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Wildlife Vehicle Collisions versus Landscape Fragmentation

Diploma Thesis

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DIPLOMA THESIS ASSIGNMENT

B.Sc. Alba Noemi Alvarez Mejia

Nature Conservation

Thesis title

Wildlife vehicle collisions versus landscape fragmentation

Objectives of thesis

The aim of the Diploma Thesis is use of GIS as a method to approach an issue of wildlife-vehicle collisions caused by the landscape fragmentation. Concretely, this study examines a relationship between the wildlife vehicle collisions and level of the landscape fragmentation in Czech Republic.

Methodology

- Analysis of the transport infrastructure in Czech Republic.

- categorization of each road class.

- Identification of the core area of each polygons, which are formed by crossing of the roads.

- Identification of wildlife vehicle collisions around the perimeter of each polygon.

The proposed extent of the thesis

50 pages

Keywords

Transport, accident, animal vehicle collision, barrier effect

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Recommended information sources

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Declaration

I hereby declare that this thesis has been composed solely by myself and that it has not been submitted, in whole or in part, in any previous application for a degree. Except where states otherwise by reference or acknowledgment, the work presented is entirely my own.

Prague, 18th of April   Alba Noemi Alvarez Mejia

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Abstract

In today's world, with the constant increase of the population, building the road network infrastructure is inevitable. Landscape fragmentation caused by such activities is one of the main drivers instigating the deaths of animals living in the areas nearby the roads. The aim of this thesis is to examine the relationship between these two phenomena - the landscape fragmentation and wildlife vehicle collisions (WVCs). It is divided into two main parts. The first part of the thesis is dedicated to the in-depth review of the current literature dealing with the main factors influencing the WVCs – traffic related factors, animal related factors, landscape related factors and landscape fragmentation. In the second part of the thesis, the case study of the relationship between the WVCs and the road infrastructure in the Czech Republic over the years 2009 – 2014 is presented. The initial hypothesis is formed as "the higher the density of the roads, the higher number of WVCs", and subsequently verified. In the first step, the author uses Geographic Information Systems software ArcGIS to identify the core area of each polygon created by crossing the roads of the 1st and 2nd class. Afterwards, statistical software R studio is used to examine the relationship between the road density within each polygon and the number of collisions, performed by using the Spearman's correlation test. The produced results confirm the initial hypothesis, however, not with such a certainty that could be expected when formulating the case study. The discussion explaining possible reasons behind such results is presented. The thesis is concluded with the recommendations towards eliminating the increasing growth of WVCs as well as the directions which further research should be oriented into.

Key words: Wildlife Vehicle Collisions, Landscape Fragmentation, Roads, Czech Republic, ArcGIS

Abstrakt

V dnešní době je se stálým nárůstem počtu obyvatel stavba silnic nevyhnutelná. Fragmentace krajiny způsobená těmito činnostmi je jedním z hlavních hnacích motorů podněcování úmrtí zvířat žijících v okolí pozemních komunikací. Cílem této práce je prozkoumat vztah mezi těmito dvěma jevy – fragmentací krajiny a střet divoké zvěře s vozidly (WVCs). Práce je rozdělena do dvou hlavních částí. První část práce je věnována rozboru současné literatury zabývající se hlavními faktory ovlivňující střet vozidel se zvěří - faktory související s provozem, faktory související se zvířaty, krajinné faktory, a faktor fragmentace krajiny. Ve druhé části práce je uvedena případová studie o vztahu mezi střety zvěře s vozidly a dopravní infrastrukturou v České republice v průběhu let 2009 - 2014. Počáteční hypotéza byla vytvořena, a následně i ověřena, na bázi "čím vyšší hustota komunikací, tím větší množství střetů zvěře s vozidly". V prvé řadě použila autorka Geografické informační systémy softwaru ArcGIS k identifikaci stěžejních ploch každého polygonu vytvořené křížením silnic 1. a 2. třídy. Následně byl s využitím softwaru R studio zkoumán vztah mezi hustotou silničního provozu v každém polygonu a počtu střetů, za pomoci Spearmanova korelačního koeficientu. Získané výsledky potvrdily počáteční hypotézu, avšak nikoliv s takovou jistotou, jaká byla očekávána při formulaci případové studie. V diskusi jsou vysvětlovány možné příčiny získaných výsledků. Práce je uzavřena doporučeními, která mohou vést k odstranění narůstajících střetů zvěře s vozidly spolu s pokyny, kam by mohl další výzkum směřovat.

Klíčová slova: Střety divoké zvěře s vozidly, Fragmentace krajiny, Silnice, Česká republika, ArcGIS

Content

1 Introduction

With the constant increase of the population, the development of cities and road networks is inevitable. The roads can be perceived by the wildlife as dangerous, representing a barrier, and thus having a negative impact on them. The most important consequences of animals' interaction with roads are the isolation of the population and the mortality due to the collisions with vehicles. The fragmentation caused by roads is usually sudden and often severe and there is frequently a simultaneous reduction in habitat quality and population size. (*Underhill et al., 2000*). Consequently, Landscape fragmentation and habitat loss is one of the biggest problems for biodiversity conservation.

Geographic Information Systems (GIS) is a technological tool widely used by conservationists and scientists. One can imagine GIS as the representation of the Earth, divided into thematic layers, each representing geographic and spatial information. This technology has a variety of uses in different disciplines. In ecology, there are many spatial components that are worth studying using GIS, for example the distribution of endangered species or the movement of the animals.

Until present day there have been many studies touching the problem of wildlife vehicle collisions, each of them focusing on several factors, such as traffic intensity, type of landscape, animal behavior or landscape fragmentation. Between them, there are numerous studies that used GIS as a tool to address the current problem of fragmentation and the isolation of population. However, there are very few studies dealing with the impact that the fragmented landscape has on the occurrence of wildlife vehicle collisions. Assuming that the road density plays an important role on the occurrence of WVCs, there is a strong need to undertake a further research and examine the relationship between these two variables.

2 Purpose and aim of this study

The thesis consists of two main parts.

The aim of the first part of the thesis is to review the existing literature and studies about road ecology and wildlife-vehicle collisions worldwide. The review is divided into different sections according to the factors influencing wildlife vehicle collisions, such as traffic, landscape and animal behavior, knowing that they contribute differently to the occurrence of this phenomena. These factors are critical for developing knowledge-based mitigation for reducing effects of wildlife-vehicle collisions and increasing public safety on highways.

The aim of the second part is to examine the usage of GIS as a method to approach an issue of aforementioned wildlife vehicle collisions caused by the landscape fragmentation. Concretely, this study examines a relationship between the wildlife vehicle collisions and the level of the landscape fragmentation in Czech Republic, comparing the road density of 1st and 2nd class roads and their impact on the WVC. Initial hypothesis formed as "higher density within an area is, the higher number of animal losses" is then verified using correlation test, followed by the set of recommendations in order to reduce current situation.

3 Review of Literature

3.1 Wildlife Vehicle Collisions

“The arguments in favor of roads are direct and concrete while those against them are subtle and difficult to express” (*Andrews, 1990 ex Marshall, 1935*). The building of roads has made our life more convenient, but these same roads have measurable negative effects on wildlife, such as natural habitat fragmentation, degradation, and the direct killing of fauna and flora, which leads to reductions in overall wildlife population size (*Cuyckens et al., 2015*; *Kušta et al., 2016; Taylor & Goldingay, 2010; Van der Ree et al., 2011; Balkenhol & Waits, 2009; Seo et al., 2013; Jackson, 2000; Garrah et al., 2015; Girardet et al., 2015; Keken et al., 2016; Litvaitis & Tash, 2008).*

The trends of increasing traffic volumes and road densities will only magnify the impacts of roads on large mammals and other vertebrates (*Gunson et al, 2005*).

Collisions between vehicles and wildlife are an increasingly serious risk factor for the safety of vehicular traffic, as well as the wildlife itself. Therefore, there is an urgent need for strategies to reduce wildlife road mortality.

3.2 WVCs in Different Countries

3.2.1 WVCs worldwide

Gunson et al., 2005 studied the influence of landscape and highway on ungulates-vehicle collisions in the Central Canadian Rocky Mountains and the results showed that mule deer (*Odocoileus hemionus*) and white-tailed deer (*Odocoileus virginianus*) were most frequently involved in collisions comprising 58 percent of the kills.

A 2006 study by *Huijser* of the Western Transportation Institute in the United States reported that the total number of deer-vehicle collisions was estimated at more than 1 million per year. These collisions were estimated to cause 211 human fatalities, 29,000 human injuries and over one billion dollars in property damage a year. These number have probably increase even further over the last decade. Wildlife-vehicle collisions cost $8 billion per year when property damage, human injuries and fatalities, carcass removal, and loss of recreation revenue are included. “If we took that cost and quartered it, we would build 200 animal crossings a year and the problem of roadkill would decrease dramatically within a generation.” (*Anonymus, 2010*).

As in Europe and North America, wildlife-vehicle collisions are a growing concern in Asia. According to *Hara, 2010* who studied the transport ecology in Japan, his report stated that the most killed specie is the raccoon dog (*Nyctereutes procyonoides*). Raccoon dog-vehicle collisions have been increasing rapidly than did traffic volume. One of the serious problems concerning wildlife-vehicle collisions in Japan is those of endangered species such as: iriomote cat (*Felis iriomotensis*), leopard cat (*Felis bengalensis*) and the amami rabbit *(Pentalagus furnesi)*. In Korea, the number of Wildlife-vehicle collisions is also increasing. Common victims in collisions with vehicles are: raccoon dog (*Nyctereutes procyonoides*), water deer (*Hydropotes inermis*), leopard cat (*Felis bengalensis*) and siberian weasel (*Mustela sibirica*) (*Hara, 2010; Seo et al., 2013*). However, for the state of wildlife-vehicle collisions in China, data to identify the collision have not been available *(Hara, 2010*) Basic research about the conflict between wildlife biodiversity and road systems have only recently begun in China (*Kong et a.l, 2013*).

One study made in South America by *Cuyckens et al., 2015* focused on the patterns and composition of roadkill wildlife in Argentina, presented the first results on the composition of animals killed on the principal, paved road of 255km length in Northwest Argentina with the grey fox (*Lycalopex gymnocercus*) being most common species killed.

In the study by *Saenz & Telleria, 2015*, they described the involved animals and evaluated the economic cost of this human-animal interaction in Spain. Results showed that wild boar (*Sus scrofa*) and roe deer (*Capreolus capreolus*), two abundant free-ranging ungulates whose populations have expanded throughout Spain during the last decades, were involved in 79% of WVCs. Their results also provided a reliable picture of WVCs in Spain and provide the first assessment of the economic cost of this wildlife-human interaction (105 million Euros annually).

3.2.2 WVCs in Central Europe Region

In Europe (excluding Russia) close to half a million deer are estimated to be hit by vehicles every year, leading to over 300 human fatalities, 30,000 human injuries and with damage to property exceeding $ 1 billion (*Pokorny, 2006*).

In the Czech Republic during the period of 1993 to 2012, every 769th person on the road was killed in crashes involving domestic and free-ranging animals (*Kušta et al., 2016 ex Besip, 2013).* This highlights the severity of WVCs since the Czech Republic has a relatively high density road network but the core network of motorways and expressways has still not been completed and does not correspond to the country's real needs. (*Keken et al., 2016).* Most common species subject of WVC in the Czech Republic, are roe deer (*Capreolus capreolus*), red deer (*Cervus elaphus*) and wild boar (*Sus scrofa*) (*Kušta et al., 2016 ex Cerveny et al., 2013).* According to the *Police of the Czech Republic (2014)* the estimated annual physical damage to vehicles in those collisions is over 88 million Euros (*Kušta et al., 2015)* but the damage caused to wildlife is uncountable.

3.3 Main factors causing WVCs

To avoid these collisions is to know where and when they happen. Traffic, landscape, and animal behavior factors may contribute in a different way to the occurrence of wildlife-vehicle collisions. For developing knowledge-based mitigation to reduce the effects of wildlife-vehicle collisions and increasing public safety on highways, these factors are critical (*Gunson et al., 2005*).

3.3.1 Traffic related factors

Traffic-related factors and their impact on wildlife-vehicle collisions have been a subject of research published by various authors (*Kušta et al., 2016; Ng et al., 2008; Oxley et al., 1973; Sullivan et al., 2009)*. *Kušta et al., 2016* studied the effect of traffic intensity and animal activity on probability of WVCs in Czech Republic. Using Spearman's rank P correlation coefficients, they examined the relationship between WVCs and traffic intensity fluctuation, as well as between WVCs and animal activity. Their results showed that is not always the case that traffic intensity is the main factor causing WVCs but rather minor factors such as locomotory activity can play a much more important role than previously thought. In another study, *Ng et al., 2008* analyzed the landscape and traffic factors influencing WVCs using a multivariate logistic regression to determine which factors increased the probability of WVC. Their model showed that there is a positive correlation between WVCs and speed limits. In one of the first studies about traffic related factors *Oxley et al., 1973* investigated the effects of roads on small mammals by using a trapping method to gather the data and observe the patterns on wildlife-vehicle collisions. Results showed that animals suffer greater mortality with higher traffic volume and higher driving speeds; also, they concluded that road mortality rises with increasing road improvements. *Danks & Porter, 2010* also found that wider roads tend to increase the risk of WVCs. According to the *Sullivan et al., 2009* study on trends of wildlife-vehicle collisions, results showed that the relative risk that a non-fatal and fatal collisions occurred in darkness, suggesting that a driver's limited vision at night plays a role in WVCs, the author mention that taking some counter step to extend the driver's forward view of the road may help to reduce the risk of a collision.

It has been shown that speed limit may play an important factor on WVCs; a fatal WVC would become non-fatal by a simple reduction of impact velocity, resulting from a reduced speed and even the avoidance of a WVCs (*Sullivan et al., 2009*). Nevertheless, lower traffic volume does not mean fewer WVCs, as traffic alone does not inhibit road-crossing by mammals (*Oxley et al., 1973*). The *Kušta et al., 2014* study demonstrated that most of the WVCs happened at times of lower traffic volume. Regardless of all the studies about traffic related factors there is a need for more research in this area.

Some authors make proactive recommendations like *Ng et al., 2008* and *Underhill & Angold 2000*. They concluded that the rates of WVCs could decrease and road safety could be improved by lowering speed limits during peak seasons, particularly in the areas where road density is high, also recommend the reduction in the width of the road. *Oxley et al.,* *1973* and *Jackson et al., 2000* both recommend recognizing the long-term ecological costs of roadways in the early planning of transportation infrastructures.

3.3.2 Landscape related factors

Previously, many studies have examined numerous habitat and landscape variables that are thought to influence the occurrence of vehicle collisions with the wildlife. (*Jensen et al., 2014; Danks & Porter, 2010; Girardet et al., 2015; Gunson et al., 2005; Ng et al., 2008; Neumann et al., 2011; Keken et al., 2016*). For example, *Jensen et al., 2014,* using geospatial technologies, showed that elevation and slope were significantly different in the immediate area around WVCs than in parts of the roads with no collisions. Results revealed that elevation was significantly lower around WVC, slope was significantly greater, and showed that there was no difference in overall vegetation. This may occur because deer tend to be more active in the lower elevations and use steeper slopes for cover. These results may differ with the work of *Danks & Porter, 2010* where the results showed the mean slope was 7% lower and mean elevation was 21% higher at the WVC compared to random points. Their analyses also showed that the proportion of cutover forest within 2.5 km of the road was positively correlated with the probability of a collision, implying that this reflects the preferable foraging conditions for moose in these areas of timber harvesting.

WVCs are common on roads with adjacent clear-cuts and young forest plantations *(Danks & Porter, 2010 ex. Seifler, 2004*). *Girardet et al., 2015* focused on the landscape network influence on the location of deer/vehicle collisions hotspots; they ascertained roe deer hotspot locations by using a predictive model combining landscape composition variables. Their study demonstrated roe deer kills are not randomly distributed. Their locations are influenced by the landscape context of road sections, especially the proportion of forest and cultivated fields within a radius of 1000m promotes roe deer kills. In another study, *Gunson et al., 2005* examined numerous habitat and landscape variables that are thought to influence the occurrence of vehicle collisions. The results showed WVCs were less likely to occur in open water, rock, and close coniferous forest relative to open habitats. In another study from Korea, *Seo et al., 2013,* recorded and analyzed cumulative roadkill data using a multiple logistic regression analysis and determined that the significant site and landscape factors that influence roadkill hotspots are a high percentage of water and rice paddies in the landscape, a high percentage of natural vegetation, an absence of road banking, and drainage. *Cuyckens et al., 2015* investigated the patterns of roadkill in Argentina, and they concluded the proportion of agricultural landscape increased the number of killed mammals. *Ng et al., 2008* studied the landscape factors influencing deer/vehicle collisions; these factors were analyzed using ArcGIS 8.3 and indicated that the deer/vehicle collisions are more likely to occur in areas with low road densities, since those areas are usually surrounded by more deer habitats.

According to *Neumann et al., 2011* their study of the difference in spatial-temporal patterns of wildlife/vehicle collisions concluded that the likelihood of collisions increased with the abundance of human-modified areas and higher-allowed driving speeds. Also, data showed that the risk of collisions was lower on forest roads. In highly-modified landscapes some species respond by becoming increasingly sedentary. Isolation is intensified by genetic and behavioral modifications of the species (*Underhill & Angold, 2000*). Another study done in the Czech Republic, *Keken et al., 2016* investigated the landscape structural changes and their role in WVC, using aerial photos from 1950 and 2012 to analyze the changes in landscape structure based on the use of a geographic information system. Results stated that each hotspot has had a relatively high reconfiguration of the landscape structure, and this activity has resulted in low landscape permeability and a much higher risk of WVC.

The results of these studies are an important step towards a better design of road infrastructure, providing a basis for developing more practical models for use in the planning and designing of road networks (*Keken et al, 2016*).

3.3.3 Animal related factors

Sullivan et al., 2009 study showed the pattern of fatal WVC follows both the diurnal and seasonal activity pattern of deer and moose. The hourly pattern confirms reports that the highest WVC risk occurs an hour after sunset, and the daily WVC levels follow the sun cycle throughout the year and are consistent with the known seasonal behavior of animals like deer and moose: mating, migration and yearling dispersal. It has also been demonstrated that the animals like elk avoided highways at times when traffic volume was high, tending to cross the highway in times during migratory season. (*Jensen et al, 2014*).

According to *Kušta et al., 2014* study, the higher occurrence of WVCs in spring and summer might be related to offspring dispersal and the search for new territory; movement activity tends to be higher in this period, since winter is the lean period in terms of food availability and quality, and the presence of snow combined with scarcity of food affects the movement of ungulates (*Kušta et al., 2014 ex Marchand, 1996*). The main peaks of WVCs occur at the times when animals are the most active, which are sunrise and sunset (*Pokorny et al., 2006; Kušta et al., 2016).*

Climate change could also enhance behavioral patterns even more, so interactions of roads with climate change are also important and there is a need for more research. (*Cuyckens et al, 2015).*

Some authors state that this forest management problem could be solved by means of intense supplementary feeding, which would make ungulates remain in a limited area and prevent them from crossing road while looking for food. (*Kušta et al., 2016*) It is also important to inform the drivers about the risks of collisions; a focus on driver attitudes may also help to reduce wildlife collisions (*Neumann et al., 2011*).

3.3.4 Landscape fragmentation

New roads will inevitably lead to habitat loss, barriers for most of the species and fragmentation of previously continuous habitat (*Underhill & Angold, 2000; Fu et al., 2000*). The fragmentation caused by roads is usually abrupt and often severe, and there is frequently a simultaneous reduction quality and population size (*Underhill et al., 2000*). Consequently, landscape fragmentation and habitat loss is one of the biggest problems for biodiversity conservation.

Fu et al., 2010 focused their work on the characterization of the fragmentation-barrier effect of road networks on landscape connectivity in China. The probability-of-connectivity index was used to evaluate the effects of road networks and their ecological impacts, and the results show that the combined fragmentation and barrier effects of road networks considerably degrade landscape connectivity; the fragmentation barrier-effect can affect connectivity to a bigger degree for ecological processes, for instance having low movement of genes, individuals, species and populations. Our perception of the landscape differs from the one that animals have, therefore we shouldn't think just on our protected areas but the connection in between and connecting these areas so they can achieve the needs of the animals *(Anonymous)*. Such connectivity is considered really important; therefore, it should be studied.

There are natural barriers like mountains, lakes and major rivers, but there are as well barriers made by man such as roads, railroads, built-up areas, and power transmission lines. These barriers are perceived by wildlife to be impossible, or dangerous, to cross (*Wildlife Institute of India 2011*), leading to small and isolated populations that are vulnerable to extinctions in heterogeneous landscapes because of inbreeding depression. (*Underhill 2000*; *Siers et al., 2015*). With the increasing human population and its increasing demands on transport, the widening of existing highways and railways is inevitable, and this will increase their barrier effect and higher volumes will contribute to an even stronger barrier effect. However, *The European Environment Agency 2011*, suggests the upgrading of existing highways is still less detrimental than the construction of new highways at another location.

Large unfragmented areas are a limited and non-renewable resource. This fact is particularly important to consider in Europe, where high human population density competes for land better used for the promotion of biodiversity. Land and soil are finite, and their destruction is irreversible within human life spans. The land in Europe has measurable economic value as "ecosystem services". The importance of protection of the remaining large unfragmented areas is a measure of high priority, and it should be implemented immediately, based on existing maps and existing knowledge about habitat types, habitat amount, and habitat quality. These areas should cover habitats of a range of species *(EEA, 2011)*.

Even if all future landscape and habitat fragmentation stopped, some wildlife populations would still disappear over the coming decades, due to their long response times to the alterations that have already occurred. This effect has been called the “extinction debt of altered landscapes” *(EEA,2011 ex Tilman et al., 1994).* Therefore, new baselines are needed that measure various pressures or threats to biodiversity. Clearly, fragmentation analysis must be integrated into transport and regional planning so cumulative effects are considered more effectively in the future *(EEA, 2011).*

4 Methodology

4.1 Study area

This study was conducted in the Czech Republic (Fig. 1), which is located in Central European Region sharing borders with Germany to the west, Austria to the south, Slovakia to the east and Poland to the northeast. With a total area of 78,867 km^2, population of 10,578,820 inhabitants and with a population density of 134 inhabitants per km^2 *(CSO, 2016)*. The Czech Republic lies on a temperate climate zone, having the difference in temperature between summer and winter relatively high due to the landlocked geographical position. The arable lands cover most parts of the territory with 38%, forests cover approximately 34%, agricultural plots 15%, built up and other areas 11% and water surface 2% *(CSO, 2016)*.

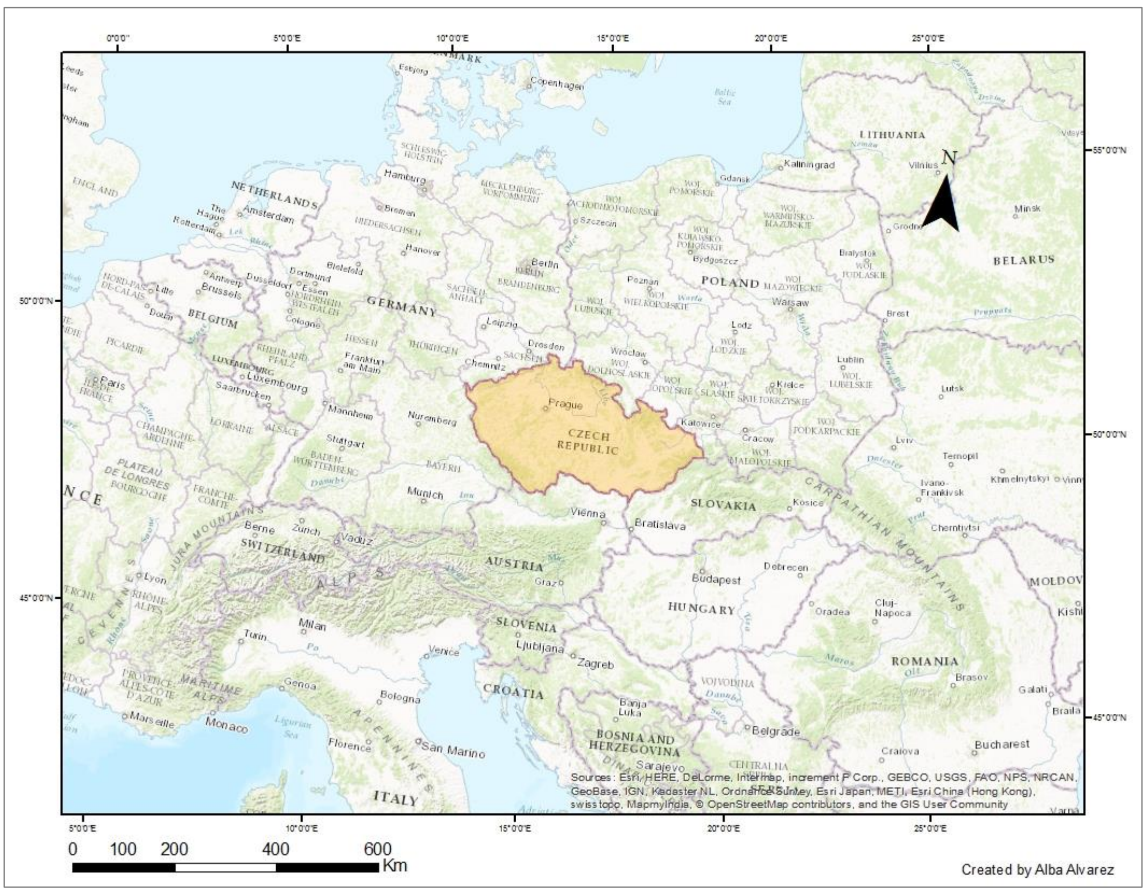


Figure 1. Location of the Czech Republic in Europe

Czech Republic's major industries are engineering and machine engineering, metallurgy, chemical production, followed by the energy industry and civil engineering. One of the main pillars of the engineering industry is the automotive industry, not only because employs a lot of people but also because it has a long tradition and produces more than a million vehicles annually. According to the Czech Statistic Office in 2010, 54.2% of export was from products of the automotive industry. The largest and most significant producer of vehicles in the Czech Republic is Škoda Auto.

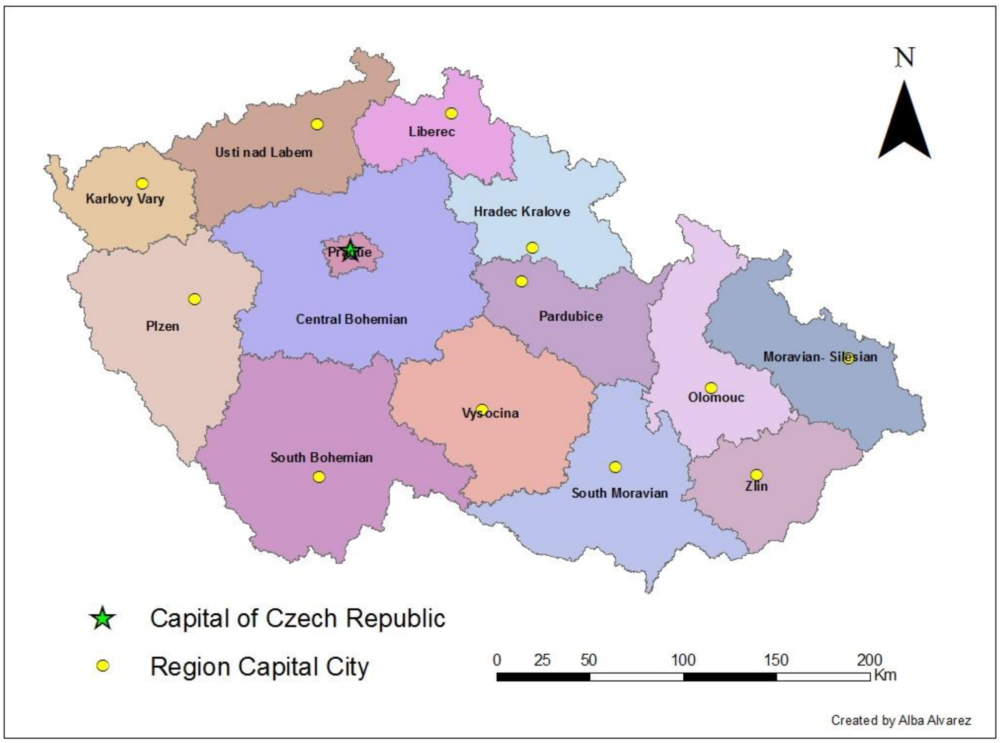


Figure 2. Map of Regions of the Czech Republic

Czech Republic is divided into 14 regions (Fig. 2). The capital and largest city is Prague situated in Central Bohemian region with 1.2 million inhabitants and with a population density of 2565 inhabitants per km^2. The next largest cities are Brno with a population of 380,000 situated in South Moravian Region, Ostrava located in the region of Moravian-Silesian with 300,000 inhabitants and Plzen with the population of approximately 180,000. Czech Republic is fundamentally a country of small cities and towns, all well connected.

Region	Capital	Population	Area [km^2]
Prague	Prague	1,272,690	496
Central Bohemian	Prague	1,274,633	11,015
South Bohemian	Ceske Budejovice	637,460	10,057
Vysocina	Jihlava	512,727	6,796
Plzen	Plzen	574,694	7,561
Karlovy Vary	Karlovy Vary	310,245	3,314
Usti nad Labem	Usti nad Labem	830,371	5,335
Liberec	Liberec	439,262	3,163
Hradec Kralove	Hradec Kralove	555,683	4,759
Pardubice	Pardubice	505,285	4,519
Olomouc	Olomouc	639,946	5,267
Moravian- Silesian	Ostrava	1,236,028	5,427
South Moravian	Brno	1,169,788	7,150
Zlin	Zlin	590,459	3,964

Table 1. Regions in the Czech Republic *(Wikipedia)*

4.2 Data

4.2.1 Wildlife Vehicle collisions

The information on wildlife vehicle collisions from the years 2009 to 2014 were obtained by the Traffic Police of the Czech Republic *(Police of the Czech Republic, 2014)*. The data collected for each collision included the date, time, and the exact GPS position. However, the information about animal species involved was not recorded by the police. The data from the Traffic Police are only records of such accidents in which the character of the accident led to the requirement for a police officer to have visited the scene of an accident (death of persons, injury of persons, total damage exceeding 100,000 CZK or damage caused to a third party) (*Kušta et al., 2016)*. Consequently, unreported wildlife vehicle collisions were not included in this study.

The number of collisions over the years 2009-2014 has been increasing dramatically. In 2009 this number was 2838, while in 2014 it was almost the triple with 7492 collisions.

The spatial distribution of all the WVCs happened during the years 2009-2014 is depicted in Fig.3.

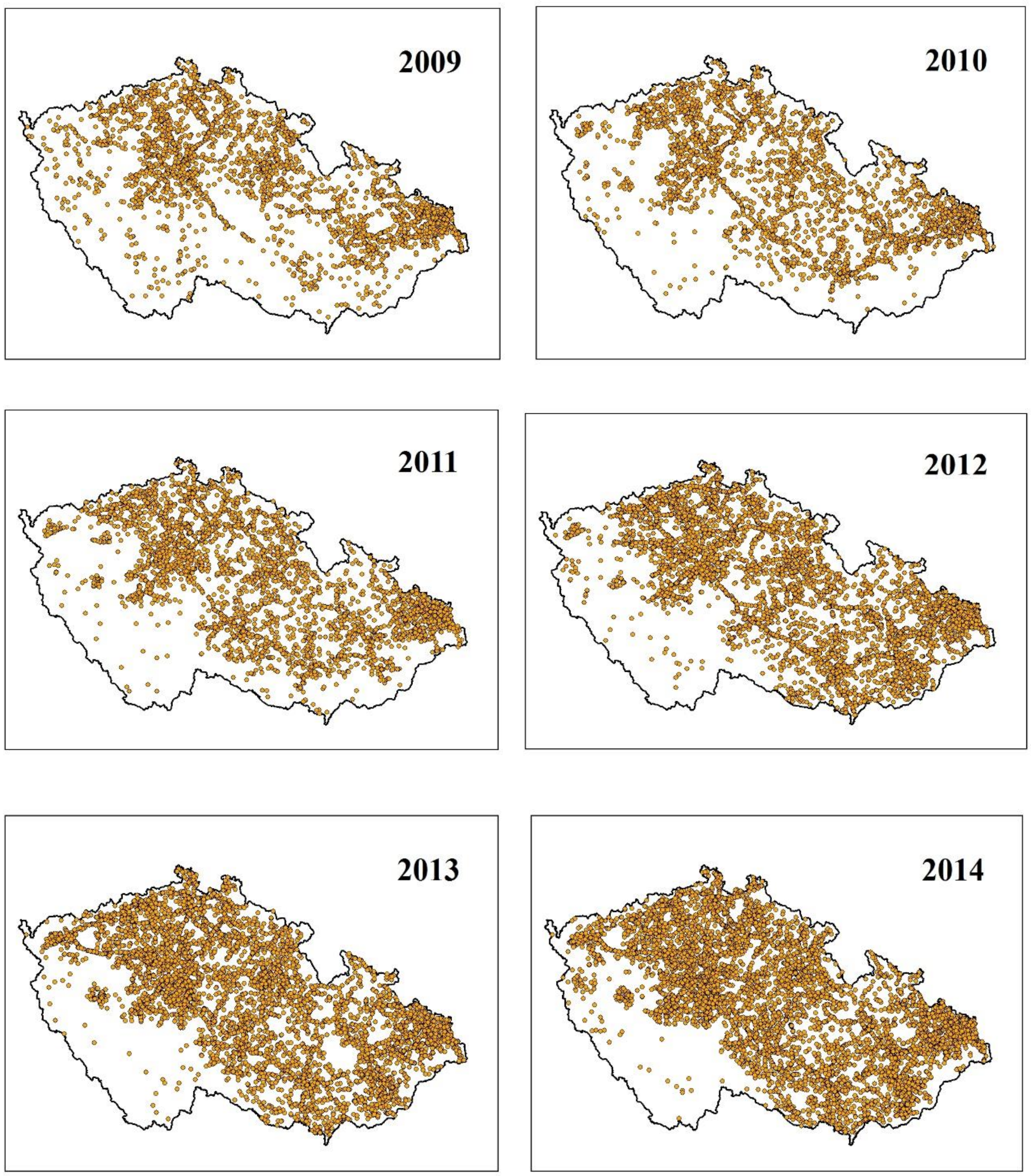


Figure 3. Spatial distribution of WVC in the Czech Republic in 2009-2014

Looking at the distribution of WVCs across the regions in the Czech Republic in the year 2014 (Fig. 4), we can see that most of them contain the very similar number of collisions (501 - 1000). The highest number of collisions is in Central Bohemian region (1700), probably caused by highest population and the highest number of vehicles. On the other hand, South Bohemian region presents the lowest number of collisions (13), but does not reflect the reality since the Traffic Police in this region has separate way of reporting the collisions and many of these accidents are not being recorded.

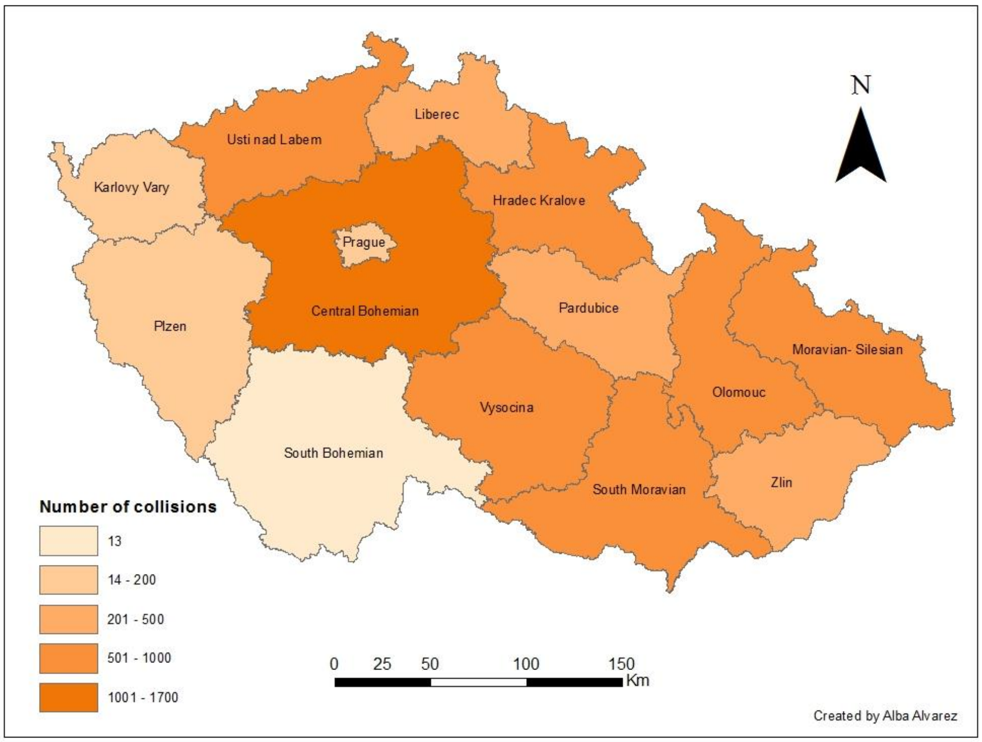


Figure 4. Number of collisions per region in 2014

4.2.2 Road Network

Czech Republic holds one of the most advanced transport networks in Central and Eastern Europe. Its geographical position in the middle of Europe makes it a natural crossroad for major transit corridors. The dense road network does not only serve the Czech Republic but also links the neighboring countries *(Czech Invest, 2017).* According to the report of the European Environment Agency 2011, Czech Republic is one of the highly-fragmented countries in Europe, together with are Belgium, Germany, France and Poland.

Roads in the Czech Republic are categorized as following: 1st class roads, 2class roads, motorways, expressway and others. For the purpose of this thesis, 1st class road and 2nd class roads were selected for the further analysis (Fig. 5). 1st class roads are designed for long-distance and international traffic. 2nd class roads are designed for traffic between districts. Motorway is a main road specially built for fast-moving traffic, having limited access, and present several lanes. An expressway is the highest-grade type of highway with limited access.

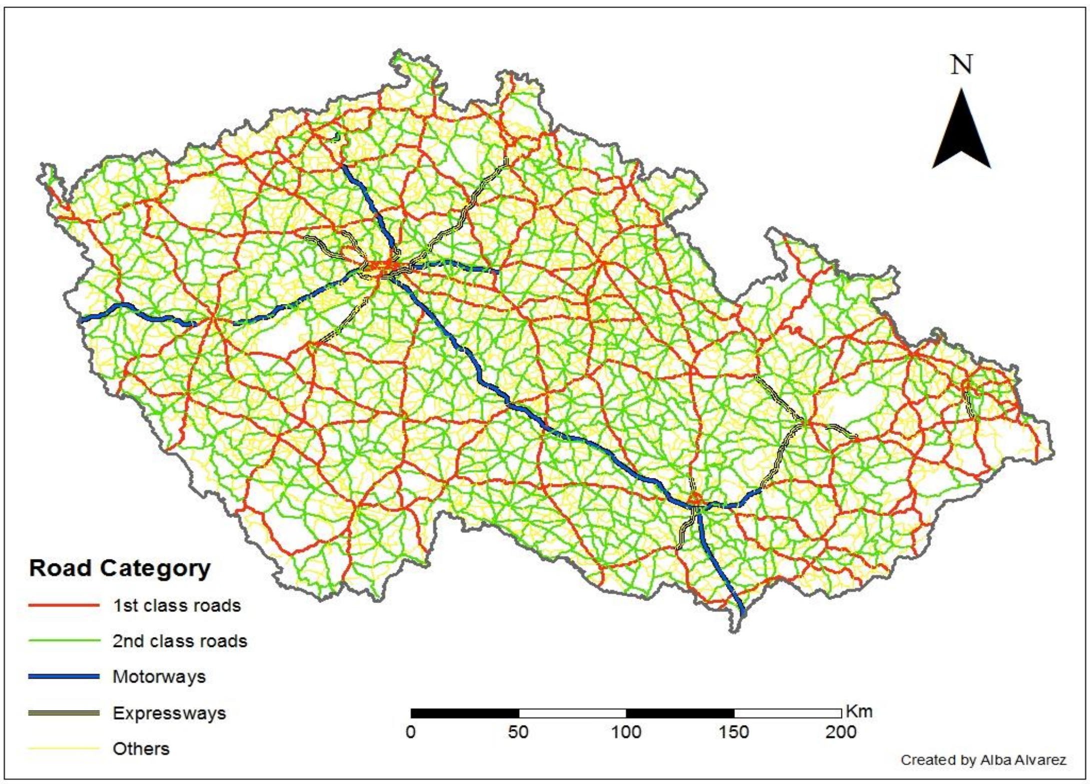


Figure 5. Road network in the Czech Republic in 2014

Road Category	1st class road	2nd class road	Motorways	Expressways	Others
Length (Km)	5647.67	13975.88	513.5	320.56	18894.02

Table 2. Roads category and length in 2014

Looking at the comparison between the total length of the roads in the Czech Republic and the number of collisions per year (Fig. 5), we can observe the constant growing trend of number of collisions while the growth of the road network not being that steep (in 2009, it was 55,653 km while in 2014 it was 55,747 km with an increase of just 94 km) *(Ministry of Transport Czech Republic, 2016)*. The reason for such trend can lay within the fact that instead of new roads being built the current ones are being upgraded, making crossing even more challenging for animals.

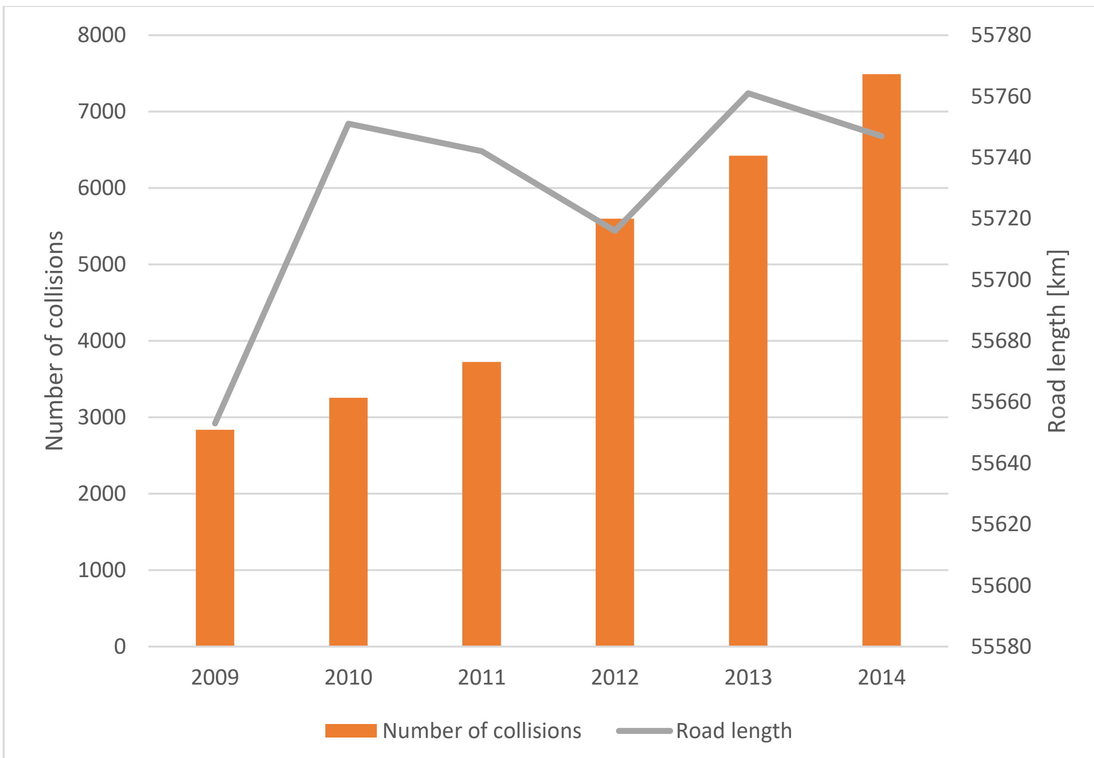


Figure 6. Number of collisions per year

4.3 Analysis

4.3.1 Software description

ArcGIS is a geographic information system for working with maps and geographic information, developed by ESRI company. It is used for analyzing mapped information and creating maps by compiling geographic data. This technology has a variety of uses in different disciplines. In ecology, there are many spatial components that are worth studying using GIS, for example the distribution of endangered species or the movement of the animals.

For the purpose of this study, ArcGIS 10.4 was used as a system to approach the problem of wildlife vehicle collisions caused by the landscape fragmentation. The access to this software was granted by the department of Applied Ecology of Environmental Science Faculty.

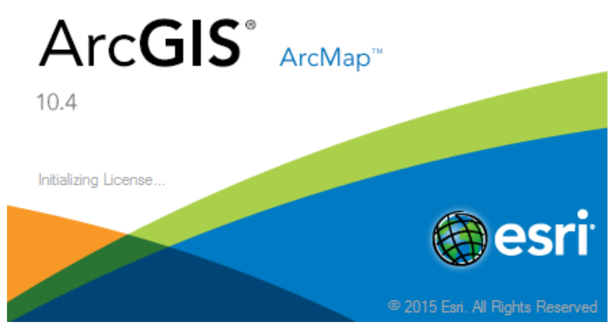


Figure 7. ArcGIS 10.4

R Studio is a cross-platform integrated development environment (IDE) for the R programing language. The R language is widely used among statisticians and data miners for developing statistical software and data analysis. In this study, R studio was used for validating the initial hypothesis by using a correlation test.

Figure 8. R Studio

4.3.2 Data preparation

In order to start with the analysis, firstly the data of both WVCs and Roads had to be inserted into ArcGIS. In case of the Roads, the data was distributed in the form of Shapefile by the Department of Applied Ecology of Environmental Sciences Faculty and therefore no further preparation was needed. As for WVCs data, since it was distributed by the Transport Police of the Czech Republic in the form of Excel files, it had to be converted to the Shapefile first, making it possible to work with it in ArcGIS. Considering that the collisions have spatial information (X and Y coordinates), the option *Display XY Data* was used to depict the data in the ArcGIS (Fig. 9).

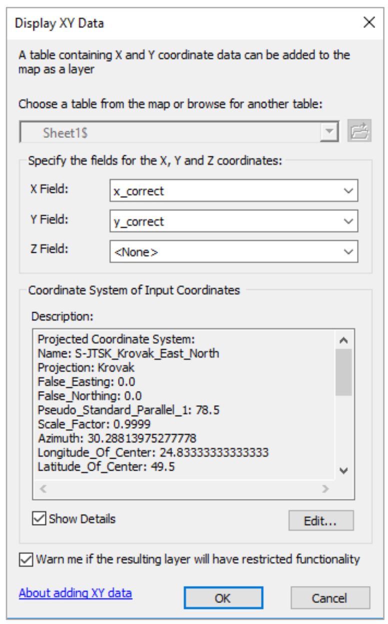


Figure 9. *Display XY Data* function in ArcGIS

4.3.3 Data Analysis

To ensure accuracy during the interpretation, the roads and collisions layers have been projected to the coordinate system *S-JTSK Krovak East North*, widely used in national mapping for Czech Republic and Slovakia.

The complete process of analyzing the data can be divided into the following parts:

A. Construction of road polygons

B. Calculation of each polygon's road density

C. Identification of WVCs for each polygon

D. Examining the relationship between the number of collisions and road density

A. Construction of road polygons

The first step in the analysis was to identify the core area of the polygons, which are formed by crossing of the roads of the 1st class and roads of the 2nd class. In order to do so, firstly two new Shapefiles were created: one containing only the 1st class roads and the second one containing the 2nd class roads. That was done by performing *Select by Attributes* function over the original Roads Shapefile.

Afterwards, using the ArcGIS function *Construct Polygons,* the 1st and 2nd class road Shapefiles were converted from polylines to polygons. To be able to work with this function, it was necessary to enable *Advanced Editing* tool. The results of this operation are depicted in Fig. 10 for the 1st class roads and Fig. 11 for the 2nd class roads. Looking at the newly created polygons, it can be seen that they do not cover the whole area of the Czech Republic. That is caused by two main reasons: firstly, the country borders were not included in the analysis since they represent natural borders and not roads; secondly, there were some roads that did not finish by meeting another road and therefore did not form any polygon.

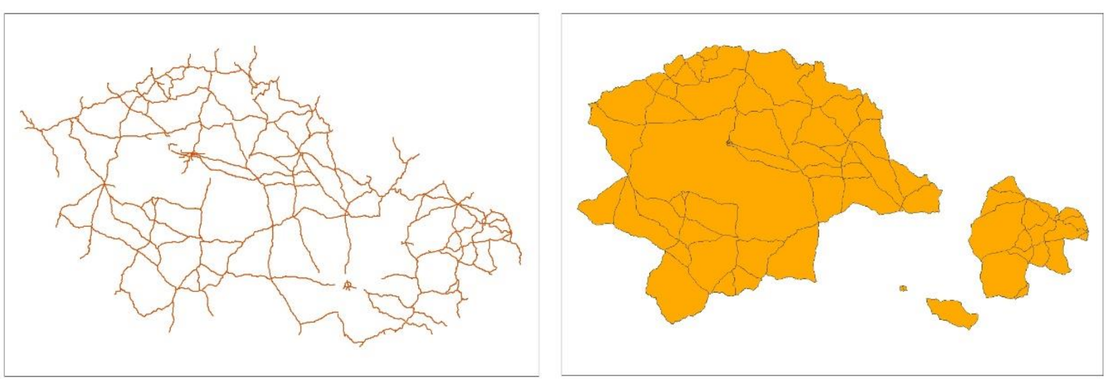


Figure 10. Construction of polygons from 1st class roads.

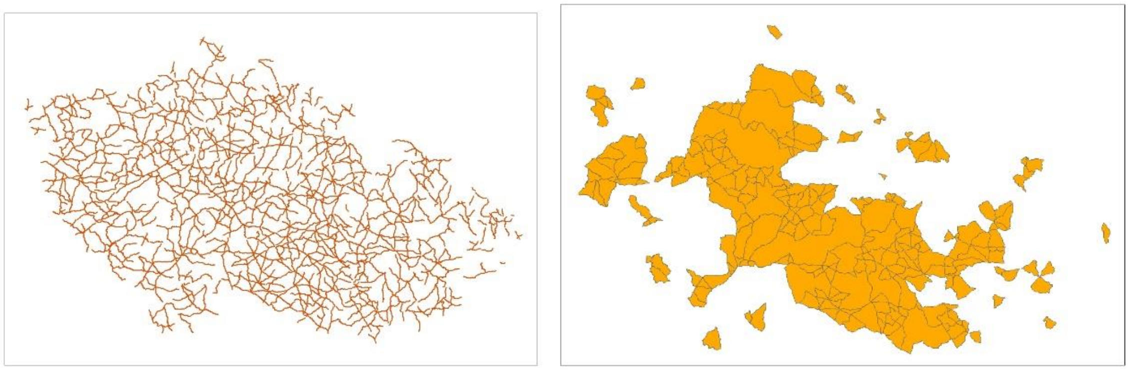


Figure 11. Construction of polygons from 2nd class roads

B. Calculation of each polygon's road density

The second step in the analysis was to calculate the road density of each polygon. For the 1st class roads polygons, the road density of polygon *p* was calculated as follows:

$$road\ density^{p}_{1^{st}\ class\ road} = \frac{length\ of\ roads^{p}_{2^{nd}\ class\ road\ and\ lower}\ [m]}{area^{p}\ \ [km^{2}]}\ (Eq. 1)$$

For the 2nd class roads polygons, the road density of polygon *r* was calculated as follows:

$$road\ density^{r}_{2^{nd}\ class\ road} = \frac{length\ of\ roads^{r}_{lower\ than\ 2^{nd}\ class\ road}\ [m]}{area^{r}\ \ [km^{2}]}\ (Eq. 2)$$

In both equations, the denominator (the area of the polygon) was calculated in the same way, by creating a new field in the attribute table of roads polygon Shapefile and performing *Geometry Calculator* function to calculate the area.

In order to calculate the nominator of both equation (length of the roads), firstly, *Intersect* function was utilized (Fig. 12). This spatial analysis tool allows us to combine the input files of different data types, in our case newly created roads polygons and original roads polylines and produce the final output as an intersection of them (Fig. 13). Additional advantage of this tool is that it preserves the attributes of all the data sets entering the function.

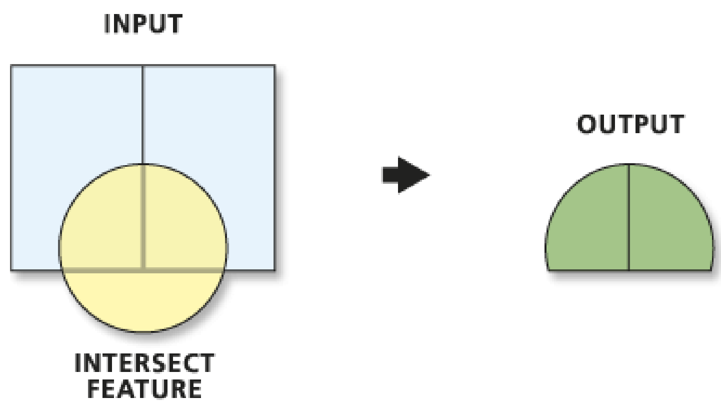


Figure 12. *Intersect* function

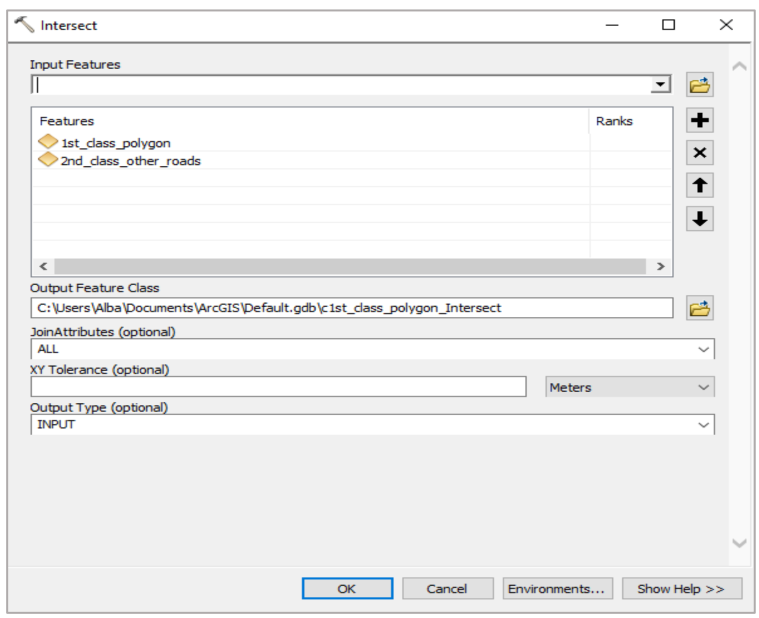
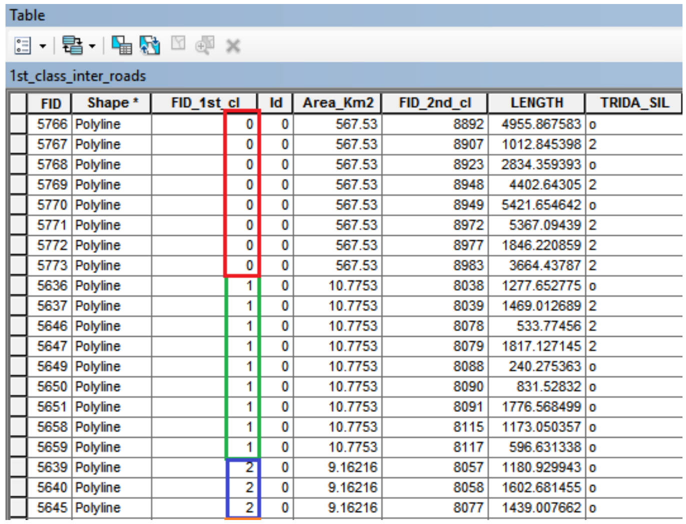


Figure 13. *Intersect* function in ArcGIS

In the second step, the output file produced by *Intersect* function needed to be further processed since it did not contain the road length aggregated for each polygon. This can be clearly seen from Fig. 14, where for the polygon with ID = 1 there are 9 records instead of 1. The aggregation was performed by using *Summarize* function over the ID attribute, producing table displaying the total road length for each polygon.

As the final step, the aforementioned output table had to be joined with the roads polygon Shapefile (Fig. 15), making it possible to calculate the road density for each polygon.



Table

1st_class_inter_roads

FID	Shape *	FID_1st_cl	Id	Area_Km2	FID_2nd_cl	LENGTH	TRIDA_SIL
5766	Polyline	0	0	567.53	8892	4955.867583	o
5767	Polyline	0	0	567.53	8907	1012.845398	2
5768	Polyline	0	0	567.53	8923	2834.359393	o
5769	Polyline	0	0	567.53	8948	4402.64305	2
5770	Polyline	0	0	567.53	8949	5421.654642	o
5771	Polyline	0	0	567.53	8972	5367.09439	2
5772	Polyline	0	0	567.53	8977	1846.220859	2
5773	Polyline	0	0	567.53	8983	3664.43787	2
5636	Polyline	1	0	10.7753	8038	1277.652775	o
5637	Polyline	1	0	10.7753	8039	1469.012689	2
5646	Polyline	1	0	10.7753	8078	533.77456	2
5647	Polyline	1	0	10.7753	8079	1817.127145	2
5649	Polyline	1	0	10.7753	8088	240.275363	o
5650	Polyline	1	0	10.7753	8090	831.52832	o
5651	Polyline	1	0	10.7753	8091	1776.568499	o
5658	Polyline	1	0	10.7753	8115	1173.050357	o
5659	Polyline	1	0	10.7753	8117	596.631338	o
5639	Polyline	2	0	9.16216	8057	1180.929943	o
5640	Polyline	2	0	9.16216	8058	1602.681455	o
5645	Polyline	2	0	9.16216	8077	1439.007662	o

Figure 14. Output Shapefile produced by *Intersect* function

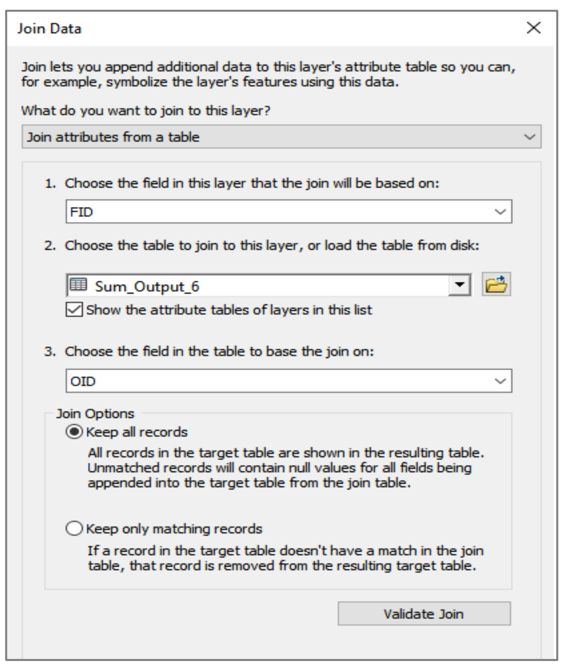


Figure 15. *Join* function in ArcGIS

C. Identification of WVCs for each polygon

The third step in the analysis was the identification of the number of WVCs for each of the polygons created. Before doing that, the original collisions data for the years 2009-2014 had to be filtered in way that only the 1st and 2nd class roads collisions were taken into consideration due to the fact that the analysis itself was performed on the 1st and 2nd class roads. That was done using *Select by Attributes* function by simply restricting the road class attribute (Fig. 16) and exporting the data as a new layer.

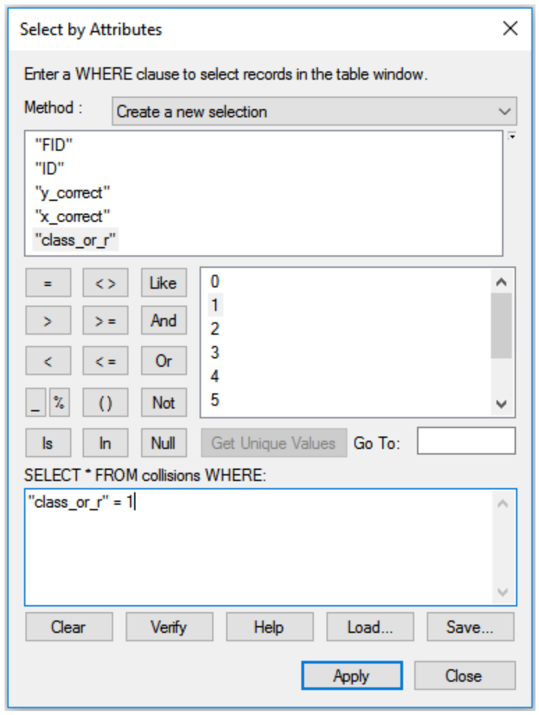


Figure 16. *Select by Attributes* function in ArcGIS

Examining the collisions more in detail, it was observed that not all of them were coinciding with the roads as expected (Fig. 17). In order to fix such anomaly, most probably caused by not the same accuracy of the roads and collisions data, the *Snap* tool was utilized. What this tool did was that it moved every point (collision) that was not coinciding with the line (road) to the line that was closest to its position.

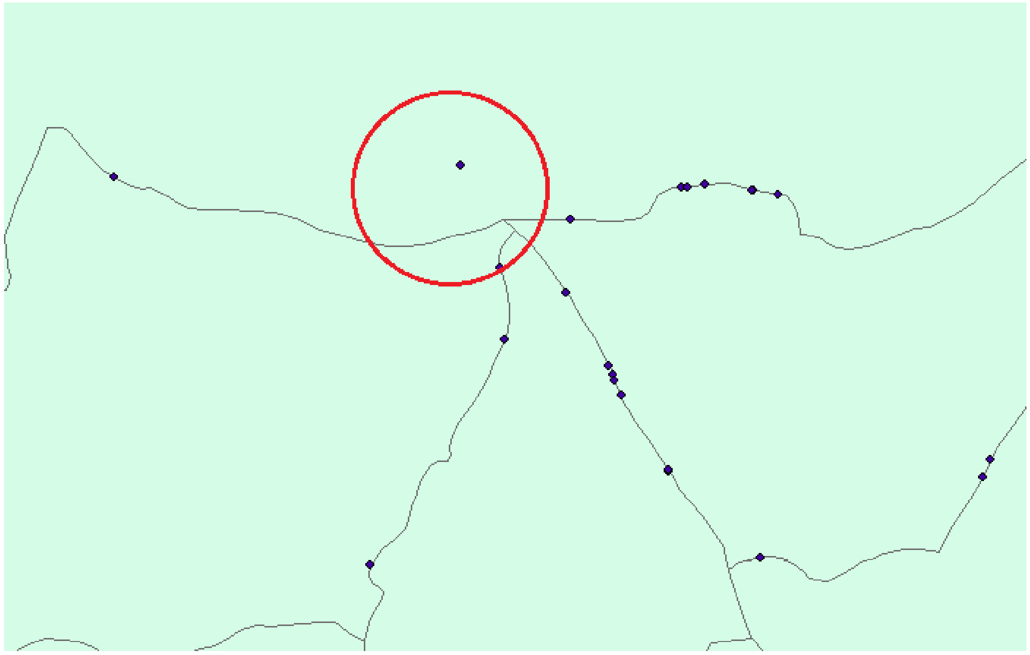


Figure 17. Misplaced collisions data

Finally, the number of the collisions that happened in the perimeter of every road polygon was calculated. In order to do that, the function *Select by Location* was used, as can be seen from Fig. 18. However, as this process would have to be repeatedly performed for each and every polygon of the 1st and 2nd class road. The ArcGIS in-built tool *Model Builder* was used instead. *Model builder* puts together sequences of geoprocessing tools, making the output of one tool as the input of the next one and this way creating workflows. It's a very useful application for making the task more efficient and this way creating your own tool.

The model constructed for the automatization of the calculation of the number of collisions in the perimeter of each polygon is depicted in the Fig. 19. One can imagine it as repeated performing of *Select by Location* function over the collisions data for each road polygon. The output of the model is a list of the number of collisions for each road polygon sorted by the polygon's ID.

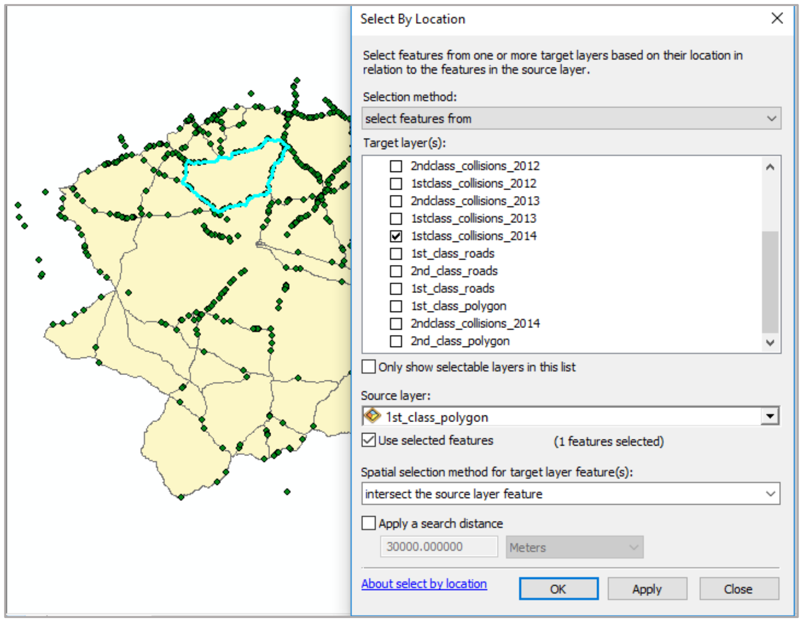


Figure 18. *Select by location* function in ArcGIS

The model starts with a feature class of roads polygons (in this case 1st class road polygons). This feature is connected to an iterator that will run continuously on each individual polygon and count the number of collisions using the *Select Layer by location* tool. *Get count* will sum the number of records returned by the *Select Layer by location* tool and *Collect values* intends to convert a list of multivalues into a single input. The same logic applies for the 2nd class road polygons as well.

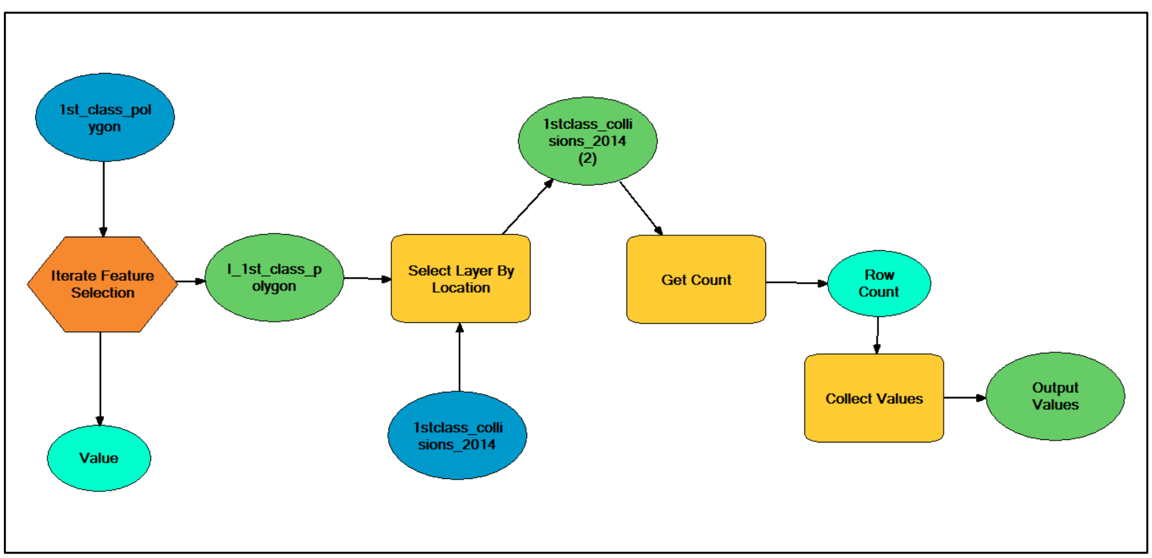


Figure 19. Model created for this study

D. Examining the relationship between the number of collisions and road density

In the last step of the analysis, the relationship between the number of collisions and the road density was examined. This part of the analysis was performed in R Studio. Firstly, the data containing the number of collisions and the road density for each road polygon were imported into the software in a form of Excel file. Afterwards, the Spearman's rank correlation test was performed in order to validate the initial hypothesis formed as "the higher the road density, the higher the number of collisions".

Spearman's correlation test is a nonparametric measure of the statistical dependence between the ranking of two variables X and Y, in this case X variable representing the road density and Y variable representing the number of collisions. The results of the test are characterizing by two main values: r_s (rho) and p-value. Rho value is always between -1 and +1, where -1 represents the strongest negative relationship between two variables, 0 represents no relationship and +1 represents the strongest positive relationship between them. P-value indicates the significance of the test itself; generally, if such value is lower than 0.05 then the results of the test can be treated as significant.

The whole workflow performed in R studio is depicted in the following code snippet:

```
# importing the data from Excel into R studio
library(readxl)
Second_class_2014 <- read_excel("C:/Users/Alba/Desktop/Second_class
2009.xlsx")
View(Second_class_2014)


# making data frame from imported data
attach(Second_class_2014)


# loading ggplot2 library in order to display the data
library(ggplot2)


# displaying number of collisions versus road density
```

```
ggplot(Second_class_2014,aes(x=Density,y=Collisions)) + geom_point() +
xlab(bquote('Road density ['*'m /'~km^2 *']')) + ylab("Number of
collisions")


# spearman's correlation test
cor.test(Density,Collisions,method = "spearman")
```

5 Results

While the Section 4 describes the methodology that author applied in order to verify the initial hypothesis of this thesis formed as “the higher the road density, the higher the number of WVCs”, this section strives to present the output of this whole process.

The scatterplot of roads density and number of WVCs serves as a first indicator of the type of the relationship that these variables exhibit (Fig. 20). We can consider such relationship to be monotonic, having a few outliers around. The similar trend is present for all other relationships tested (number of WVCs over the years 2009 – 2014 and the 1st and 2nd class roads density) and can be further explored in the Appendix A.

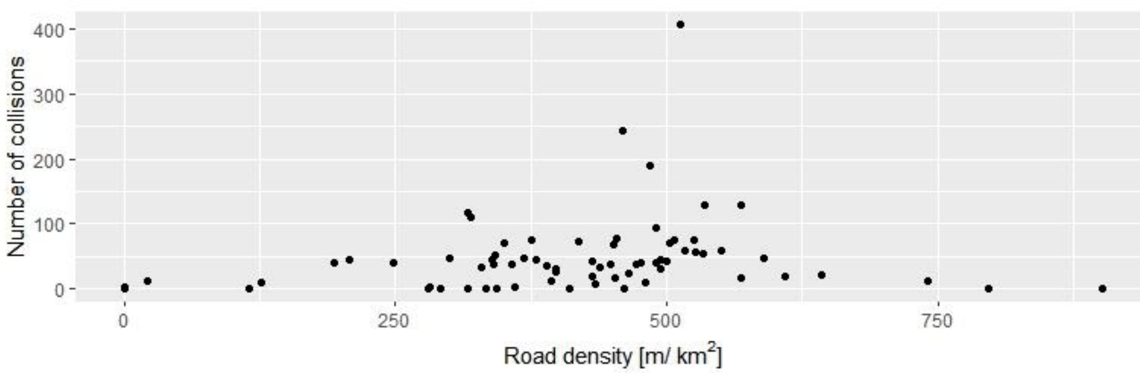


Figure 20. Number of collisions vs Road density on 1st class roads 2014

Spearman’s correlation coefficients r_s indicate us a strength of the relationship between the aforementioned two variables (Table 3). As can be seen, such values oscillate between 0.26 to 0.37, indicating the positive relationship between them, although not as strong as probably could be expected. Also, it can be observed that the relationship of the 1st class polygons roads density with the number of WVCs proves to have stronger correlation than the relationship between the 2nd class roads polygons density and number of WVCs.

	Year	2009	2010	2011	2012	2013	2014
Road Category	1st class roads	0.334770	0.370902	0.350178	0.311824	0.311297	0.332851
	2nd class roads	0.298559	0.298559	0.316933	0.281510	0.261729	0.303346

Table 3. Spearman's correlation coefficient r_s

In order to consider the results presented by Spearman's correlation test as significant, one has to examine the *p* value as well. Looking at the Table 4, it can be stated with a confidence that the results of the Spearman's correlation test are significant, having *p* value lower than the threshold 0.05 for each of the cases.

	Year	2009	2010	2011	2012	2013	2014
Road Category	1st class roads	0.004049	0.00134	0.002566	0.007666	0.007775	0.004275
	2nd class roads	9.90e-07	9.90e-07	1.88e-07	4.19e-06	1.99e-05	6.49e-07

Table 4. Spearman's correlation test p values

6 Discussion

While the results of this work confirm the initial hypothesis stated and the correlation between the roads density and number of WVCs indeed exists, it proves to be not that strong as it was expected before the commence of the analysis. After further review, there were four main factors indicated which could possibly influence the results.

Firstly, the roads polygons that were created did not cover the whole area of Czech Republic, as could be initially assumed. This was caused by two main reasons: firstly, the borders of the country were not included in the process of polygons' construction as they do not necessarily represent roads but are rather natural borders; and secondly, there were some roads present that did not happen to be finished by meeting any other road and thus the polygons could not be created.

Secondly, the road network data used for the analysis were representing the reality as of year 2014. This could influence the quality of the results when estimating the number of WVCs within the roads polygons for the years 2009 – 2013. In the ideal situation, for each investigated year, there would be a road network data presented as well.

Thirdly, the accuracy of the road network data and collisions data was probably not the same. While the WVCs point data were collected using GPS (with no specified accuracy), the road network polyline data were probably created by digitization of the underlying raster data (assumed by the author). This resulted into the fact as described in the Section 4; there were cases when the position of the animal collision did not coincide with the 1st or 2nd class road exactly, making the final interpretation of the results possibly biased.

Lastly, the WVCs data did not represent all the collisions that happened in reality. As was revealed after the data visualization onto the map of the Czech Republic, the area of South Bohemian region lacked the high number of WVCs (Fig. 4). After further investigation, it was shown that the methodology that the Traffic Police in this region applies in collecting such type of data varies from the other regions, which subsequently reduces magnitude of it.

When approaching the last step of the analysis, and so the correlation test, the decision had to be made regarding which one of the two most common correlations tests to choose from: Pearson's or Spearman's correlation test. In this case, Spearman's correlation test was chosen for several reasons: the relationship between the number of collisions and the road density was rather monotonic than linear (Fig. 20), there were couple of outliers present and the distribution of the variables was not following the normal distribution, which is normally a strong sign to prefer Pearson's correlation test.

Comparing this work with other studies, the similar results were achieved. The study of *Cuyckens et al.,2010* conducted in South America, concluded that higher road density could negatively affect animal's population, especially endangered species. The specifically mentioned species were jaguar *(Panthera onca)* and white lipped peccary *(Tayassu peccary)*, which both need huge areas for their development.

In another study, *Litvaitis & Tash, 2008* examined the distribution of species and road density in United States. As a result, they found out that some of the animals such as bobcats *(Lynx rufus)* usually prefer habitats with a lower density of 1st class and 2nd class roads. As a reason, it was stated that animals with wide home ranges are the most sensitive to road density due to the frequent crossing. Both of these studies suggest a need for more research on population and distribution of species in order to design roads that reduce the impact on the environment.

Apart from confirming the results with other studies, we could also observe some inconsistencies. Specifically, in the work of *Ng et al., 2008*, it was shown that the deer vehicle collisions in Canada are more likely to occur in areas with low road density, since those areas are usually surrounded by more deer habitat. This could be however misleading and two main factors have to be taken into consideration: firstly, the study area of both case studies differed (Czech Republic versus Canada), and secondly, the WVCs in this work included all the wildlife animals, while in the mentioned study, only deers were taken into consideration.

In this work, as well in many others *(Danks & Porter, 2010; Garrah et al., 2015; Girardet et al., 2010; Keken et al., 2016; Kušta et al., 2014; Kušta et al., 2016)*, GIS technology proved to be a valuable tool for those who are trying to conserve the wildlife. Scientific analysis is essential for successful planning and this technology give us the ability to analyze the data in several ways with an aim to uncover hidden patterns.

7 Conclusion

With the trend of increasing road densities, there is a need to reduce the negative impacts that roads have on animals. One of the most important consequences of animals' interaction with roads is the mortality due to the collisions with vehicles.

An effective way to avoid the collisions is to know where and when they happen. There have been many studies focusing on particular factors influencing WVCs, such as traffic intensity, landscape variables, animal behavior and landscape fragmentation that help us to understand the pattern. After conducting a comprehensive literature review, a research gap was identified, intended to be filled by this work.

In this work, the author explored the impact that landscape fragmentation has on the occurrence of Wildlife Vehicle Collisions. Specifically, this study examined a relationship between the wildlife vehicle collisions and the level of the landscape fragmentation in Czech Republic, comparing the road density of 1^{st} and 2^{nd} class roads. Geographic information systems, ArcGIS was used as a tool to approach this issue in the first step, the core area of each polygon was identified. Afterwards, the road density of of each such polygon was calculated, followed by calculating the number of the WVCs in each of them. As the last step, using R Studio statistical software, Spearman's correlation test was utilized in order to validate initial hypothesis stated.

Examining the results, the initial hypothesis of this study formulated as "the higher the density of the roads, the higher number of WVCs", was confirmed. The results indicate the medium positive relationship between these two variables and reflect the initial assumptions. It was also shown the relationship between the 1^{st} class roads polygons density and number of WVCs is higher than the relationship between the 2^{nd} class roads polygons density and number of WVCs.

The work presented in this thesis is one of the first of its kind for the study area of Czech Republic, trying to fill the gap in the investigation of the effect that landscape fragmentation can have on the WVCs. Future studies could derive from this work and even extend it to in various dimensions. One such dimension that is definitely worth to be investigated is enlarging the number of parameters which could possibly influence the WVCs. For instance, additionally to the road density, the area of the road polygon, number of vehicles, traffic intensity or season climate could be included in the study and further investigated.

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List of Figures

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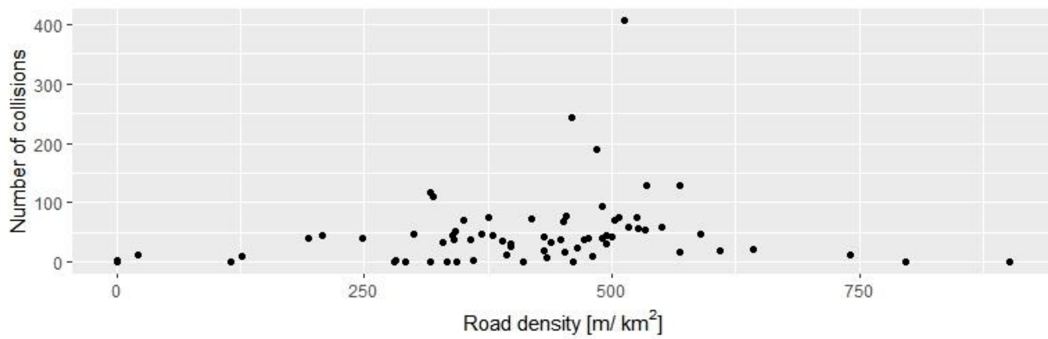
Appendices

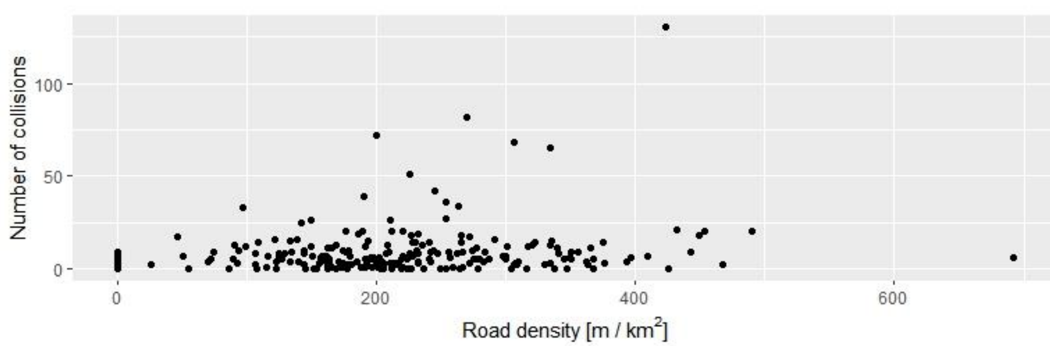
Appendix A

Data visualization and Spearman's correlation test results:



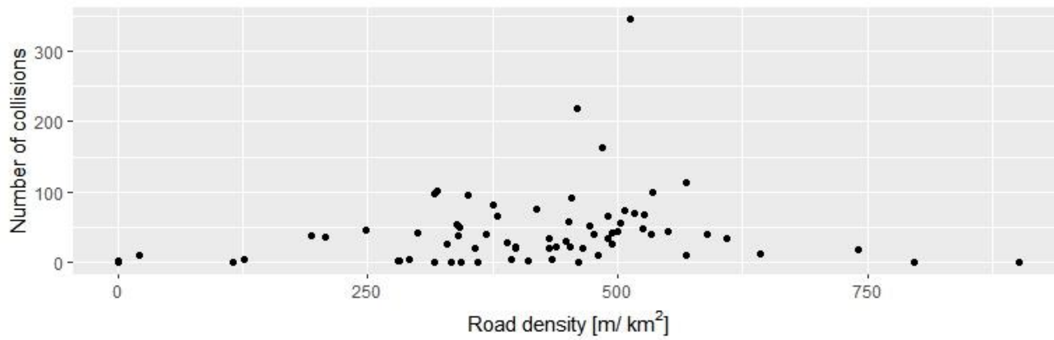
Number of collisions vs Road density on 1st class roads 2014

```
Spearman's rank correlation rho

data:  Density and Collisions
S = 41494, p-value = 0.004279
alternative hypothesis: true rho is not equal to 0
sample estimates:
      rho
0.3328506
```



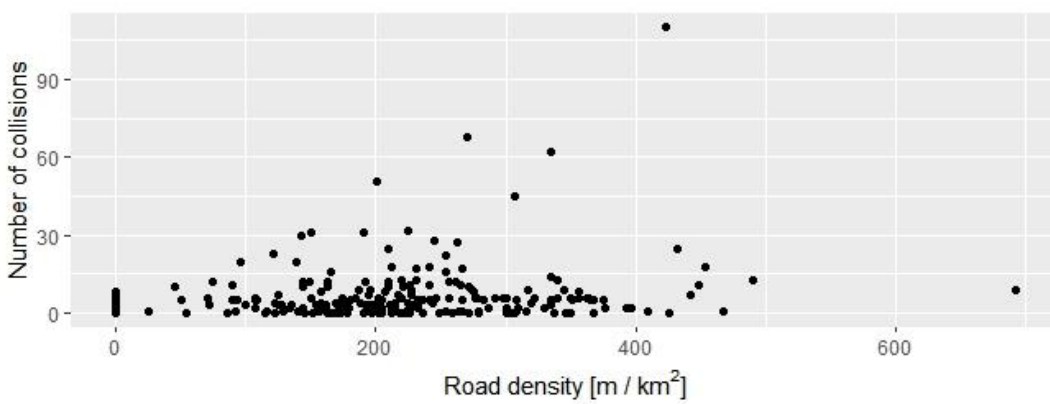
Number of collisions vs Road density on 2nd class roads 2014

```
Spearman's rank correlation rho

data:  Density and Collisions
S = 2017200, p-value = 6.49e-07
alternative hypothesis: true rho is not equal to 0
sample estimates:
      rho
0.3033462
```



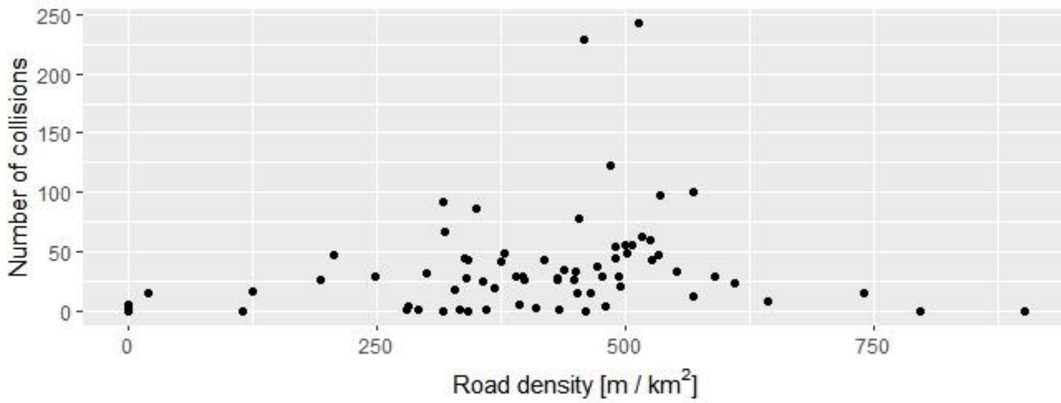
Number of collisions vs Road density on 1st class roads 2013

```
Spearman's rank correlation rho

data:  Density and Collisions
S = 42835, p-value = 0.007775
alternative hypothesis: true rho is not equal to 0
sample estimates:
      rho
0.3112966
```



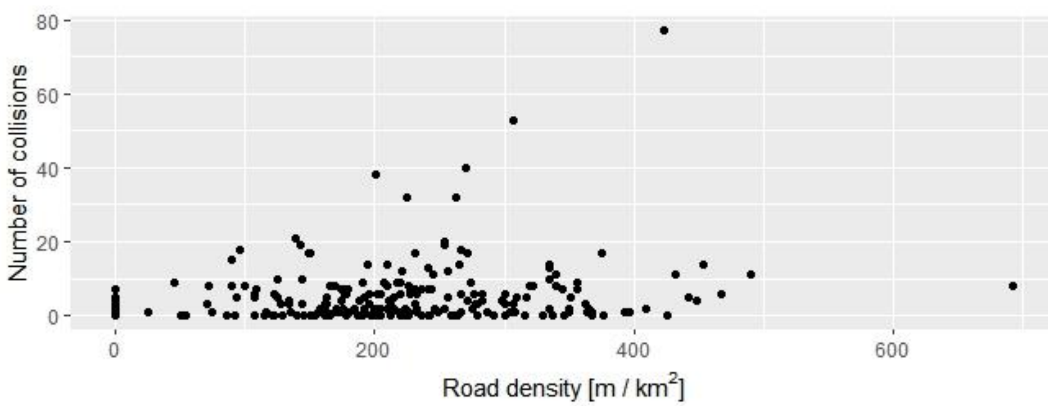
Number of collisions vs Road density on 2nd class roads 2013

```
Spearman's rank correlation rho

data:  Density and Collisions
S = 2137800, p-value = 1.987e-05
alternative hypothesis: true rho is not equal to 0
sample estimates:
      rho
0.2617294
```



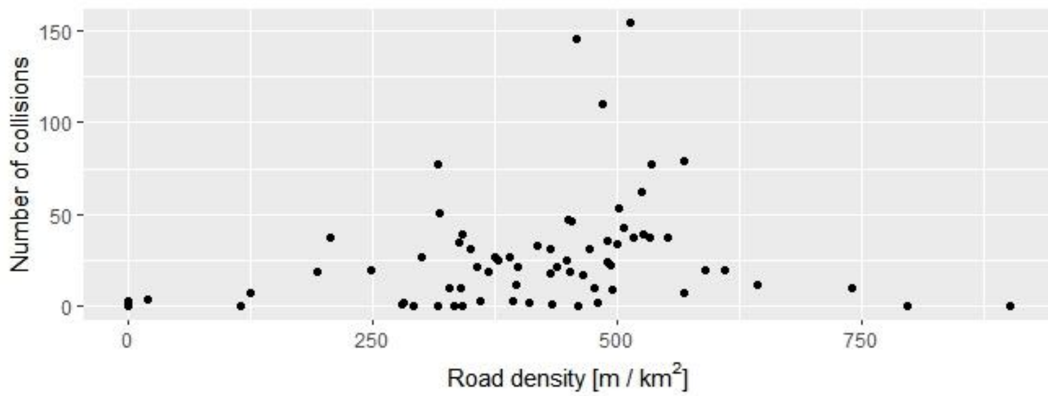
Number of collisions vs Road density on 1st class roads 2012

```
Spearman's rank correlation rho

data:  Density and Collisions
S = 42802, p-value = 0.007666
alternative hypothesis: true rho is not equal to 0
sample estimates:
      rho
0.3118241
```



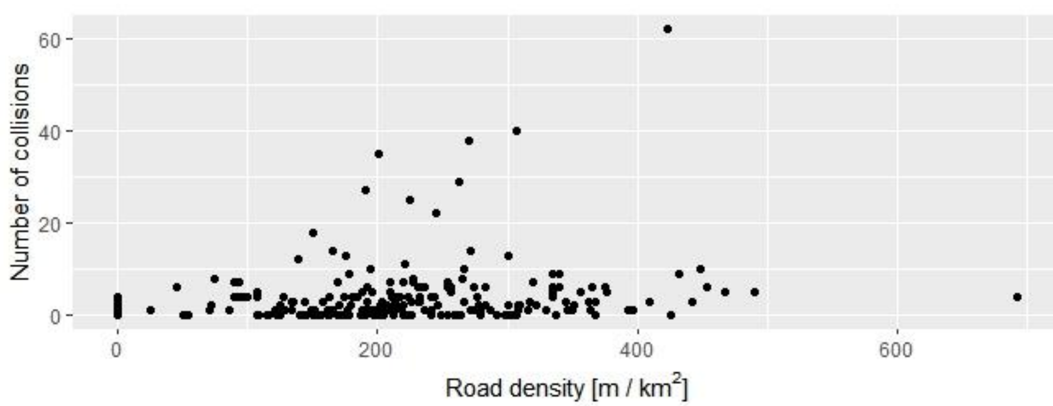
Number of collisions vs Road density on 2nd class roads 2012

```
Spearman's rank correlation rho

data:  Density and Collisions
S = 2080500, p-value = 4.185e-06
alternative hypothesis: true rho is not equal to 0
sample estimates:
    rho
0.28151
```



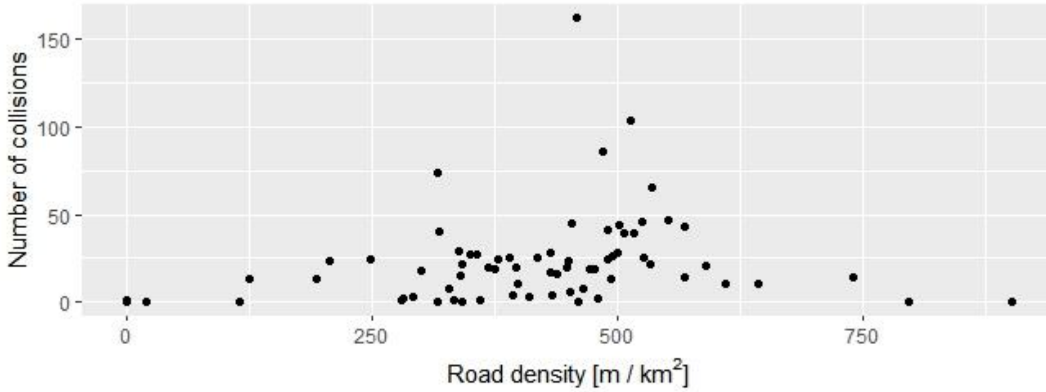
Number of collisions vs Road density on 1st class roads 2011

```
Spearman's rank correlation rho

data:  Density and Collisions
S = 40416, p-value = 0.002566
alternative hypothesis: true rho is not equal to 0
sample estimates:
      rho
0.3501777
```



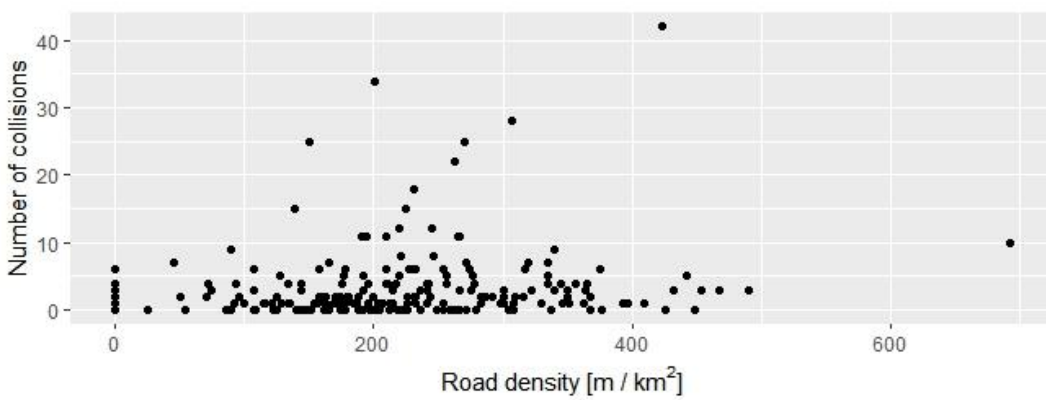
Number of collisions vs Road density on 2nd class roads 2011

```
Spearman's rank correlation rho

data:  Density and Collisions
S = 1977900, p-value = 1.88e-07
alternative hypothesis: true rho is not equal to 0
sample estimates:
     rho
0.316933
```



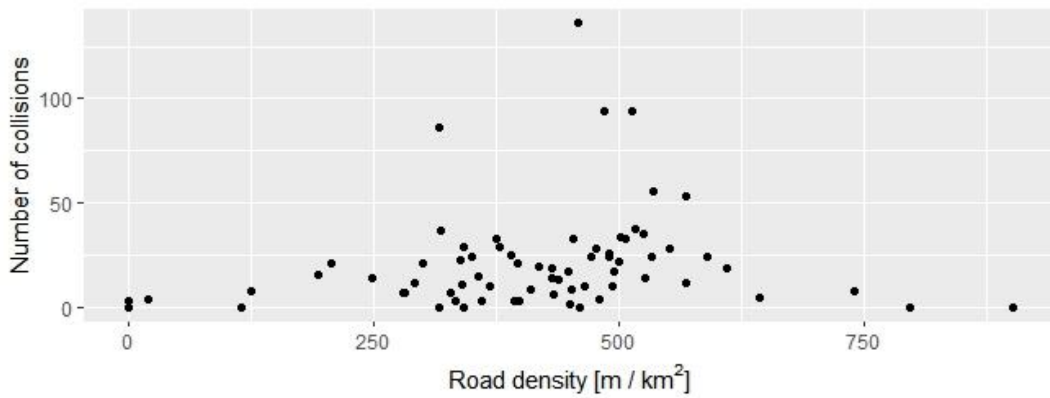
Number of collisions vs Road density on 1st class roads 2010

```
Spearman's rank correlation rho

data:  Density and Collisions
S = 39127, p-value = 0.00134
alternative hypothesis: true rho is not equal to 0
sample estimates:
      rho
0.3709024
```



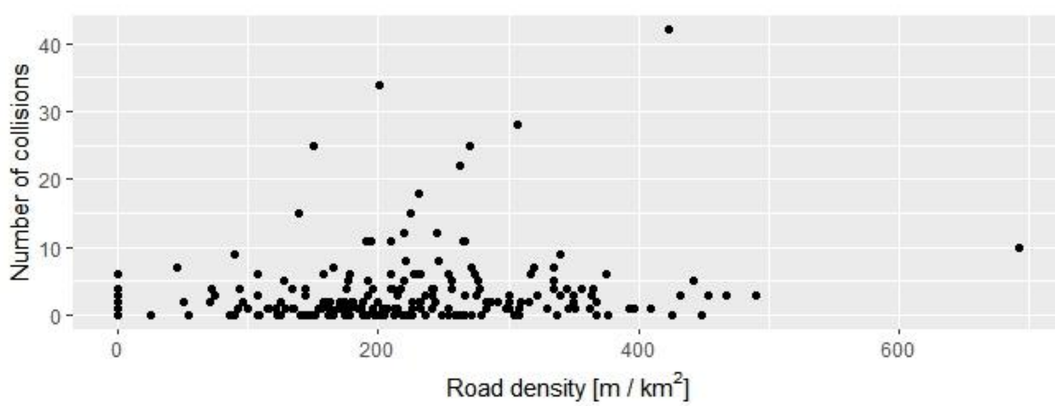
Number of collisions vs Road density on 2nd class roads 2010

```
Spearman's rank correlation rho

data:  Density and Collisions
S = 2031100, p-value = 9.897e-07
alternative hypothesis: true rho is not equal to 0
sample estimates:
      rho
0.2985587
```



Number of collisions vs Road density on 1st class roads 2009

```
Spearman's rank correlation rho

data:  Density and Collisions
S = 41375, p-value = 0.004049
alternative hypothesis: true rho is not equal to 0
sample estimates:
      rho
0.3347696
```



Number of collisions vs Road density on 2nd class roads 2009

```
Spearman's rank correlation rho

data:  Density and Collisions
S = 2031100, p-value = 9.897e-07
alternative hypothesis: true rho is not equal to 0
sample estimates:
      rho
0.2985587
```