, 2006). However expert knowledge proves that roads themselves have low and medium impedance for badger and roe deer movements, respectively. For example, local roads have low impedance value of 1.32 for badger and 0.6 for roe deer, while provincial roads have medium impedance value of 4.95 for badgers and 5.5 for roe deer. Even the A73 highway does not have a full barrier effect, but instead also produces a medium impedance effect for badger and roe deer movements with values 6.33 and 5.5 respectively. Only fenced roads prove to be absolute barrier.

However, experts felt that even this may not always be the case as badgers have a habit to dig below the fencing. This has been observed in certain locations in the Netherlands and also in the UK (Bekker *et al.*, 1995, Clarke *et al.*, 1998). Experts also have commented that if the fencing is less than 5 meters then roe deer tend to jump over it proving that the fence is not an absolute barrier. Hence in the impedance model it is evident that unfenced roads do not pose a barrier for animal movements. Experts were unable to assign an impedance value for traffic intensity as most of the experts felt that an animal will cross the road if required regardless of the road traffic intensity.

The concepts of impedance and barrier are often used interchangeably and the chances of road kill are specified as impedance. However this research proves that impedance and road kill are independent concepts and therefore should not be mixed. Impedance defines the resistance to animal movement in a particular landcover and does not decide the chance of animal being killed in the vehicular collision. The possibility of a road kill is not determined in any impedance class as animal movements are not entirely predictable. But high impedance areas will have lesser chance of animal movement thereby posing a lesser possibility of road kill.

During meetings with experts, local agencies and government officials it was observed that road kill was perceived as impedance. The general misconception is that higher road kill represents higher impedance for animal movements. However, we contend that higher road kill represents lower impedance as the animal is trying to traverse through a particular segment of the road irrelevant of traffic speed, intensity and road characteristics. If the animal is killed by vehicular collision then it represents the probability of road kill. Hence it is imperative to understand the difference between impedance effect and road kill; both must be treated separately.

Habitat fragmentation due to road development has a major impact on animal movements due to corridor loss. Several studies present methodologies for identifying corridor loss but these are not sufficient for understanding animal movements (Alexander *et al.*, 2000, Austin *et al.*, 2005, Grift *et al.*, 2006). Change detection can help in identifying the removal of corridors or forest cover. However, this does not necessarily imply obstruction to animal movements. Impedance modelling will help to understand the impacts of landcover change on animal movement if the previous landcover is replaced by some other. In India some case studies describe the removal of wildlife corridor due to agricultural encroachment. Still wild animal species such as the elephants and deer tend to use the agricultural fields for their migration and feeding grounds thus causing human-wildlife conflicts (Rajvanshi A *et al.*, 2001).

Habitat fragmentation due to road development also shows cumulative effects. Wildlife habitats and wildlife corridors if replaced by landcover producing higher impedance values will lead to isolated populations. Recent studies in Central Europe and The Netherlands have shown lower genetic exchange in roe deer populations which are isolated due to changing landscape structures (Wang *et al.*, 2002, Coulon *et al.*, 2006). The impedance modelling methodology provides a key to identify isolated populations and also predict and mitigate the possible areas of future isolation.

The selection of indicator species is critically important for the application of the impedance models. For this research, badger and roe deer were selected with the intention of extending the use of this model to other countries around the world having similar species. Badger represents burrowing social species - nocturnal and omnivorous. Badger represents species such as mongoose *(Herpestes javanicus)*, civet cat *(Viverricula Indica)* and porcupine *(Hystrix indica)*. Similarly roe deer represents larger mammal groups displaying diurnal behaviour. Roe deer shows both solitary and social behaviour as well as a tendency to approach agricultural fields. Many deer varieties such as spotted deer *(Axis axis)*, sambar *(Cervus unicolour)*, barking deer *(Muntiacus muntjak)* show similar behaviour to roe deer.

The selection of experts is equally important. The chosen experts should have excellent knowledge of species habitat, their interaction with different landcover types and species movements in the selected study area. For current research correlation analysis was done for each expert. Depending upon selected species and expert knowledge each species should have an individual impedance model. Krisp, (2004) proposed a methodology to study habitat fragmentation using expert knowledge. During his research 8 different species were selected and overall mean value was calculated for all the species. However, this method poses a major disadvantage as every species has different interaction and different impedance levels depending upon species' characteristics. Hence the methodology developed in this research proves to be more effective by being more representative of each group of species.

5.2. Significance of 3 – dimensional impedance mapping

In order to conserve species, reduce road kills and prevent habitat fragmentation, involvement of government officials, local people and environmentalists is necessary. Not everyone will understand the concept of impedance on movement of animals. Use of modern GIS techniques will help simplify the concepts to ensure that all agencies involved in developing ecological corridors understand the concept of impedance and are able to further explain it to local people for public participation. It was observed by experts that fencing along the road side, ecological corridors, and ecoducts were often misused by public and also sometimes not properly maintained. In order to ensure that everyone understands the importance of wildlife mitigation measures it necessary that they understand the problems faced by wildlife in their movement. The values gained from the experts were converted into an impedance map and then projected in ArcScene to produce the 3-dimensional impedance map (Fig 4.6 and 4.7). The visualization of impedance along-with wildlife movements makes it more appealing. Such maps can be used for simplifying the understanding of road development and its impact on wildlife movements. Similarly the 3-dimensional impedance map also helps to visualize and identify access to animal movements, ecological corridors and bottlenecks easily.

At the same time, if biologists need to use impedance map for identifying the genetically isolated population, then identification of isolated areas will be easier through the use of 3-dimensional techniques. Through 3D impedance maps, the visualisation of animal barriers is more prominent and easy to understand than having 2D still-images. If necessary, 3D movies can also be created to make it more interesting for public participation.

5.3. Classification of the impedance map in circular buffers of 250m radius

The impedance map was classified into three categories low, medium and high impedance (See Table 4.3 & 4.4). These categories were further used for identifying the mortality locations. Unpredicted circles were produced if higher number of mixed landcover classes were present in circular buffers with radius of 250 meter. In annexure figure 9.1 of a circular buffer with radius of 250m covers six different landcover types widely verifying in impedance values for badger movements, namely, water (8.0 impedance), recreational centre (5.5 impedance), grassland (0.53

impedance), agriculture (0.90), A73 highway (6.3), urban areas (9), settlement (9) and forest (0). If we look at all the different impedance values then the standard deviation is opt to go above 3 and hence it cannot be classified into any of the impedance class in this study. Hence nearly 29 such circles for badger and 27 for roe deer were categorised as unpredicted circles. This problem could be overcome by reducing or increasing the buffer but should be considered for future study and was not opted for this research.

5.4. Use of traversability equation to assign the road mortality risk

The Traversability Equation was developed by (Jaarsma *et al.*, 2006) for predicting the probability of badger deaths along different local roads in the Netherlands. This study successfully implemented this equation to the A73 highway for the first time. The Traversability equation predicts the probability of a road kill using traffic density, average traffic speed and species characteristics. It is important to predict the probability of road kills along different segments of the road. Development of ecological corridors or wildlife mitigation measures is expensive. Only for A73 highway, 5.8% of construction has been allotted for development of ecological networks (Cuperus *et al.*, 2002).

Traversability equation estimates the probability of animal death with respect to traverse angle of animal and vehicle. In this study it was observed that traverses at a 30^0 angle have resulted in a higher probability of roe deer and badger mortality. As at 30^0 angle with respect to vehicle animal will traverse the road in slanting position, towards the vehicle. Also the distance travelled from one point of road to other will increase in this angle increasing the chances of road kill. The lowest probability of a road kill for badger and roe deer was estimated at traverse at 300^0 angle. As (cos) of 300^0 is a low value the final output gained will have less probability. This is also true as at 300^0 angle probability of road kill occurs at rear wheels of vehicles. However considering the speed of vehicles possibility of animal being killed is low as vehicle can pass before animal arrives. As predicting the traverse angle of animal crossings is not possible in this study, mean of all angle probabilities have been considered.

According to Traversability equation road kills are related to traffic intensity. As estimated probability was plotted against traffic density a continuous rise in the estimated probability was observed for roe deer and badger mortality (See fig 4.11). This is evident as increased traffic density means reduced gap between two vehicles. This in turn will give less space and time for an animal to successfully traverse the road before passing of first car and arrival of second on a given spot. Traversability equation is not able to predict the exact number of road kills but gives relative understanding of mortality risk posed by the road. We can predict the number of road kills if we have enough data on wildlife movements, telemetry data and home range occupancy areas for instance to use a "small step" model.

The Traversability equation gives final output in three classes, low, medium and high probability of road. In terms of mitigation this could be interpreted as low probability zone to be ignored while, medium probability road to have fencing upto appropriate height as mitigation measure and high probability areas should have wildlife crossings. The equation helps to prioritise the budget allocated for developing the mitigation measures.

Estimated probability for two types of road scenarios differed to certain extent (See figs. 4.12 and 4.13). The estimated probability will decrease if there is gap between two lanes. As the landcover between two lanes such as grass strip or any other will have "0" probability of animal being killed as no vehicle will pass through that particular patch between two roads. On the other hand in case of 4 continuous lanes the animal will have to cross with continuous traffic flow hence increasing its chances of being hit by a vehicle. This is also proved as the observed number of road kills is relatively high for badger and roe deer on 4 continuous lanes of A73 highway in comparison with 2 separate lanes (See table 4.5). This is an interesting finding and also supports the current mitigation measures. The Dutch Road Planning Authorities are planning to have 50m forest patches between two lanes of the new highway (See Annexure figure 9.3) (Muskens *et al.*, 2008).

5.5. Identification of relative mortlaity locations

Literature shows limited work has been done to identify the possible mortality location for developing wildlife crossings. One such effort is being carried out in The Netherlands for pine marten *(Martes martes)* along the A50 highway using a regression model for circular buffers of 50m (Muskens *et al.*, 2008). Similarly, research has been undertaken to find factor causing road mortality, number of road mortalities on different types of roads for both roe deer and badger but has not addressed the issue of identifying the possible mortality areas (Madsen *et al.*, 2002, van Langevelde *et al.*, 2009). Even Traversability equation was developed to predict the probability of animal death on a particular segment of road and not for predicting the location of mortality (Jaarsma *et al.*, 2006). This study addresses the issue of identifying the possible mortality location for developing wildlife crossings making appropriate use of Traversability equation and the impedance map.

Identification of possible mortality locations was done using two scenarios. Both scenarios were able to identify the mortality locations of badger and roe deer along the A73 highway. However, scenario 1 predicted more number of high mortality risk zones than that of scenario 2 for both badger and roe deer. On the other had, Scenario 1 failed to predict the low mortality risk zones in comparison with scenario 2. The output of identification of possible mortality locations can then be used for deciding the density of wildlife crossings. Considering the population of the species in high mortality areas number of wildlife crossings can be decided using the STELLA model.

5.6. Validation of the model

Results obtained for possible mortality locations from both scenarios were validated using observed mortality data of badger and roe deer. Also the comparative analysis between two scenarios of mortality locations helped to determine the better method. Scenario 1 for badgers identified high mortality risk zones having 84% of road kill (See table 4.8) while scenario 2 identified high mortality locations having 74% of road kill. However if we see table 4.9 & 4.11 for badgers it is clear that scenario 1 has over estimated number of higher mortality circles, as 36% of high mortality circles have reported "0" badger road kills. On the other hand scenario 2 has identified the high mortality risk zones with more accuracy as only 20% of high mortality risk zones have reported "0"badger road kills. This observed extrapolation may be due two reasons. As verified mortality data of badger & roe deer was selected within the buffer of 250 m on either side of the road reducing actual numbers of road kills. As animals might be hit by vehicles but may die away from road, or at different location which goes unreported (Cachon, 2003).

Recent research undertaken to evaluate efficiency of wildlife crossings have shown that structure of wildlife crossings is less important than the density (Cachon, 2003, Clevenger *et al.*, 2005, Mata *et al.*, 2008). Hence more the high mortality locations indentified by the model, higher should be the density of the wildlife crossings. Hence scenario 2 seems to be preferred for both requirements by limiting number of high mortality locations to require number and using STELLA model the density of wildlife crossing can be estimated.

The model has been validated qualitatively with wildlife crossing prior to use it for development of wildlife crossings. For this study most of the proposed and present wildlife crossings are falling within modelled high mortality locations including two overpasses for roe. This shows that the model is able to predict the appropriate locations for the wildlife crossings.

6. Conclusion

1. Impedance modelling through expert's knowledge assists to identify the resistance effect for badger *(Meles meles)* and roe deer *(Capreolus capreolus)* movements in different landcover classes.
2. The Impedance model proves that the A73 highway does not pose to have a barrier to badger *(Meles meles)* and roe deer *(Capreolus capreolus)* movements. Impedance mapping proves to be effective for evaluating the possible areas for animal movements along the road to indentify relative mortality risk zones.
3. A 3-dimensional impedance map helps to visualize the impedance effect and locate the isolated areas. It can be effectively used for pubic participation and awareness.
4. The Traversability equation has potential use in identifying road segments which have high mortality risk due to vehicular collision.
5. A highway with 4 adjacent lanes carries high risk for animal mortality than the 4 lanes separated as 2x2 by grass strip or other vegetation cover.
6. This model was able to successfully predict the relative mortality location for badger *(Meles meles)* and roe deer *(Capreolus capreolus)* while using only limited wildlife datasets.
7. The validation of the model shows that scenario 2 for identification of mortality locations of badger *(Meles meles)* and roe deer *(Capreolus capreolus)* is more efficient that scenario 1.
8. The model is able to identify the locations with highest mortality risk which should be prioritized for developing mitigation measures such as wildlife crossing and validation results prove its reliability.
9. The model developed in STELLA can be applied to prioritise wildlife crossings in other areas for mammalian species with similar behaviour as badger *(Meles meles)* and roe deer *(capreolus capreolus)*.

7. Recommendations

1. The current model can be applied to similar species and road networks in other developed and developing countries and build it with a programming language for its effective use.
2. The use of 3–dimensional impedance maps is recommended to ensure public understands their effectiveness.
3. Detailed impedance mapping for anthropogenic effects such disturbance in forest and peripheral zones is necessary to have more detailed view of impact on animal movements.
4. This study using “Small step” model for stretches of 500 meters for estimating the actual mortality of animal is challenging for predicting locations for wildlife crossings more accurately.
5. Validation of STELLA model is necessary for its reliable use in future.
6. Sensitivity analysis for circular buffers by changing its radius size should be done to predict changes in relative mortality locations.
7. Impact on road mortality with changes in traffic speed should be evaluated.
8. It is further necessary to investigate relationship between two road widening scenarios - 4 lanes separated in 2x2 and 4 adjacent lanes and its impact on mortality for different species.

8. References

AARIS-SORENSEN, J. (1995) Road-Kills of Badgers (Meles meles) in Denmark. *Annales Zoologici Fennici* 32**,** 31-36.

AFFUM, J. K., AND BROWN, ALAN L. (1997) A GIS Based Method for Estimating the Environmental Impacts of Road Traiffc. *Journal of the Eastern Asia Society for Transportation Studies,* 2**,** 1981-1994.

ALEXANDER, S. M. (2008) Snow-tracking and GIS: using multiple species-environment models to determine optimal wildlife crossing sites and evaluate highway mitigation plans on the Trans-Canada Highway. *Canadian Geographer / Le. Gaographe canadien,* 52**,** 169-187.

ALEXANDER, S. M. & WATERS, N. M. (2000) The effects of highway transportation corridors on wildlife: a case study of Banff National Park. *Transportation Research Part C: Emerging Technologies,* 8**,** 307-320.

AUSTIN, J. M., VIANI, K., HAMMOND, F. & SLESAR, C. (2005) A GIS-based identification of potentially significant wildlife habitats associated with roads in Vermont. *IN: Proceedings of the 2005 International Conference on Ecology and Transportation, Eds. Irwin CL, Garrett P, McDermott KP. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC***,** 185-196.

BEKKER, H. & CANTERS, K. J. (1995) The Continuing story of badgers and their tunnels. *Habitat Fragmentation & Infrastructure. Proceedings Of The International Conference On Habitat Fragmentation, Infrastructure And The Role Of Ecological Engineering, 17-21 September 1995, Maastricht And The Hague, The Netherlands.***,** 344 - 353.

BEKKER, H. & DIERCKX, C. (2003) European Habitat Fragmentation due to infrastructure. Cause, Counteracting and Co - operation. *International Conference on Habitt Fragmntation due to Transportation Infrastructure and Presentation of COST action 341 prodcuts*.

CACHON, J. (2003) Effectiveness of Wildlife Crossing Structures and Adapted Culverts in a Highway in Northwet Spain. *International Conference on Ecology and Transportation*.

CAPISTRANO, D., SAMPER, C., LEE, M. & HEARNE, C. R.-. (2005) Ecosystem and Human Well - being: Multiscale Assessments: Findings of the Sub - Gloabl Assessmenets Working Group of the Millennium Ecosystem Assessment. *Published by Island Press*.

CARR, L. W. & FAHRIG, L. (2002) Effect of Road Traffic on Two Amphibian Species of Differing Vagility. *Conservation Biology,* 15**,** 1071 - 1078.

CLARKE, G. P., WHITE, P. C. L. & HARRIS, S. (1998) Effects of roads on badger Meles meles populations in south-west England. *Biological Conservation,* 86**,** 117-124.

CLEVENGER, A. P. & WALTHO, N. (2005) Performance indices to identify attributes of highway crossing structures facilitating movement of large mammals. *Biological Conservation,* 121**,** 453-464.

CLEVENGER, A. P., WEIRZCHOWSKI, J., CHRUSZCZ, B. & GUNSON, K. (2002) GIS - Generate, Expert - Based Models for identifying Wildlife Habitat Linkages and Planning Mitigation Passages. *Conservation Biology,* 16**,** 503 - 514.
COFFIN, A. W. (2007) From roadkill to road ecology: A review of the ecological effects of roads. *Journal of Transport Geography,* 15**,** 396-406.
CORNELIS, J., CASAER, J. & HERMY, M. (1999) Impact of season, habitat and research tecniques on diet composition of roe deer (Capreolus capreolus): a review. *Journal of Zoology,* 248**,** 195-207.
COULON, A., COSSONT, J. F., ANGIBAULT, J. M., CARGNELUTTI, B., GALAN, M., MORELLET, N., PETIT, E., AULANGNIER, S. & HEWISON, A. J. M. (2004) Landscape connectivity influences gene flow in a roe deer population inhabiting a fragmented landscape: an individual - based approach. *Molecular Ecology,* 13**,** 2841-2859.
COULON, A., GUILLOT, G., ANGIBAULT, J. M. A., AULAGNIER, S., CARGNELUTTI, B., GALAN, M. & HEWISON, A. J. M. (2006) Genetic structure is influenced by landscape features: empirical evidence from a roe deer population. *Molecular Ecology,* 15**,** 1669 - 1679.
COULON, A., MORELLET, N., GOULARD, M., CARGNELUTTI, B., ANGIBAULT, J.-M. & HEWISON, A. J. M. (2008) Inferring the effects of landscape structure on roe deer *(Capreolus capreolus)* movements using a step selection function. *Landscape Ecology,* 23**,** 603 - 614.
CUPERUS, R., CANTERS, K. J. & PIEPERS, A. A. G. (1996) Ecological compensation of the impacts of a road. Preliminary method for the A50 road link (Eindhoven-Oss, The Netherlands). *Ecological Engineering,* 7**,** 327-349.
CUPERUS, R., KALSBEEK, M., HAES, H. U. D. & CANTERS, K. J. (2002) Preparation and Implementation of Seven Ecological Compensation Plans for Dutch Highways. *Environmental Management,* 29**,** 736 - 749.
DANIELSON, D. B. J. & HUBBARD, D. M. W. (1998) "A literature review for assessing the status of current methods of reducing deer - vehicle collisions" *A report prepared for The Task Force on Animal Vehicle Collisions, The Iowa Department of Transportation, and The Iowa Department of Natural Resources*.
DEMIR, M. (2007) Impacts, management and functional planning criterion of forest road network system in Turkey. *Transportation Research Part A: Policy and Practice,* 41**,** 56-68.
DEMIREL, H., SERTEL, E., KAYA, S. & ZAFER SEKER, D. (2008) Exploring impacts of road transportation on environment: a spatial approach. *Desalination,* 226**,** 279-288.
EIGENBROD, F., HECNAR, S. J. & FAHRIG, L. (2008) The relative effects of road traffic and forest cover on anuran populations. *Biological Conservation,* 141**,** 35-46.
EPA (1994) Evaluation of Ecological Impacts from Highway Development. *United States Environmental Protection Agency,* EPA 300-B-94-006.
FINKE, J., STREIN, M. & SONNENSCHEIN, M. (2008) A simulation framework for modeling anthropogenic disturbances in habitat networks. *Ecological Informatics,* 3**,** 26-34.

European Environmental Agency (EEA), Copenhagen, (2007) (Accessed on 15th December 2008) http://dataservice.eea.europa.eu/dataservice/metadetails.asp?id=760

FORMAN, R. T. T. & ALEXANDER, L. (1998) Roads and Their Major Ecological Effects. *Annual Review of Ecology and Systematics,* 29**,** 207-C2.

FORMAN, R. T. T., FIEDMAN, D. S., FITZHENRY, D., MARTIN, J. D., CHEN, A. S. & ALEXANDER, L. (1995) Ecological Effetcts of Roads: Towrads three summary indices and an overview for North America. *Habitat Fragmentation & Infrastructure. Proceedings Of The International Conference On Habitat Fragmentation, Infrastructure And The Role Of Ecological Engineering, 17-21 September 1995, Maastricht And The Hague, The Netherlands.***,** 40 - 52.

GENELETTI, D. (2003) Biodiversity Impact Assessment of roads: an approach based on ecosystem rarity. *Environmental Impact Assessment Review,* 23**,** 343-365.

GENELETTI, D. (2006) Some common shortcomings in the treatment of impacts of linear infrastructures on natural habitat. *Environmental Impact Assessment Review,* 26**,** 257-267.

GRIFT, E. A. V. D. & POUWELS, R. (2006) Restoring habitat connectivity across transport corridors: identifying high - priority for de-fragmentation with the use of an expert - based model. *Environmental Pollution,* 10**,** 205 - 231.

HELLDIN, J. O., SEILER ANDREAS., HANS JERNELID AND GRANGSTEDT PER (2003) The barrier impact on migratory moose of highway E4 in the High Coast area, Sweden. *International Conference on Habitt Fragmntation due to Transportation Infrastructure and Presentation of COST action 241 prodcuts*

HUGHES, M. S., NEILL, S. D. & ROGERS, M. S. (1996) Vaccination of the badger (Meles meles) against Mycobacterium bovis. *Veterinary Microbiology,* 51**,** 363-379.

JAARSMA, C. F., VAN LANGEVELDE, F., BAVECO, J. M., VAN EUPEN, M. & ARISZ, J. (2007) Model for rural transportation planning considering simulating mobility and traffic kills in the badger Meles meles. *Ecological Informatics,* 2**,** 73-82.

JAARSMA, C. F., VAN LANGEVELDE, F. & BOTMA, H. (2006) Flattened fauna and mitigation: Traffic victims related to road, traffic, vehicle, and species characteristics. *Transportation Research Part D: Transport and Environment,* 11**,** 264-276.

JAEGER, J. A. G., BOWMAN, J., BRENNAN, J., FAHRIG, L., BERT, D., BOUCHARD, J., CHARBONNEAU, N., FRANK, K., GRUBER, B. & VON TOSCHANOWITZ, K. T. (2005) Predicting when animal populations are at risk from roads: an interactive model of road avoidance behavior. *Ecological Modelling,* 185**,** 329-348.

JHA, C. S., LAXMI GOPARAJU, ANSHUMAN TRIPATHI, BISWADEEP GHARAI, A.S. RAGHUBANSHI & SINGH, J. S. (2005) Forest fragmentation and its impact on species diversity: an analysis using remote sensing and GIS. *Biodiversity and Conservation,* 14**,** 1681-1698.

JONES, A. P., HAYNES, R., KENNEDY, V., HARVEY, I. M., JEWELL, T. & LEA, D. (2008) Geographical variations in mortality and morbidity from road traffic accidents in England and Wales. *Health & Place,* 14**,** 519-535.

JORRITSMA, A. (1995) Habitat Fragmentation and infrastructure: The Dutch approach. *Habitat Fragmentation & Infrastructure. Proceedings Of The International Conference On Habitat Fragmentation, Infrastructure And The Role Of Ecological Engineering, 17-21 September 1995, Maastricht And The Hague, The Netherlands.***,** 20-22.

KELLER, V. & PFISTER, H. P. (1995) Wildlife passages as a means of mitigating effects of habitat fragmentation by roads and railway lines. *Habitat Fragmentation & Infrastructure. Proceedings Of The International Conference On Habitat Fragmentation, Infrastructure And The Role Of Ecological Engineering, 17-21 September 1995, Maastricht And The Hague, The Netherlands.***,** 70-79.

KESHKAMAT, S. S., LOOIJEN, J. M. & ZUIDGEEST, M. H. P. (2008) The formulation and evaluation of transport route planning alternatives: a spatial decision support system for the Via Baltica project, Poland. *Journal of Transport Geography,* In Press, Corrected Proof.

KRISP, J., M., , VARE S., DAME J & VIRRANTAUS (2004) Visualizing Moose Habitat Changes Due to Infrastructure Construction in Southern Finaland. *Commission IV/6 Lanscape Modelling and Visualization*.

KRISP, J. M. (2004) Three-dimensional visualisation of ecological barriers. *Applied Geography,* 24**,** 23-34.

KRUUK, H. (1978) Forgaing and Spatial Organisation of the European Badger, Meles meles L. *Behavioral Ecology and Sciobiology,* 4**,** 75-89.

LIU, S. L., CUI, B. S., DONG, S. K., YANG, Z. F., YANG, M. & HOLT, K. (2008) Evaluating the influence of road networks on landscape and regional ecological risk--A case study in Lancang River Valley of Southwest China. *Ecological Engineering,* 34**,** 91-99.

LURZ, P. W. W., HEWITT, S. M., SHIRLEY, M. D. F. & BRUCE, J. (2005) Mammals in Cumbira: examples of what publicly collected records can tell us about the distribution and ecology of our local species. *The Carlisle Naturalist,* 13.

MADSEN, A. B., H, H. S. & A, P. (2002) Factor causing traffic killings of roe deer Capreolus capreolus in Denmark. *Wildlife Biology* 8**,** 55 - 61.

MATA, C., HERVÁS, I., HERRANZ, J., SUÁREZ, F. & MALO, J. E. (2008) Are motorway wildlife passages worth building? Vertebrate use of road-crossing structures on a Spanish motorway. *Journal of Environmental Management,* 88**,** 407-415.

MUSKENS, G. & BROEKHUIZEN, S. (2008) Pine Marten road victims in relation to verge features and possible measures to reduce their numbers. *26th Mustelid Colloquium Budapest*.

"Ministerie van Verkeer en Waterstaat Rijkswaterstaat" website "Data – ICT – Dienst" http://81.18.1.212/index.html (Accessed on 7th November 2008)

OLSSON, M. P. O., WIDÉN, P. & LARKIN, J. L. (2008) Effectiveness of a highway overpass to promote landscape connectivity and movement of moose and roe deer in Sweden. *Landscape and Urban Planning,* 85**,** 133-139.

ORLOWSKI, G. (2008) Roadside hedgerows and trees as factors increasing road mortality of birds: Implications for management of roadside vegetation in rural landscapes. *Landscape and Urban Planning,* 86**,** 153-161.

PROVINCE OF NOORD – BRABANT (2008) Agriculture and Agricultural Sector – Facts and Figures over Braban Province (Accessed on 23rd December 2008) http://www.brabant.nl/Besturen/Feiten%20en%20cijfers%20over%20Brabant/Landbouw%20en%20agrarische%20sector.aspx

PROVINCE OF NOORD – BRABANT (CD-ROM) Digitale Atlas revitalisering landelijk gebied (RLG), (2005).

PROVINCE OF LIMBURG, (2008), , http://www.limburg.nl/en/html/algemeen/Limburg/economyandemployment/economyandemployment.asp (Accessed on 14th December 2008)

PUTMAN, R. J. & MOORE, N. P. (2002) Impact of deer in lowland Britain on agriculture, forestry and conservation habitats. *Mammal Review,* 28**,** 141 - 164.

RAJVANSHI A, V. MATHIR, G.C. TELEKI & MUKHERJEE, S. K. (2001) "Roads Sensitive Habitats and Wildlife: Environmental Guide for India and South Asia", Wildlife Institute of India, Dehradun and Canadian Environmental Collabration Ltd., Toronto.

REIJNEN, R. & FOPPEN, R. (1994) The effects of car traffic on breeding bird population in woodland. I. Evidence of reduced habitat quality for willow warbles (Phylloscopus trochilus) breeding close to a highway. *Journal of Applied Ecology,* 31**,** 85 - 94.

REIJNEN, R., FOPPEN, R. & MEEUWSEN, H. (1996) The effects of traffic on the density of breeding birds in Dutch agricultural grasslands. *Biological Conservation,* 75**,** 255-260.

ROEVER, C. L., BOYCE, M. S. & STENHOUSE, G. B. (2008a) Grizzly bears and forestry: I: Road vegetation and placement as an attractant to grizzly bears. *Forest Ecology and Management,* 256**,** 1253-1261.

ROEVER, C. L., BOYCE, M. S. & STENHOUSE, G. B. (2008b) Grizzly bears and forestry: II: Grizzly bear habitat selection and conflicts with road placement. *Forest Ecology and Management,* 256**,** 1262-1269.

ROGERS, L. M., CHEESEMAN, C., MALLINSON, P. J. & HADLEY, R. C.-. (1997) The demography of high - density badger (Meles meles) population in the west of England. *Journal of Zoology,* 242**,** 705 - 728.

ROKORNY, B. (2006) Roe deer - vechicle collisions in Solvenia: situation, mitigation stratergy and counter measures. *Veterinarski Arhiv,* 76**,** S177 - S187.

ROPER, T. J. (1994) The European Badger Meles melse: Food specialist or generalist? *Journal of Zoology,* 234**,** 437-452.

ROPER, T. J. (2008) Madger Meles meles seets-architecture, internal environment and function. *Mammal Review,* 22**,** 43 - 53.

Rikjswaterstaat Province of Limburg (2008) http://66.102.9.104/translate_c?hl=en&u=http://www.vialimburg.nl/index.php&usg=ALkJrhgVi8ESBCaXLPBsiAksNJysj4jpxA (Accessed on 12th December 2008)

SAID, S., GAILLARD, J. M., DUNCAN, P., GUILLON, N., GUILLON, N., SERVANTY, S., PELLERIN, M., LEFEUVRE, K., MARTIN, C. & LAERE, G. V. (2006) Ecological correlates of home-range size in spring-summer for female roe deer (Capreolus capreolus) in a deciduous woodland. *Journal of Zoology,* 267**,** 301 - 308.

SEILER, A. (2003) The toll of the automobile: Widlife and roads in Sweden. *Doctoral Thesis,* Swedish University of Agricultural Sciences, Uppsala.

SPEZIALE, K. L., LAMBERTUCCI, S. A. & OLSSON, O. (2008) Disturbance from roads negatively affects Andean condor habitat use. *Biological Conservation,* 141**,** 1765-1772.

SPOONER, P. G. & SMALLBONE, L. (2008) Effects of road age on the structure of roadside vegetation in south-eastern Australia. *Agriculture, Ecosystems & Environment,* In Press, Corrected Proof.

TANNER, D. & PERRY, J. (2007) Road effects on abundance and fitness of Galápagos lava lizards (Microlophus albemarlensis). *Journal of Environmental Management,* 85**,** 270-278.

TREWEEK, J., VEITCH, N (1996) The Potential Application of GIS and Remotely Sensed Data to the Ecological Assessment of Proposed New Road Schemes. *Global Ecology and Biogeography Letters,* 5**,** 249-257.

VAN LANGEVELDE, F., VAN DOOREMALEN, C. & JAARSMA, C. F. (2009) Traffic mortality and the role of minor roads. *Journal of Environmental Management,* 90**,** 660-667.

VERBOOM, J., ALKEMADE, R., KLIJN, J., METZGER, M. J. & REIJNEN, R. (2007) Combining biodiversity modeling with political and economic development scenarios for 25 EU countries. *Ecological Economics,* 62**,** 267-276.

VOS, C. C. (1995) Effects of road density; a case study of the moor frog. *Habitat Fragmentation & Infrastructure. Proceedings Of The International Conference On Habitat Fragmentation, Infrastructure And The Role Of Ecological Engineering, 17-21 September 1995, Maastricht And The Hague, The Netherlands.***,** 95 - 97.

WAHLSTROEM, L. K. & LIBERG, O. (1995) Pattern of dispersal and seasonal migration in roe deer (Capreolus capreolus). *Journal of Zoology,* 235**,** 455 - 467.

WANG, M. & SCHREIBER, A. (2002) The impact of habitat fragmentation and social structure on the population genetics of roe deer (Capreolus capreolus L.) in Central Europe. *Heredity,* 86**,** 703 - 715.

WOODROFFE, R., MACDONALD, D. W. & SILVA, J. D. (1995) Dispersal and philiparty in the European badger, Mlese meles. *Journal of Zoology,* 237**,** 227 - 239

9. Annexures

Table 9.1 Expert knowledge analysis for badger (Meles Meles)

Method 1: Different weight for each expert, Method 2: Equal weight for each expert

Class Code	Landcover Class	Different Weights for Experts	Equal Weights for Expert	S.D.
1	Ponds	3.82	3.98	0.79
2	River	8.11	8.30	1.63
3	Canal	7.33	7.30	0.51
4	Lakes	8.78	8.80	1.83
5	Grassland	0.33	0.33	0.52
6	Forest	0.00	0.00	0.00
7	Human Settlement 0m buffer	9.70	9.10	0.82
8	Human Settlement 50m buffer	7.56	7.10	0.82
9	Human Settlement 100m buffer	5.50	5.10	1.33
10	Industrial Area 0m buffer	9.72	9.12	0.55
11	Industrial Area 50m buffer	7.06	7.48	0.75
12	Industrial Area 100m buffer	5.02	4.98	1.41
13	Mineral Exploration Site	7.92	7.10	1.52
14	Agriculture	0.53	0.50	0.55
15	Recreational Centers	7.14	6.97	0.79
16	Airfield	7.59	7.14	1.12
17	Landfill & Waste Disposal Sites	3.56	3.12	0.47
18	Local Roads	1.32	1.33	1.03
19	Provincial Road without fence	4.95	5.06	0.66
20	Provincial Road with fence	9.56	9.01	0.82
21	Highways without fence	6.33	6.47	0.35
22	Highways with fence	9.79	9.14	0.52

Table 9.2 Expert knowledge analysis for Roe Deer (Capreulus capreolus)
Method 1: Different weight for each expert, Method 2: Equal weight for each expert

Class Code	Landcover Class	Different Weights for Experts	Equal Weights for Expert	S.D.
1	Ponds	1.2	1.00	1.41
2	River	2	2.25	0.71
3	Canal	7.7	7.75	0.96
4	Lakes	3.4	3.25	0.26
5	Grassland	1.5	1.25	1.50
6	Forest	0.2	0.25	0.50
7	Human Settlement 0m buffer	9.8	9.75	0.50
8	Human Settlement 50m buffer	7.2	7.25	0.96
9	Human Settlement 100m buffer	5.4	5.50	0.89
10	Industrial Area 0m buffer	10	10.00	0.00
11	Industrial Area 50m buffer	6.7	6.75	0.96
12	Industrial Area 100m buffer	5.4	5.50	1.29
13	Mineral Exploration Site	8.6	8.75	1.26
14	Agriculture	2.1	1.75	1.86
15	Recreational Centers	10	10.00	0.00
16	Airfield	8.7	8.50	1.29
17	Landfill & Waste Disposal Sites	5.7	5.50	1.08
18	Local Roads	0.6	0.75	0.96
19	Provincial Road without fence	4.1	4.00	0.82
20	Provincial Road with fence	9.2	9.25	0.50
21	Highways without fence	5.5	5.50	0.58
22	Highways with fence	9.4	9.50	0.58

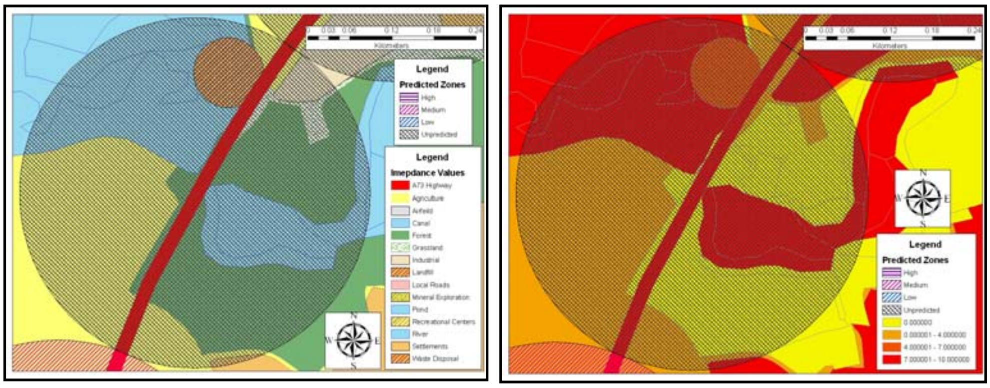


Figure 9.1 The impedance values for badger *(Meles meles)* movement using expert knowledge for each landcover along the A73 highway (Method 2)

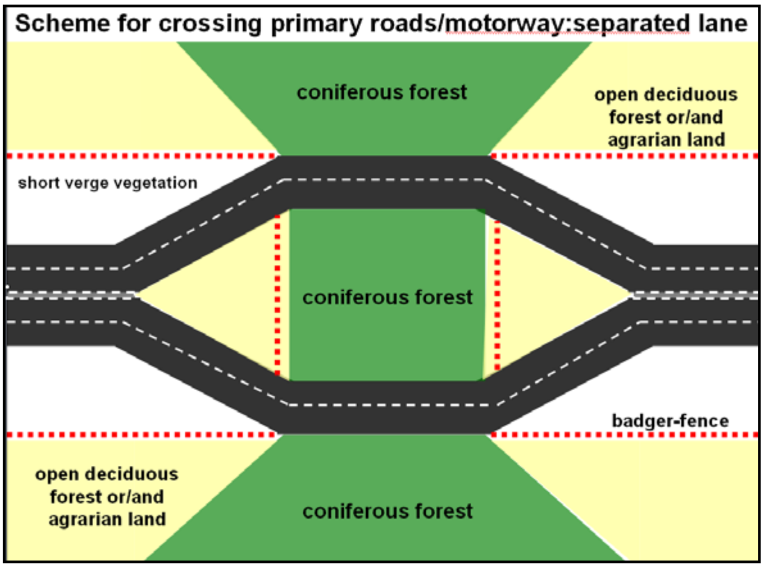


Figure 9.2 New proposed road deign by the Dutch authorities as forest patch between two road lanes

(Muskens et al., 2008)

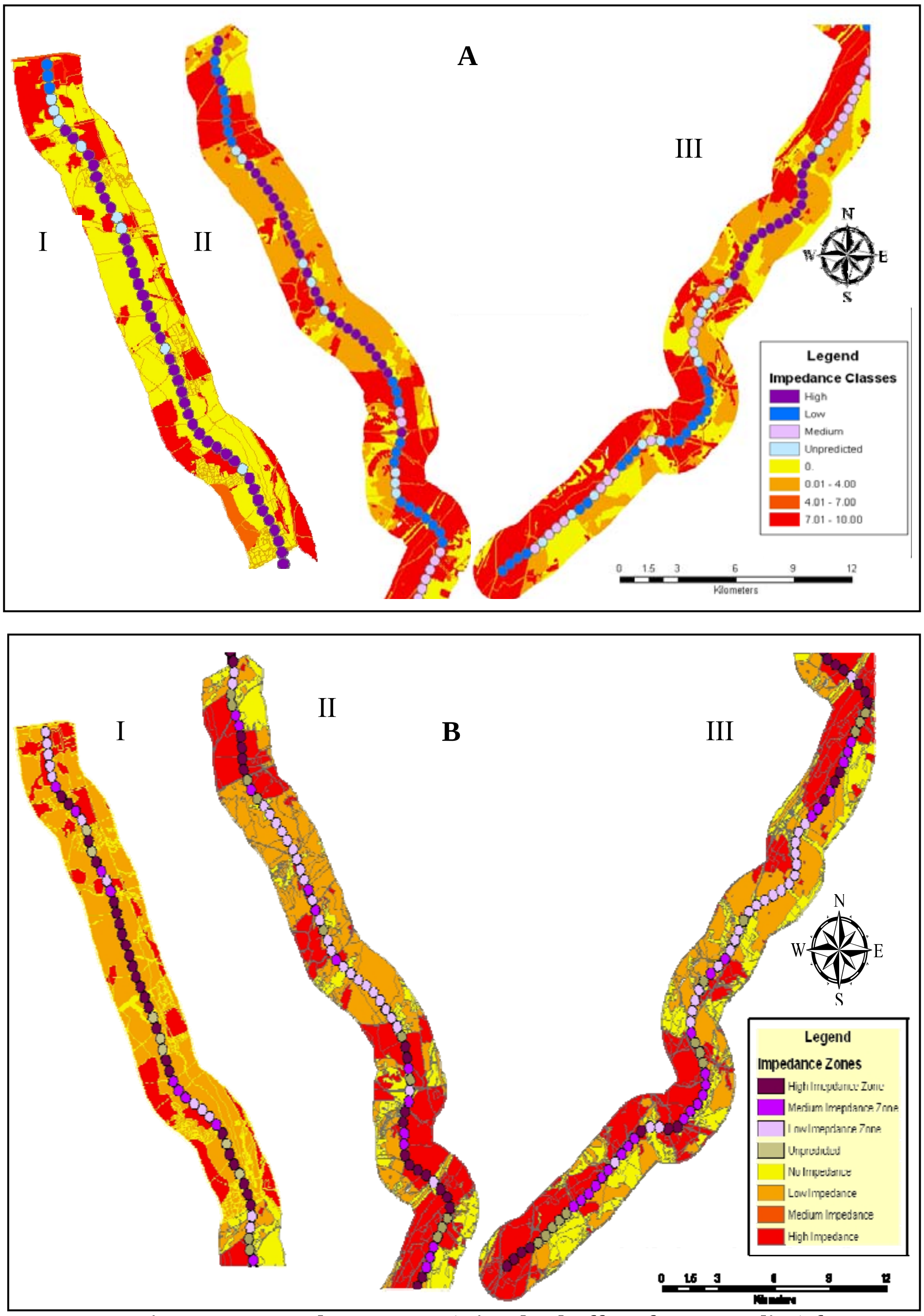


Figure 9.3 Impedance zones (Circular buffer of 250m radius) for A) Badger *(Meles meles)* B) Roe deer *(Capreolus capreolus)* I. Northern section II. Central Section and III. Southern section of the A73 highway

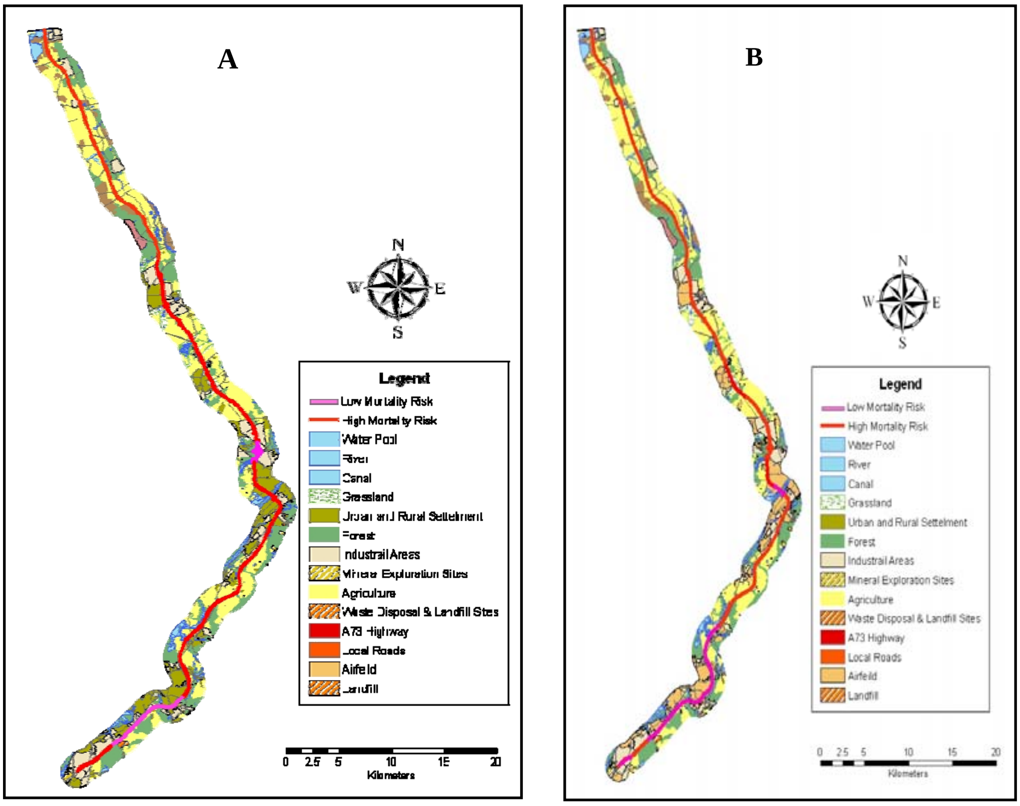


Figure 9.5 Mortality threat posed by the A73 highway using Traversability equation A) Badgers B) Roe Deer

A

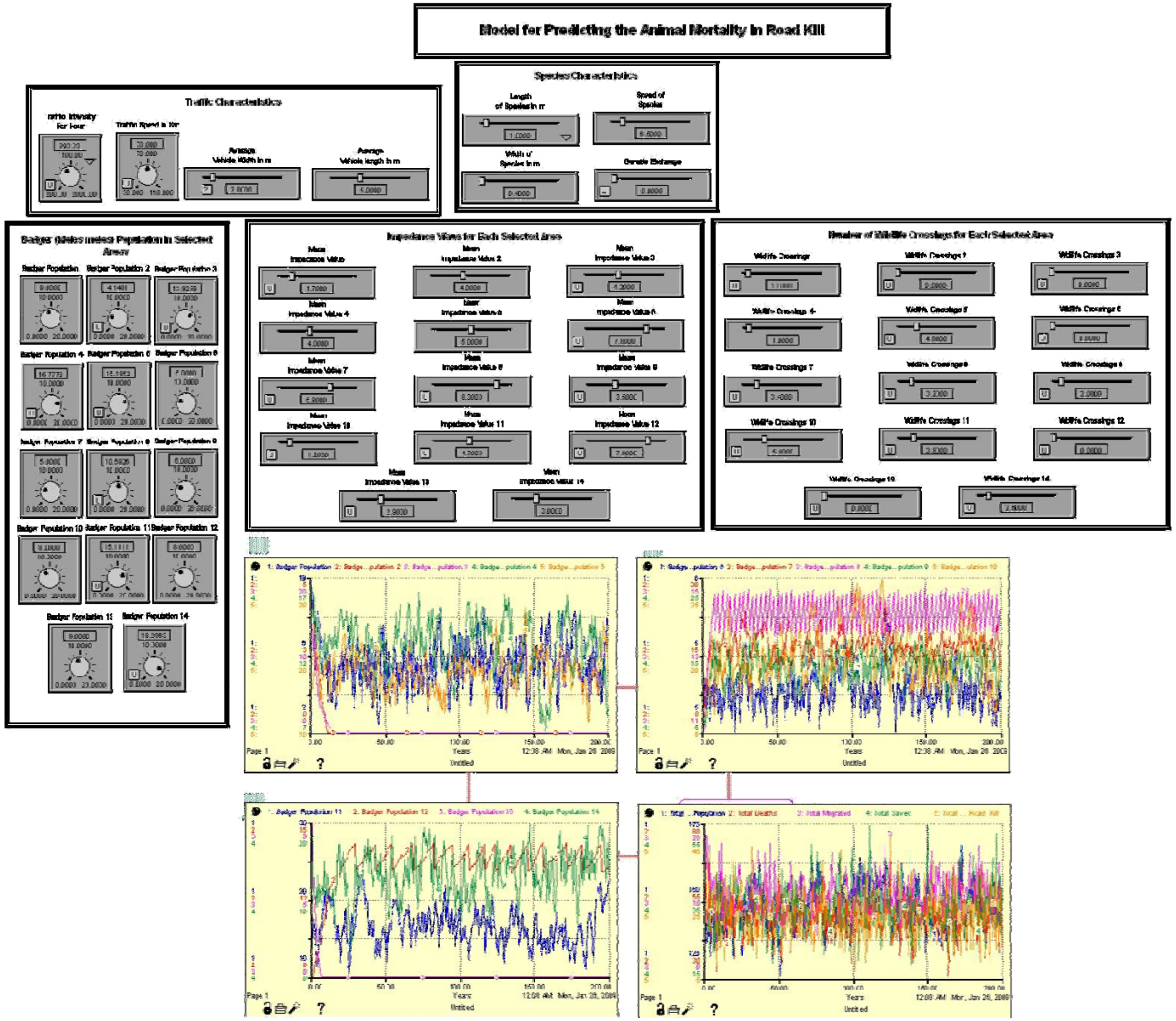


Figure 9.4: STELLA model Interface