TOOLS USED TO IDENTIFY SPATIAL AND TEMPORAL PATTERNS OF WILDLIFE-VEHICLE COLLISIONS ALONG ROADS AND THEIR APPLICATION FOR MITIGATION PLANNING

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Abstract

Over the past few decades collisions with wildlife has become an important safety issue for transportation planners, especially with the increase of ungulate populations in some regions in North America. For example, by March 2009 a stretch of Highway 1 in Nova Scotia had already had over 200 deer-vehicle collisions. In Ontario, collisions with moose and deer resulted in 7 fatalities, and 542 injuries for motorists in 2004. Highway maintenance contractors and transportation planners have been collecting wildlife-vehicle collision (WVC) data (the location, and date) along roads. From this data, geospatial analyses have determined that there are hotspots or clustering patterns with WVCs due to specific road and environmental factors, e.g. traffic volumes and forest cover. This paper reviews a series of exploratory and statistical tools that can determine the 1-dimensional space, and time, and 2-dimensional spatiotemporal characteristics of collision patterns on roads using the kernel density estimator and Ripley's K statistic. These tools can be applied to assess the spatiotemporal dynamics for any type of vehicle- collision dataset along roads that contains space and time information, to assist transportation planners with mitigation planning.

Résumé

Au cours des dernières décennies, les collisions avec des animaux sont devenues une importante question de sécurité pour les planificateurs de transport, particulièrement avec l'augmentation des populations d'ongulés dans certaines régions d'Amérique du Nord. Par exemple, en mars 2009, un tronçon de la route 1 en Nouvelle-Écosse a déjà enregistré plus de 200 collisions avec des cerfs. En Ontario, les collisions avec des orignaux et des cerfs ont causé 7 décès et 542 blessures d'automobilistes en 2004. Les entrepreneurs en entretien des routes et les planificateurs de transport recueillent des données relatives aux collisions entre véhicules et animaux (l'endroit et la date) le long des routes. À partir de ces données, des biologistes spécialisés dans le domaine géospatial ont déterminé qu'il existe des points chauds ou des profils de regroupement par rapport aux collisions entre véhicules et animaux en raison de facteurs particuliers relatifs aux routes et à l'environnement, p. ex. les volumes de trafic et la couverture forestière. Ce document examine une série d'outils qui peuvent déterminer 1) les caractéristiques dans l'espace dimensionnel et le temps ainsi que 2) les caractéristiques spatiotemporelles dimensionnelles des tendances relatives aux collisions le long des routes en utilisant l'estimateur à noyaux de densité et la statistique K de Ripley. Ces outils peuvent être utilisés pour évaluer les dynamiques spatiotemporelles pour tout type d'ensemble de données sur les collisions des véhicules le long des routes qui comprennent des renseignements spatiotemporels, afin d'aider les planificateurs de transport avec la planification des mesures d'atténuation.

INTRODUCTION

Over the past few decades motor-vehicle collisions with wildlife have increased or become more conspicuous throughout the world. Hotspots of collisions tend to occur in regions with increasing traffic volumes, and or increasing wildlife numbers. In areas of eastern North America, where moose have been reintroduced and are expanding, moose-vehicle collisions have shown a dramatic increase. For example, in Vermont, collisions with moose have increased from 2 in 1982 to 164 in 2002 concurrent with an expanding moose population [1].

Wildlife-vehicle collisions (WVCs), especially with large animals, can have serious human safety implications for motorists. Moose are of particular concern for motorist safety because their tall stature (upward of nine feet tall) and heavy weight (over 1000 pounds) typically causes intrusion into the passenger compartment of vehicles, resulting in personal injury and human death (Maine Department of Transportation, 2001). In Vermont, one-third of all vehicle collisions with moose result in injury or fatality, and traffic statistics from 2002 to 2005 showed 33% of all moose-vehicle collisions (MVC) resulted in injury or fatality as compared to only 7% with deer-vehicle collisions (Vermont Agency of Transportation, unpublished data).

A variety of road mitigation measures such as the use of fencing, and wildlife crossing structures have been documented to reduce road-related wildlife mortality [2-4], while also increasing human motorist safety. Research has shown that WVCs are not random occurrences, and are spatially and temporally clustered for large mammals, e.g. moose and deer [5-7] and small vertebrate fauna [8-10]. The assessment of spatiotemporal patterns of collisions can assist transportation and environmental planners to assess what type and where mitigation planning is required to meet their safety and environmental obligations when constructing new roads.

REVIEW

The purpose of this paper is to review a series of algorithms that have been used by the authors to explore the spatial and temporal clustering patterns of WVCs along roads. We will then discuss possibilities for using the algorithms as tools by transportation, wildlife, and environmental planners for mitigation planning to provide safer roads for wildlife and motorists. All algorithms can be applied to modeling the spatiotemporal patterns of any type of vehicle crash data which has also shown similar patterns of spatial clustering [11].

1. First order properties-Kernel density estimation

The kernel density estimation calculates a weighted density of events per unit area [12]. In section 1 we will show how the function was adapted to calculate a weighted density for wildlife-vehicle collisions (WVCs) per unit length of road [13,14]. We will show output from the function in 1-dimensional space and time and in 2-dimensional space and time together. For this section all output was derived from a moose-vehicle collision (MVC) data set on four major roads in the northeastern highlands of Vermont (Vermont Department of Fish & Wildlife) [14]. Each MVC had the month and spatial location (closest 5 m road-marker) associated with it. For each scenario we present a figure to demonstrate the output derived from each application.

1.1 Space

To determine a weighted density per unit length of road the kernel function calculates a density value within a consistent, specific distance at each distance-marker along the road. The user specifies the search distance (e.g. kilometer) and kernel shape, and the interval step between distance-markers along the road. The calculated density value for each distance-marker is weighted because the collisions closest to the distance marker have the highest weight and drops to zero as the collisions approach the search distance. This gradual weighting is determined by the shape of the kernel function, e.g. quartic kernel [12].

Figure 1 below is an example of the output produced from the kernel function with a search distance of 4 km. It represents the weighted density of MVCs in space along one road, state highway 114 [14]. Along the x-axis is the km location spanning the road and along the y-axis is the weighted density of collisions. The highest density is shown at the top right at ~ km 34, spanning a distance of 6 km, a noticeably higher collision hotspot than other locations on the road.

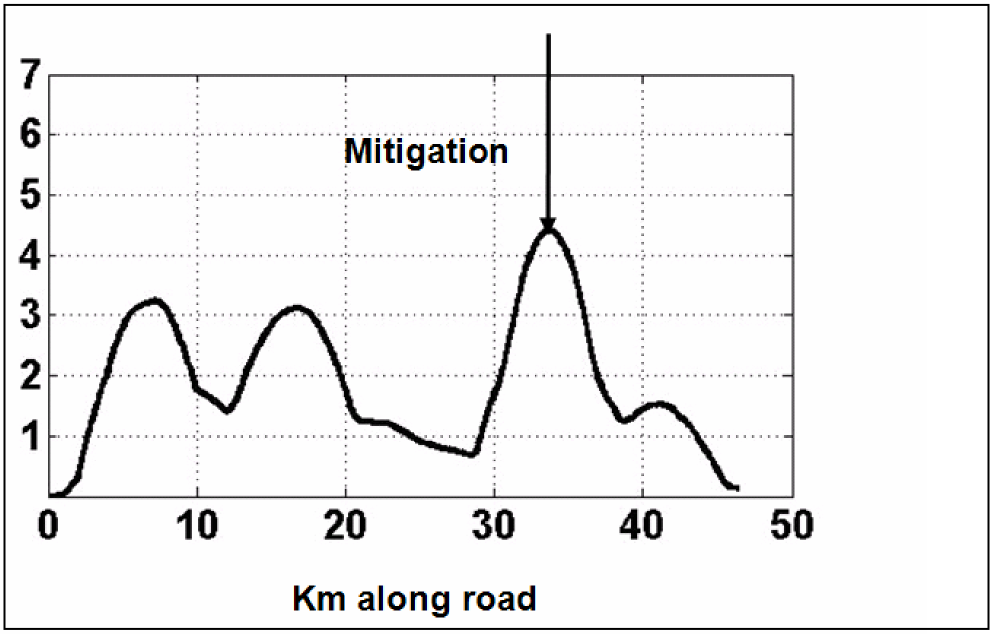

Figure 1 – Output from the kernel density estimation of moose-vehicle collisions along state highway 114 in Vermont (Figure modified from Mountrakis and Gunson 2009, [14])

1.2 Time

The kernel density estimator can be modified to calculate the density of WVCs per unit time [14]. The algorithm now calculates a weighted density value within a consistent, specific distance between time-markers along the timeline of collisions. Again the user specifies a search distance (e.g. months, hours), kernel shape, and the interval between time-markers spanning the timeline.

Figure 2 below is an example of the density of moose-vehicle collisions in time along the four selected roads in Vermont [14]. Along the x-axis is the time in years and the y-axis displays collision density. The highest density of collisions is shown between 1995 and 1996. The figure also displays annual periodicity with peak collisions occurring in July and August. The mitigation arrow in this example is arbitrarily selected and displays that if the acceptable threshold for density of collisions on a section of road is ~ 2 collisions then transportation planners need to act accordingly in 1993 to reduce the number of collisions. The acceptable point of tolerable collision rates can be mathematically calculated. For example, if the rate of change of collisions changes from a linear to exponential rate of increase the inflection point can be the acceptable threshold. Furthermore, the acceptable threshold can also be translated into direct and indirect costs and or number of injuries or personal death.

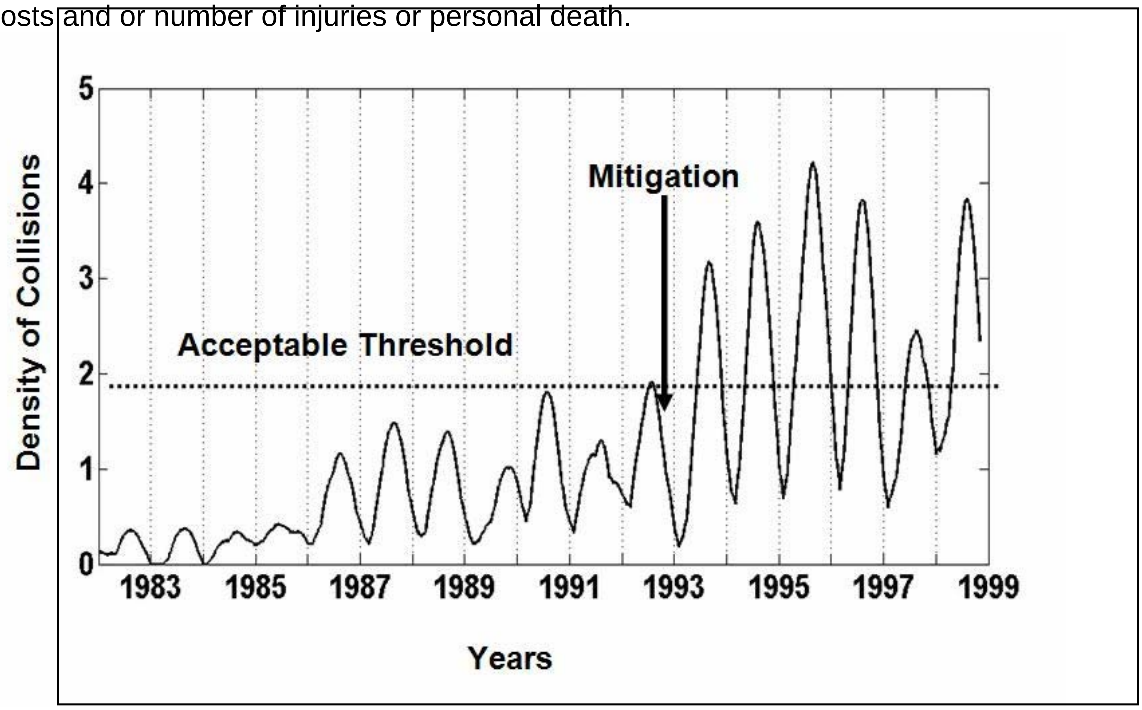

Figure 2 – Output from the kernel density estimation of collisions along a timeline for all four roads combined in Vermont (Figure modified from Mountrakis and Gunson 2009, [14])

1.3 Space and Time

The kernel density estimator can be modified to a 2-dimensional algorithm that calculates the density of collisions per unit length, and per unit time. The algorithm calculates a weighted density of collisions in a predefined search distance for time and space combined [14]. Figure 3 below as an example of output from US highway 2 in Vermont. The hotspots at a particular location are not constant through time. For example, at km 15 there is a moderate density of collision in 1989 which becomes low in 1991 to 1993 (spatiotemporal coldspot), and peaks from 1993 to 1997 (spatiotemporal hotspot). This hotpot spans 10 km for more than 4 years possibly requiring mitigation at this location.

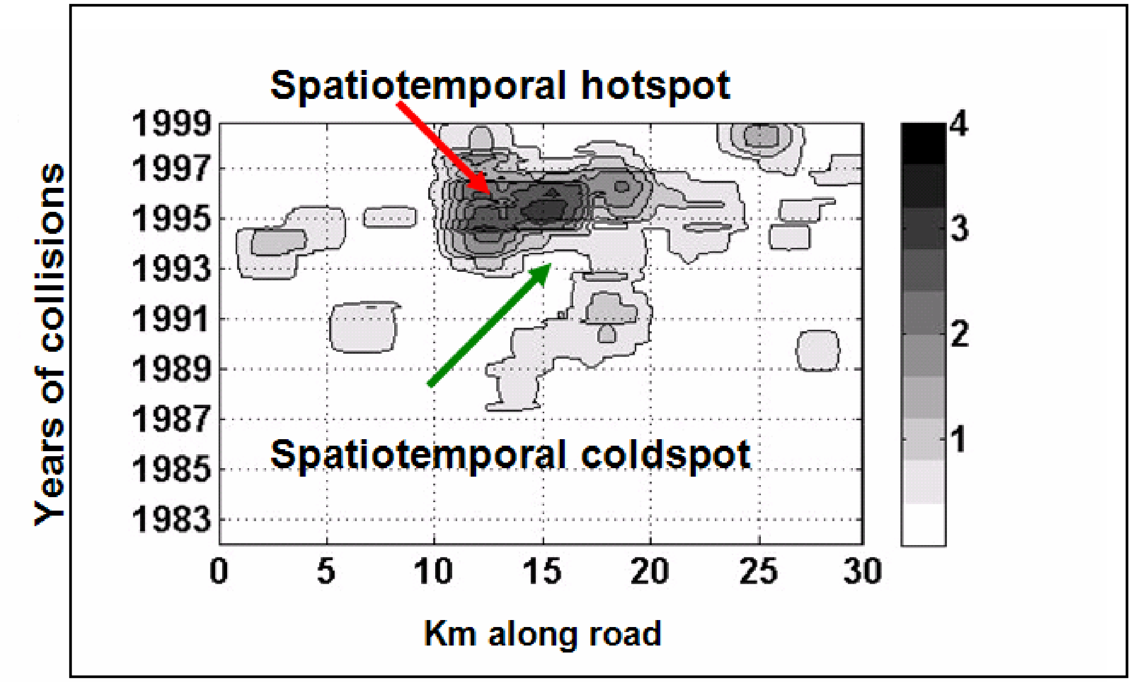

Figure 3 – Output from the spatiotemporal kernel density estimation of moose-vehicle collisions on US highway 2 in Vermont (Figure modified from Mountrakis and Gunson 2009, [14])

2. Second order properties-Ripley’s K function

The second algorithm uses the Ripley’s K statistic that provides an estimate of spatial dependence over a wide range of scales [15].The Ripley’s K function can be transformed into an L function that essentially compares the observed K-function to the expected distribution under a random event process [12]. In addition, a statistical deviation from randomness can be assessed by generating numerous random point distributions, and calculating the L function for these distributions. A comparison of the output from the observed versus the random data will determine if there is a statistically significant deviation from randomness, e.g. clustering or regularity [14]. The section to follow will show the application of the Ripley’s K function to determine the scale at which wildlife-vehicle collisions are clustered spatially along specific roads (1 dimension).

2.1 Space

Figures 4A & B are examples of the output produced from the Ripley's K and L algorithms described above. It demonstrates two different spatial patterns of WVCs along roads. The solid black line is the observed pattern of collisions while the dashed line is the 95% confidence envelope for a random spatial distribution along the same road. When the observed pattern is above the upper envelope it demonstrates clustering. The collisions in Figure 4A are from the same state highway 114 used in the kernel space analysis (Figure 1). The first major peak corresponds to clustering at a scale of ~3 km. Since this is a measurement that occurs on both sides of the road it is multiplied by two to obtain the length of road where clustering is significant. Therefore significant clustering at 6 km corresponds to approximately the same road segment lengths of the three major hotspots (~8 km) shown in Figure 1. In Figure 4B this is an example of a turtle-vehicle collision data set obtained from a road in upstate New York where each collision had a location measurement to the closest meter along a road. Significant clustering for these species occurs at approximately 500 m.

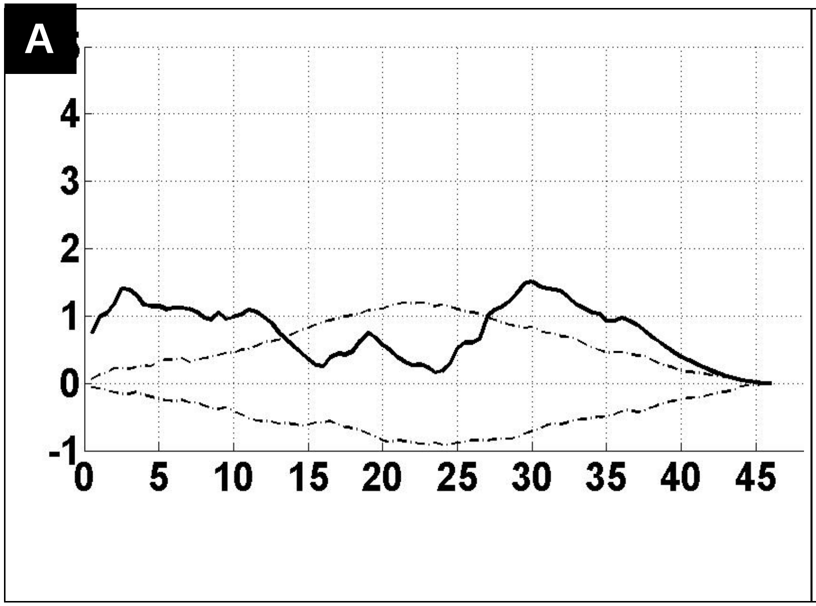

Figure 4 – The spatial distribution of collisions along a road showing peak clustering, as calculated from the Ripley's K and L algorithms, A. is derived from moose-vehicle collision data set (Figure modified from Mountrakis and Gunson 2009, [14]) and B is derived from a turtle-vehicle collision data set

APPLICATIONS FOR MITIGATION PLANNING

Transportation and environmental planners need to answer four main questions when determining how to devise a mitigation strategy for a new road construction project:

1) Where should a mitigation measure go?

2) When should a mitigation measure be implemented?

3) What type of mitigation measure is appropriate?

4) How much mitigation is needed?

Mitigation measures should be placed where there are hotspots of collisions, however usually road project budgets limit the type and number of mitigation measures. The kernel density estimation in space (Figure 1) is an excellent tool to determine where the greatest hotspot is relative to other sites, and can determine where monies should be invested to create safer roads for motorists and wildlife.

It is most economical to place mitigation measures, e.g. fencing and crossing structures, during a road construction project when the highway is being widened or a new road is being constructed. However, not all problem collision sites can be anticipated before highway construction. The kernel density estimation in time (Figure 2) is an innovative tool to determine when the number of collisions has reached an inflection point and will continue to increase at exponential rates as a function of animal population abundance and traffic volumes warranting mitigation efforts.

Mitigation measures used to increase wildlife and motorist safety range in cost and construction complexity. Wildlife warning signs and modified speed limits are good temporary, less expensive measures to mitigate a collision hotspot, however their effectiveness in reducing collisions is minimal [16] (Figure 5A). Wildlife crossing structures, and associated fencing are effective permanent measures, however are typically more costly to implement (Figure 5B) [3]. Temporary measures (Figure 5A) may be effective for seasonal collision hotspots displayed in Figure 2 where permanent measures are not feasible. Figure 3 demonstrates the applicability of the kernel space-time tool to determine if a permanent expensive structure is warranted for a collision hotspot (Figure 5B). There would be a good return on the investment at the hotspot displayed in Figure 3, since high collisions reoccur here over relatively long temporal and spatial periods.

Figure 5 – Examples of mitigation measures used to prevent wildlife-vehicle collisions, A. represents a temporary inexpensive solution and B. represents a more permanent expensive solution.

Mitigation planning varies from large-scale (tens of kms, Figure 6A), to smaller scale more localized projects (500 m, Figure 6B). An example of a large-scale mitigation project is the Trans-Canada Highway in Banff National Park, with over 25 km of fencing, 2 overpasses, and 22 underpasses (Figure 6A) [2]. A localized project may be the implementation of one culvert on with 200 m of fencing for smaller animals to traverse safely across the road (Figure 6B). In combination the various tools can be used to assess the need for multiple mitigation measures over a long expanse of highway or a more localized project for a particular hotspot. The Ripley's K algorithm can be used to determine first whether the clustering or hotspots are significantly different from random and second to determine the average scale of clustering of hotspots (e.g. numbers of crossing structures and length of fencing). The kernel algorithm will determine how many and where the significant clustering occurs.

Figure 6 – Examples of highway mitigation projects, A. large scale, Banff National Park, B. small scale, southern Ontario

CONCLUSIONS

This paper demonstrates the applicability of geospatial tools to assist transportation planners in providing comprehensive mitigation solutions to build safer roads for wildlife and motorists. These tools can be applied to any type of collision, such as multiple vehicle, off-road, and wildlife collisions. It is important to note that these tools are exploratory and require a collision data set collected consistently over multiple years with two components of data: 1) a spatial location preferably with a spatial accuracy of less than 100 m and 2) a temporal location with a resolution of at least the month and year of occurrence. Future work would be to consider and compare other tools used in road safety spatial and temporal analyses such as the weighted regression or bayes models. In addition these types of analyses strike up further questions to understand the processes that are contributing to the spatiotemporal patterns. It would be beneficial to determine and discuss what factors are contributing to these hotspots, e.g. weather, or surrounding road habitat as has been done in other studies [7,8].

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