Mathematical modeling of roads’ wildlife losses considering the (agricultural/ non-agricultural) surrounding habitats

**Rahmani Doust Mohammad Hossein1, Modoodi Mohammad Nasser\*2, Mowdoudi Arash3**

1 Department of mathematics, faculty of Basic Sciences, University of Neyshabur , Neyshabur, Iran

2\* Department of horticulture scince and engineering, Torbat-e Jam Univeersity, Torbat-e Jam, Iran

3 BSc student in Informatics, Universita della Svizzera Italiana, Loganu, switzerland

1 mh.rahmanidoust@neyshabur.ac.ir

2\* mnmodoodi@gmail.com

3 arashmodoodi@gmail.com

Abstract

*Every year, wildlife collides, caused by vehicles accidents on the roads, are injuring and killing millions of animals and thousands of people around the world. This research work computes the most important reasons for the above phenomenon which is mainly related to climatic, human and roadsides characteristics, on one of the international roads in eastern Iran (97E). The sampling was done after the occurrence and the results showed that the maximum wildlife road’s deaths occurred for small and large mammals, followed by birds and reptiles, respectively. The number of casualties in the middle month of spring was more than the other two months, and the morning observations showed more casualties than the evenings. The number of casualties also was correlated with the type of habitats surrounded the road, passing through pristine and range lands, the road deaths were higher than when the road had been surrounded by agricultural lands or industrial, urban and rural areas. In continuation, a logistic mathematical model was proposed aiming to investigate the relationship between the animals’ losses and the vehicles’ collisions. After finding the equilibrium points for the said logistic modeling, we are able to analyze the solution behavior around mentioned equilibria.*

Keywords: Road, wildlife mortality, differential equation, surrounding habitat, growth rate.

Mathematical Subject classification 2021: 34A30, 34D20, 92D40

# Introduction

Despite of its numerous benefits, roads cause a lot of damages to environment, including the injury or deaths of millions of animals and thousands of people every year. Roads’ casualties are mainly resulted from four general conflicts including climatic, animal-related, human-wise (fragmentation of natural habitats) as well as the road structure characteristics (Denneboom et al., 2021). The larger the animal and the lower its growth rate and fertility, Species will be more susceptible to road accidents and the other human-related mortality causes. Road casualties are not limited to the road’s surface because they may have significant impacts on the food chains of ecosystem, especially in arid and semi-arid areas, sometimes overshadowing the food network leading to the direct population decline. Roads are also indirectly linked to the death toll of infants through which losing their mothers in roads are being perished soon or late. This type of accidents are also matter of moral concerns for the community, as well as economic and safety concerns for drivers. The present study tries to provide a picture about the situation of wildlife road casualties in one of Iran’s international roads, while mathematical modeling verifies the field study.

# The study area and the survey method

The study road is a part of Iran’s East Asian Road (97E), between cities Taybad and Torbat-e-Jam, with an approximately 60 kilometers long, and ends with a distance of 18 kilometers to the Iran and Afghanistan border line (Dogharoon Customs); the road’s overall width is about 7 meters and the driving speed limit is 95 kilometers per hour in most parts, due to being a two-ways road; Its daily traffic volume is around 4580 cars and the peak hours of traffic occurred between 11 and 13 in winter and between 17 and 19 in hot seasons. The road was monitored for 42 days during three months of spring, two weeks in each month. The daily monitoring has been done twice in the morning hours between 7 and 8 am. and in the evening hours between 17 and 18 pm. Considering the type of lands around, the road was divided into three separate sites; site No. 1 (0-20 km from Taybad city) was occupied by the ridged areas plus human residential settlements (including one small town and two villages), site No. 2 (20-40 km) was almost entirely surrounded by plains and pristine rangelands without any man-made towns or facilities, and site No. 3 near Torbat-e Jam city (40-60 km), passing near a small town, the road has been entirely surrounded by dispersed agricultural and industrial lands.

# The field results and discussion

A total of 130 animal deaths were recorded in three categories: mammals, birds and reptiles. Mammals (excluding unknown cases) with a total of 113 deaths (87% of total observations) had the highest mortality rate among the lost animals. After them, birds and reptiles were recorded with 17 cases (13% of the total observations). Out of 42 days of monitoring period, only 14% of the days were without casualties and 86% of the days experienced casualties in one of the two mentioned shifts. Species losses were not evenly observed at three sites (Figures 1-3).

**Figure 1. Comparison of total animals’ road casualty numbers**

**Figure 2. Comparison of animals’ road casualty numbers at each site**

**Figure 3. Comparison of roads’ casualty records at monitoring times**

Although mammals were more observed in site 2, they were recorded at all three sites. Birds were also often present at all three sites in almost equal numbers. Most of the casualties occurred at site No. 2, which enjoyed a perfectly smooth road with no speed limit, and its surrounding habitats include pristine pastures, natural vegetation and open plains (non-agricultural lands);

While the lowest number of casualties was observed in site No. 3, which may be due to enjoying the larger human population centers and higher traffic density in this site. The destruction of animals’ natural habitats and their conversion into agricultural lands and industrial facilities may reduce the number of these creatures on both sides of the site or can prevent them crossing the road. This results confirms another researchers findings (Yalpanian and Ranaei, 2017) which emphasize that the better conditions on both sides of the road for the birds to live and nest (sites No.1 and No. 2, respectively), the higher presence of them in these areas, resulting in higher casualties. Also the obtained results confirms the results of other research in the United Kingdom (Underhill, 2002), however, they are in contrast to a research findings of Tanzania (Kioko et al., 2015), where the highest road casualties were related to birds and then mammals. The presence of domestic animals in the road casualty statistics clearly showed a correlation with proximity to residential areas, so that most of the casualties were observed in site No. 1, which has the highest number of settlements among the road. Since 60% of these casualties were dogs, this could be due to the large number of stray dogs near the settlements or sometimes herding dogs walking alongside the road with sheep.

# Modelling

In the following, we consider ecological modeling of deer population having two-species. The suggested model can be defined as a “wildlife species model” supposing a negative impact of vehicles on animals.

We assume that mortality and the other assumptions as follow:

The mentioned animals, in the absence of vehicles, enjoy a logistic growth rate.

Also, all the collisions lead to wildlife casualties; while the animals will have no effect on increasing or decreasing of vehicles number. In other words, the vehicles can be considered as a nuisance factor for animals crossing the road.

The variables and parametric coefficients used in this research are $t, x,y,a,b,c,M,h$. Now, we consider the following hypothesis:

* The independent variable t which represents time;
* The dependent variables x and y indicate the number of animal populations and vehicles respectively;
* Parameters a and d illustrates the exponential growth rate of animals and vehicles respectively;
* Parameter b shows the logistics growth rate of animals;
* Parameter c indicates the impact factor of vehicles on animals;
* Parameter M represents the source capacity of the environment for wildlife;
* Parameter h indicates the harvesting factor for animals annually.

All the above parameters are mathematically positive and based on the mentioned hypotheses, the following model is to be introduced:

$\left\{\begin{array}{c}\frac{dx}{dt}=x(a-\frac{bx}{M}-cy-h)\\\frac{dy}{dt}=dy\end{array}\right.$ (1)

In the above system indeed, we entered some parameters such as carrying capacity and harvesting factor that have a negative impact on animal mortality. It is assumed that the mentioned animals, in the absence of above factors, have a logistic growth rate. Also, the decrease in deer population has no effect on increasing the number of poachers and vehicles.

Equilibrium points for system (1) and their stability are analyzed. Model (1) has trivial equilibrium point which is origin, and nontrivial equilibrium point which is $x=(a-c)\frac{K}{b}$. Some related mathematical models and their application in ecology are discussed in [5, 6, 7, 8, 9].

# Concluding

The conversion of roadside habitats to agricultural lands in comparison to remaining as rangelands or plains was effective in reducing wildlife road casualties. As well as, by help of analyzing of solutions for system (1), we are able to predict the animal population. This is very important in the area of environmental science.

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