GeoTAIS: An Application of Spatial Analysis for Traffic Safety Improvements on Provincial Highways in Saskatchewan

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Abstract

Saskatchewan Government Insurance (SGI) is responsible for collecting and maintaining a comprehensive database of traffic accidents. This data is used by SGI and other safety partners for monitoring, decision making and the evaluation of traffic safety program initiatives in Saskatchewan. The GeoTAIS project was launched in July of 2010 in an effort to enhance the quality of Saskatchewan's traffic accident database to keep up with cutting edge traffic safety analysis/research and to facilitate the provision of well informed traffic safety programs in Saskatchewan.

The overarching goal of the project is to develop a Geographic Information System (GIS) that would allow for the visual representation of the traffic accident data captured in the SGI's Traffic Accident Information System (TAIS) and SGI's claims information systems in a spatial format. The second goal of the project is to deploy guidelines from the recently published AASHTO Highway Safety Manual combined with the spatial data from GeoTAIS to develop Safety Performance Functions (SPFs) for all provincial highways in Saskatchewan. The final goal of the project is to utilize the spatial data, SPFs and the Empirical Bayes (EB) method to visually identify collision hotspots and areas in the provincial road network with high potential for safety improvements. The success of the project will help ensure that traffic safety problem identification, investments, monitoring, and program evaluation in Saskatchewan are informed by the best data in a speedy and efficient manner. This paper discusses the development of the GeoTAIS project and its application in identifying hazardous wildlife crash locations as part of the ongoing efforts to improve traffic safety on Saskatchewan's provincial highways.

Introduction

The likelihood of encountering wildlife on North American highways has seen significant increases over the last decade. As urban sprawl continues to impede on natural habitats and deer populations continue to rise, collisions with wildlife become inevitably more frequent. Current estimates suggest that as many as 1.6 million vehicles collide with deer every year in the United States causing costs upwards of $3.6 billion dollars in damages with an additional $1 billion in medical costs [1]. Tracking wildlife collisions is unfortunately tricky. Over 95% of such collisions result in property damage often less than a few thousand dollars, and often below reporting thresholds [2]. In Canada, few studies have attempted to determine exact numbers but indications show an increasing trend since 1996 [3].

In Saskatchewan, wildlife related collisions remain one of the major contributing factors in highway collisions. With only two larger urban centers, a substantial number of the population is vastly dispersed and consequently, are forced to drive long distances at high speeds on a regular basis. The unfortunate result is frequent and unavoidable collisions with wildlife. Data from Saskatchewan`s accident database indicate that between 2003 and 2009, a total of 80,100 collisions were reported on Saskatchewan highways that were above the $1000 damage threshold. Of these collisions, 52,200 or 65% involved wildlife resulting in 1544 injuries and 13 deaths [4]--an average of over 30 highway collisions with wildlife per day. Figure 1 shows the increasing trend in wildlife related collisions that Saskatchewan has observed over the last 7 years. The data shows that collisions with wildlife have increased by 30% since 2003.

There are indications that Saskatchewan's population is growing at the same time that wildlife populations are on the increase [5]. The growth in human population also leads to a growing number of drivers on the road, which further increases vehicle interactions with wildlife leading to increasing insurance costs. In 2010, the amount paid out in claim costs due to wildlife accidents in Saskatchewan totaled nearly 48 million dollars--over 75% of wildlife encountered on Saskatchewan roads is deer.

The need for solutions to wildlife-related collisions is obvious, but identifying the hotspots and the most appropriate countermeasures present some unique challenges to traffic safety agencies in the Province. In Saskatchewan, highway safety is primarily a joint effort between the Ministry of Highways and Infrastructure, Saskatchewan Government Insurance (SGI) Ministry of Environment and Saskatchewan Wildlife. SGI is responsible for collecting, maintaining and analyzing a comprehensive database of traffic collisions. The Ministry of Highways is responsible for the maintenance and operation of the 26,292 kilometers of highways within the province [6]. This incredibly vast number of roads and highways in the province presents it own challenges with respect to identifying exact locations of safety improvement. The Ministry of Environment and Saskatchewan Wildlife also contribute to this effort by tracking and controlling wildlife populations.

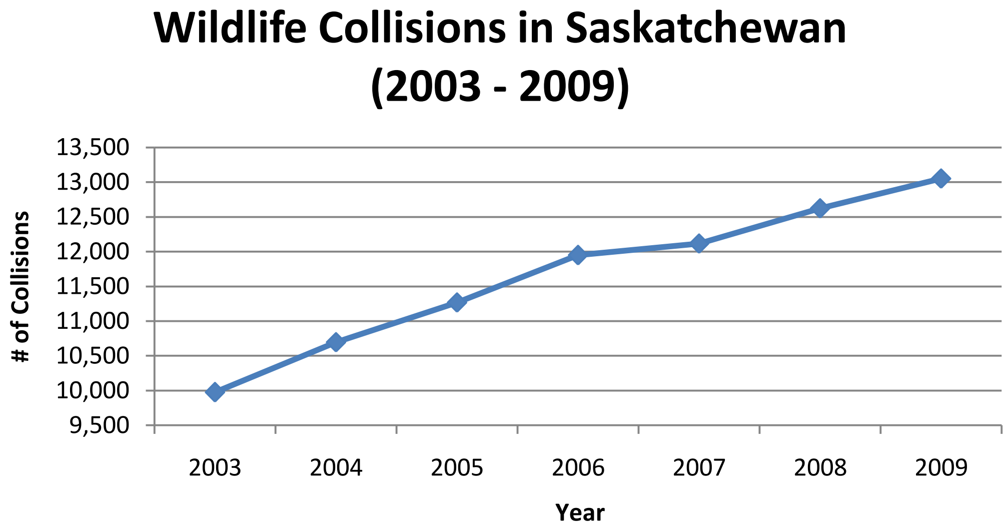

Figure 1 - Saskatchewan Wildlife Collision Trend

In the past, the collective efforts by the agencies responsible for traffic safety in the province have used accident frequencies to identify specific areas of the highway network most suited for improvement; however, the safety literature suggests that this method suffers from a number of drawbacks [7, 8]. Random variations in collision counts over an observation period may lead to the phenomenon known as the regression-to-the-mean effect. The implication is that a location with a high crash count in one year may subsequently decrease the following year due to random fluctuation without any type of safety improvement. Secondly, although the relationship between accident frequency and risk exposure (ex. traffic volume) is non-linear, procedures based on accident rates treat it as if it were. Given these issues, a direct comparison of crash records for different roadway locations to identify areas for improvements would be inappropriate. This presents a need for a more rigorous approach to identifying collision hotspots for safety improvements.

The GeoTAIS project was launched in July of 2010 in an effort to enhance the quality of Saskatchewan's traffic accident database to keep up with cutting edge traffic safety analysis/research and to facilitate the provision of well informed traffic safety programs in Saskatchewan. The overarching goal of the project is to develop a Geographic Information System (GIS) that would allow for the visual representation of the traffic accident data captured in the SGI's Traffic Accident Information System (TAIS) and SGI's claims information systems in a spatial format. The second goal of the project is to deploy guidelines from the recently published AASHTO Highway Safety Manual combined with the spatial data from GeoTAIS to develop Safety Performance Functions (SPFs) for all provincial highways in Saskatchewan. The final goal of the project is to utilize the spatial data, SPFs and the Empirical Bayes (EB) method to visually identify collision hotspots and areas in the provincial road network with high potential for safety improvements.

Purpose

This paper discusses the development of the GeoTAIS project and its application in identifying hazardous wildlife crash locations as part of the ongoing efforts to improve traffic safety on Saskatchewan's provincial highways. Specifically, the study applies modern, non-biased statistical methods to the process of finding and ranking wildlife collision hotspots. Once hotspots have been determined, Geographic Information System (GIS) software will enable stakeholders to see beyond the numbers by displaying the hotspot locations visually so that the spatial nature and patterns of the data could be appropriately analyzed.

Data Preparation

Data for this project came from two primary sources, SGI and the Saskatchewan Ministry of Highways and Infrastructure. Wildlife collision data was extracted from SGI's Traffic Accident Information System (TAIS) database. The TAIS database contains data on all reported accidents in the province that are obtained either directly from police reports or SGI's own claims database. Three years of data from 2007 to 2009 was extracted which included the highway number and control section, crash location, collision frequency and severity for each accident. In total, 583 individual highway control sections with observed wildlife collisions were considered for the analyses.

The data from the Ministry of Highways included segment lengths (km), lane width (km), traffic volumes (Average Annual Daily Traffic or AADT), speed limit (km/h), surface type (Paved or Gravel) and the number of lanes for each highway control section. The average traffic volume (AADT) over the three year period was used for each control section in order to simply calculations. Since the segment lengths and lane widths varied slightly between the years, it became necessary to use average length and width for the analyses.

After all the data had been collected and formatted appropriately, the data from each source was then merged by highway number and control section using *SAS Enterprise Guide 4.1* software. In all, a matrix of three-year collision frequencies and roadway characteristics were created for control sections that included 481 paved undivided highways, 39 paved divided highway, and 33 gravel roads.

Methodology

The first task was the creation of a GIS system followed by the development of safety performance functions developed for each type of highway. The SPFs were then programmed into the GIS system, and hotspots identified using the guidelines provided in the Highway Safety Manual for network screening purposes. Finally, the hotspots for wildlife collisions were plotted on the GIS system. In this section we describe how GeoTAIS was developed as well as the analytical procedure employed in developing the safety performance functions and the subsequent ranking of the hotspots.

GeoTAIS Development

The first phase of developing the GeoTAIS involved the creation of a file geodatabase—defined as a container used to hold a collection of databases. This was created to store both the spatial and non-spatial data needed for this project using the *ESRI ArcGIS 9.3.1* software suite. A file geodatabase was chosen as it is most suitable for single users and small workgroups where data are stored as folders in a file system as opposed to other restrictive formats such as Microsoft Access and Oracle databases. Three separate spreadsheets were created for each highway type (Paved-Divided, Paved-Undivided and Gravel) to be imported into the GIS system. Shape files--a simple, non-topological format for storing the geometric location and attribute information of geographic features—[9] of the entire Saskatchewan road network were provided by the Ministry of Highways and imported into the geodatabase as well. These shape files contained highway numbers, control sections and location descriptions in their attributes. Data on urban municipalities were also obtained from GeoSask (www.geosask.ca) and imported into the geodatabase to be used as reference locations.

Once all of the necessary data was imported into the geodatabase, the highway spreadsheet data was linked to the road network shape files. Both the spreadsheets and shape files were added to a workspace document using *ArcMap* and then joined by highway number and control section using the *Join Data* tool.

Development of the Safety Performance Functions

Safety performance functions (SPFs) are models that link accident frequency to roadway geometrics, traffic volumes and crash severity. The SPFs provide an average performance for each specific roadway site within a group which can then be compared to actual observed crash counts.

SPFs were developed for the highways control sections in three distinct groups: Paved-Undivided, Paved-Divided and Gravel roads. The Safety Performance Functions were developed using the Generalized Estimation Equations (GEE) approach with a negative binomial distribution in a logarithmic between dependent variables and independent variables.

GEEs provide an extension to generalized linear models (GLMs) and have been proven to be a robust procedure for temporally or spatially correlated crash data [10]. The negative binomial distribution was also used as it possesses most of the desirable statistical properties for describing crash data that tends to be random, discrete, nonnegative, significantly over dispersed, and typically sporadic.

The general form of the Safety Performance Function is:

SPF = lna*exp (bTYPE+clnAADT+dlnLength)

Where a, b, c, d are estimated parameters from the model. TYPE is defined as a dichotomous variable (paved or unpaved), AADT is the average annual daily traffic volume, and Length is the length in kilometres of the control segment. The rest of the dependent variables were not found to be significant at the 95% confidence level. Table 1 presents the SPFs developed for subsequent network screening for all network, paved undivided, paved divided and gravel roads. The SPFs were validated by using the ASSESSMENT procedure in SAS to check whether the cumulative plots oscillate about the zero axis [11].

The safety functions presented in Table 1 were used for screening the network and for hotspot ranking purposes.

Table 1: Safety Performance Functions, Dispersion Parameters (ϕ) by Highway Network Type

Highway Network Type	No of Segments	Safety Performance Function	Dispersion Parameter
All Network Combined	583	$0.0113*T^{1.4389)}*L^{2.7571}*AADT^{1.8439}$	0.2063
Paved Undivided	463	$0.0148*L^{2.8582}*AADT^{1.8341}$	0.2023
Paved Divided	39	$0.0007*^{2.3542}*AADT^{2.7177}$	0.2119
Gravel Roads	81	$0.08659*AADT^{2.3695}$	0.6487

Network Screening

One of the most common approaches for identifying hazardous locations on road networks is the Empirical Bayes Method (EBM). This method combines observed and expected accident frequencies to provide unbiased estimates of the safety performance at specific sites. The primary input for the EBM was the safety performance functions. We used the AASHTO

Highway Safety Manual guidelines and an approach suggested by Powers and Carson [12] to screen the highway network.

Since the control sections vary in length and characteristics, a unique overdispersion parameter (ϕ_i) had to be developed for each section. Powers and Carson describe two methods of calculating the overdispersion parameter. We used both methods to conduct separate analysis. The first method assumes that control section length is the primary determinant affecting overdispersion represented by the following equation:

$$\phi_i = \phi * L_i^{\beta}$$

Where: ϕ_i = The adjusted overdispersion parameter for control section i

ϕ = The global dispersion parameter for all combined control sections for each highway type.

L_i = The length of control section i

β = Constant between 0 and 1 (β = 0 would represent completely unique control sections, β = 1 would represent identical control sections, we used β = 0.3)

The second method for determining the overdispersion parameter assumes a unique gamma distribution for each control section and is given by the following equation where all variables are as previously defined:

$$\phi_i = \phi * SPF_i$$

For each control section, a relative weight (α) as follows:

$$\alpha_i = 1 / (1 + SPF_i / \phi_i)$$

Where α_i represents the relative weight for control section i and all other variables are as previously defined:

The expected crashes (π) for each highway control section were estimated as follows:

$$\pi_i = (\alpha_i) * (SPF_i) + (1 - \alpha_i) * (\lambda_i)$$

Where: π_i = The expected number of crashes per three years on control section i

λ_i = The actual number of crashes per three years on control section i

All other variables are as previously defined.

The variance (σ_i^2) for each control section was the calculated using the following equation where the variables are as previously defined above):

$$\sigma_i^2 = (1 - \alpha_i) * \pi_i$$

The final step in this analysis was the computation of the Performance Index (θ_i) for each control section. The function for calculating the Performance Index is given by:

$$\theta_i = (\lambda_i / \pi_i) / 1 + (\sigma_i^2 / \pi_i^2)$$

The output produced two different Performance Index (θ) values for each control section due to the two adjustments made for the dispersion parameters. Thus, an average of each of these Performance Index values was computed for each control section. The average Performance Index was the final number used to rank the control sections. All control sections with a Performance Index > 1 were then ranked for each of the three highway groups. The Performance Index provides a measure of how a specific site is performing compared to what would be expected based on its characteristics and its performance relative to a reference group of similar roadway sites. To plot the hotspots, we used the relative indices for the control section with the lowest performance index as the reference.

Spatial Treatments of Hotspots

For each of the three highway groups we created a selectable hotspot layer. These layers allow for a province wide overview of all the hotspots within each highway group. At this point a fully interactive map within the GIS software that displays the results of our Performance Index rankings was created which enable us to browse, analyze and create maps from the result.

A province wide overview is a great starting point to help narrow the search but still to large a scale to be particularly useful. The average length for a highway control section is around 36 km which is not very precise. In order to take a closer look, we essentially zoomed in to a particular control section and plotted the exact locations of the collisions along that road segment. To accomplish this we first created a route layer using the *Create Routes* tool in *ArcMap*. This tool takes as input a line shapefile, its length and the ‘from’ and ‘to’ measurements to create a new layer. The new layer is essentially a copy of the original layer but allows events to be plotted on that line based on distance measurements. For example, a control section that is 10 km long with a collision event that occurred 5km from the start of the control section would have that event plotted in the middle of that control section.

Once we a route layer had been identified, it was possible to plot the actual collision locations using the *Make Route Event Layer* tool in *ArcMap.* This tool takes as input a route layer (the layer created in the last step), an event layer with an 'at km' field (collision data) and a common identifier field from both the route and event layers (highway and control section). The output is a multiple point shapefile with all of the accident locations plotted along every highway section, making it possible for it to be viewed at any scale using the *Zoom In* and *Zoom Out* tools.

The only limitation is that an 'at km' measurement is not known for every single accident. When accident reports lack this information, they have to be entered into the TAIS database as having an unknown 'at km' measurement. It was necessary therefore, to filter out such collisions. With this accomplishment, an analyst could take a close look at each control section individually and look for patterns related to accident density, clusters and locations relative to other spatial features such as vegetation or water. Thus, the tool offered us the opportunity to pinpoint very specific and manageable areas to focus for safety improvements.

Results

We successfully developed a fully interactive map of Saskatchewan within the GIS software that can display the entire highway network with wildlife hotspots and actual accident locations. It is possible to zoom in and out to any scale desirable, analyze patterns either visually or with spatial statistic tools and create maps and diagrams of the results.

Table 2, Table 3 and Table 4 show the top 5 accident hotspots from the Performance Index rankings for each of the three highway groups. These tables are a small subset of the results from the Empirical Bayes network screening. Figure 2, Figure 3 and Figure 4 are maps of the hotspot locations (Performance Index > 1.0) for each highway group. The hotspots are displayed by increasing the size and darkness of the control section as Performance Index increases. These maps are examples of the province wide overviews we first used to narrow down the search for hotspot locations. Figure 5 is a close up map of Highway 16, control section 24 showing the actual wildlife accident locations. Accident clusters are circled in red with the number of accidents in each cluster shown beside each circle. This map is an example of how we can zoom in to take a close look at a control section to identify precise locations that would benefit from safety improvement.

Table 2 – Top 5 Wildlife Accident Hotspots on Paved Undivided Highways

Rank	Highway-Control Section	Location Description	Length (km)	AADT	3-Year Collisions	Expected 3-Year Collisions	Performance Index
1	003-14	Shell Lake - Spiritwood	24.62	1024	101	94	1.0649
2	219-04	White Cap FN. - Saskatoon	31.69	1994	148	140	1.0547
3	012-04	Big Grass Lake - Shell Lake	21.02	451	46	43	1.0540
4	055-16	Peerless - Alberta Border	52.10	884	142	134	1.0519
5	060-01	Pike Lake - Saskatoon	23.92	1161	80	75	1.0516

Table 3 - Top 5 Wildlife Accident Hotspots on Paved Divided Highways

Rank	Highway-Control Section	Location Description	Length (km)	AADT	3-Year Collisions	Expected 3-Year Collisions	Performance Index
1	016-24	North Sask. River - Radisson	19.26	5811	163	152	1.0677
2	011-08	Dundurn - Saskatoon	32.19	7453	246	232	1.0575
3	011-04	E Jct Hwy 2 - Aylesbury	24.66	4564	87	83	1.0355
4	001-13	N Jct Hwy 2 - Mortlach	45.29	5015	126	122	1.0227
5	016-28	Bresaylor - Maidstone	39.44	4006	88	86	1.0188

Table 4 - Top 5 Wildlife Accident Hotspots on Gravel Highways

Rank	Highway-Control Section	Location Description	Length (km)	AADT	3-Year Collisions	Expected 3-Year Collisions	Performance Index
1	047-04	Jct Hwy 48 - W Jct Hwy 1	26.55	73	13	7	2.240
2	980-02	Woody Lake - Hwy 3	83.95	20	4	2	2.229
3	310-03	Jct Hwy 52 - Foam Lake	50.87	141	17	10	1.955
4	058-04	Jct Hwy 363 - Jct Hwy 1	36.17	58	8	4	1.915
5	371-01	Fox Valley - Alberta Border	41.47	258	27	16	1.887

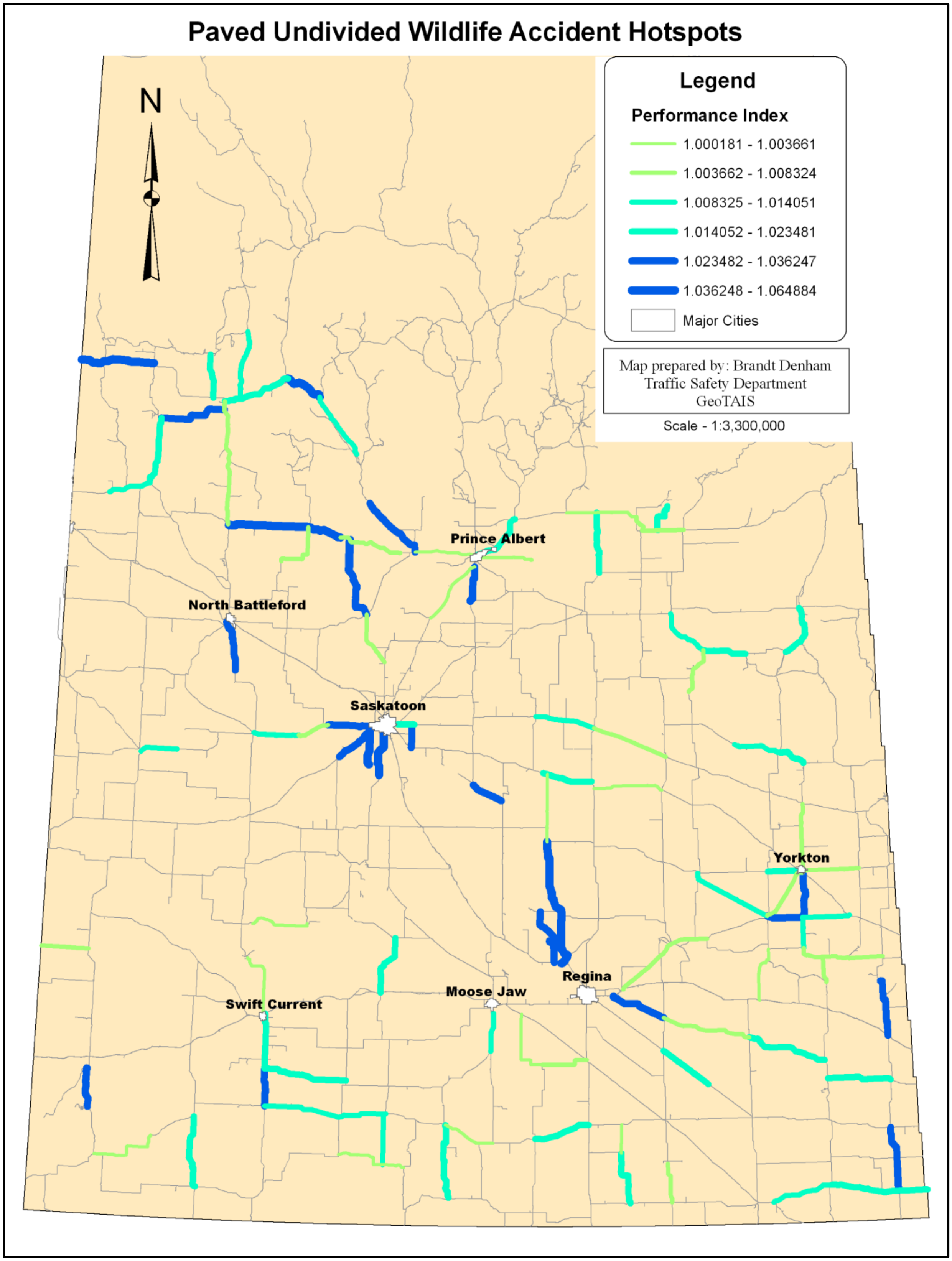

Figure 2 - Top Wildlife Accident Hotspots (Performance Index > 1.0) on Paved Undivided Highways

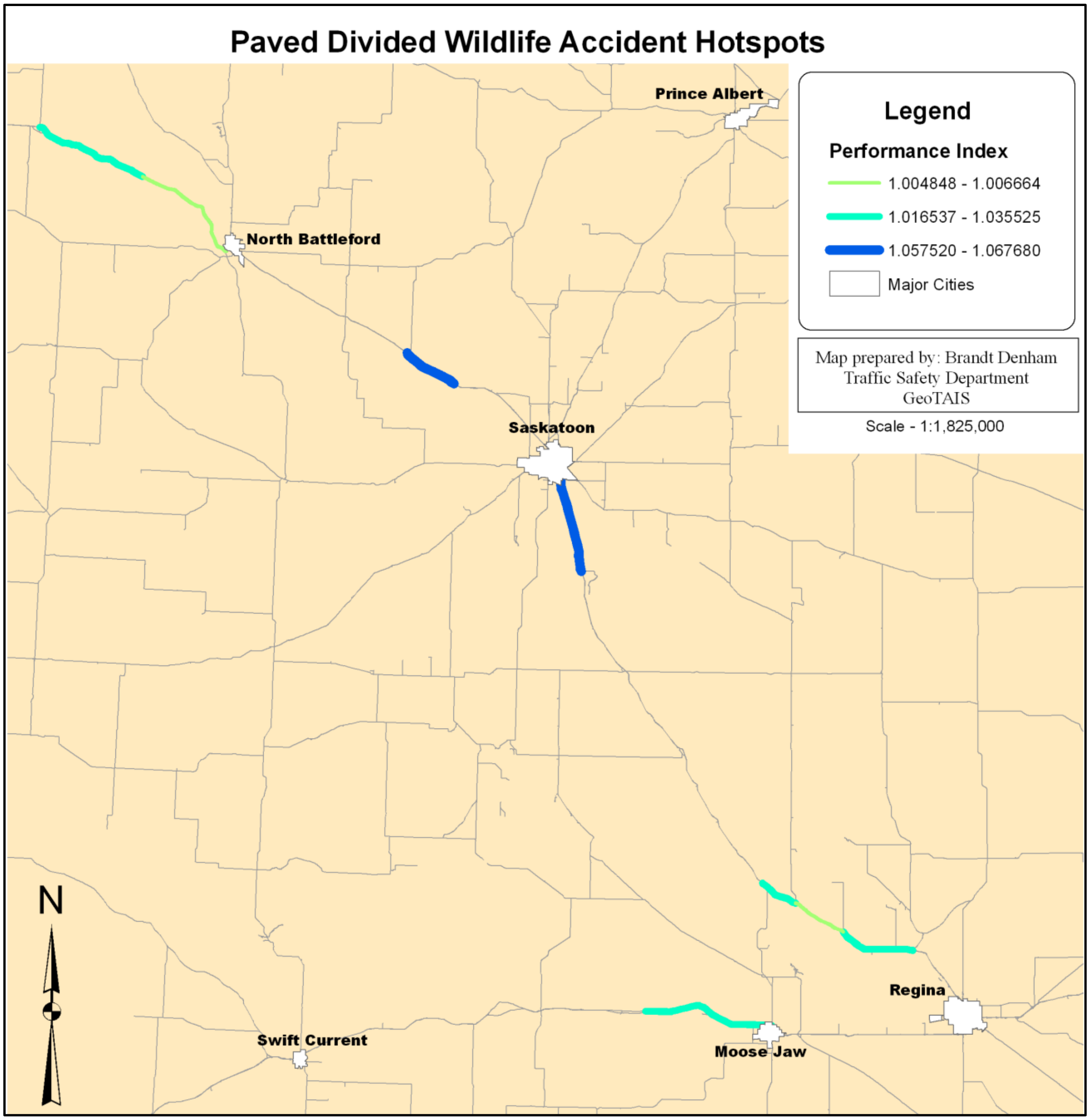

Figure 3 - Top Wildlife Accident Hotspots (Performance Index > 1.0) on Paved Divided Highways

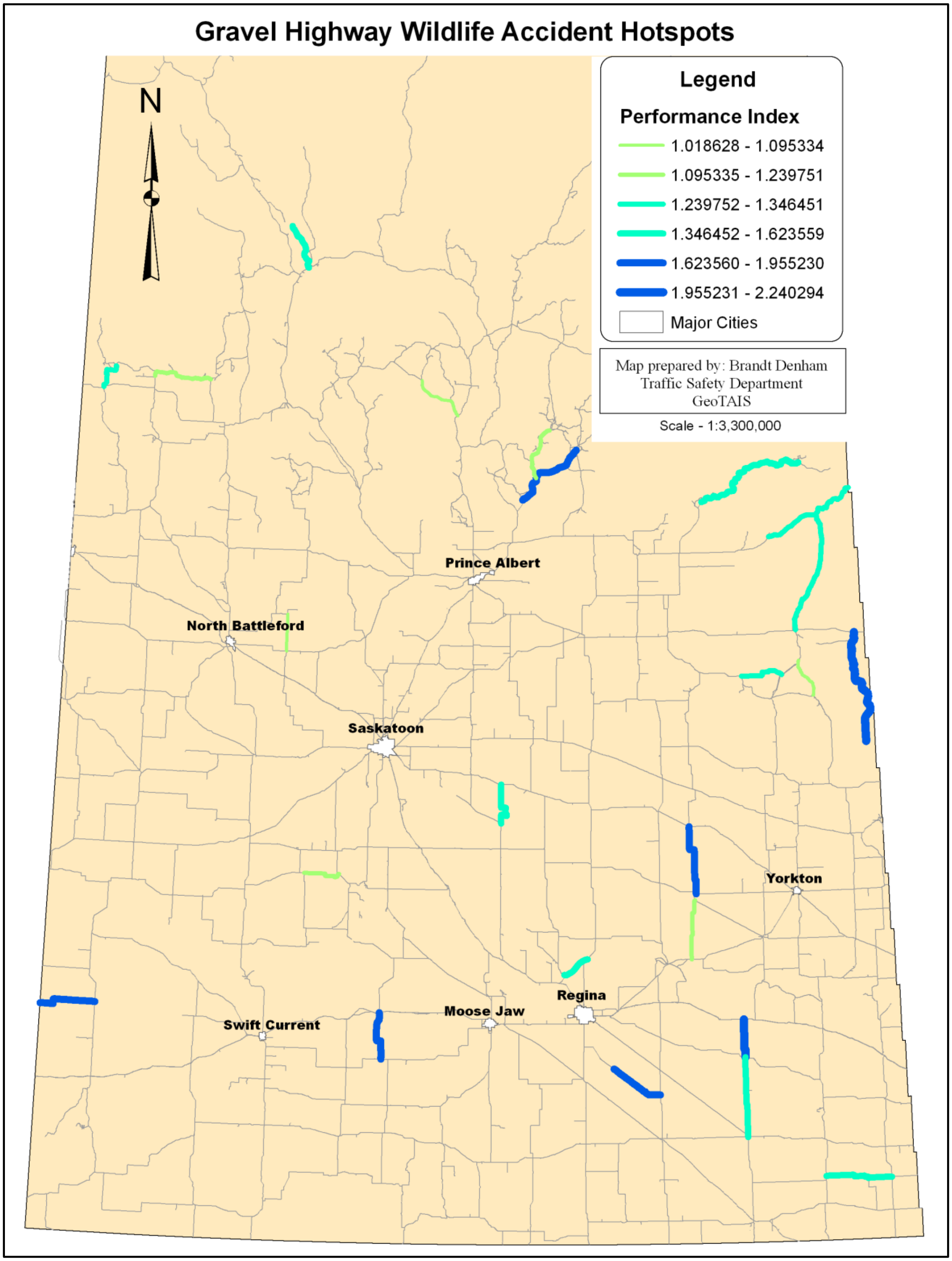

Figure 4 – Top Wildlife Accident Hotspots (Performance Index > 1.0) on Gravel Highways

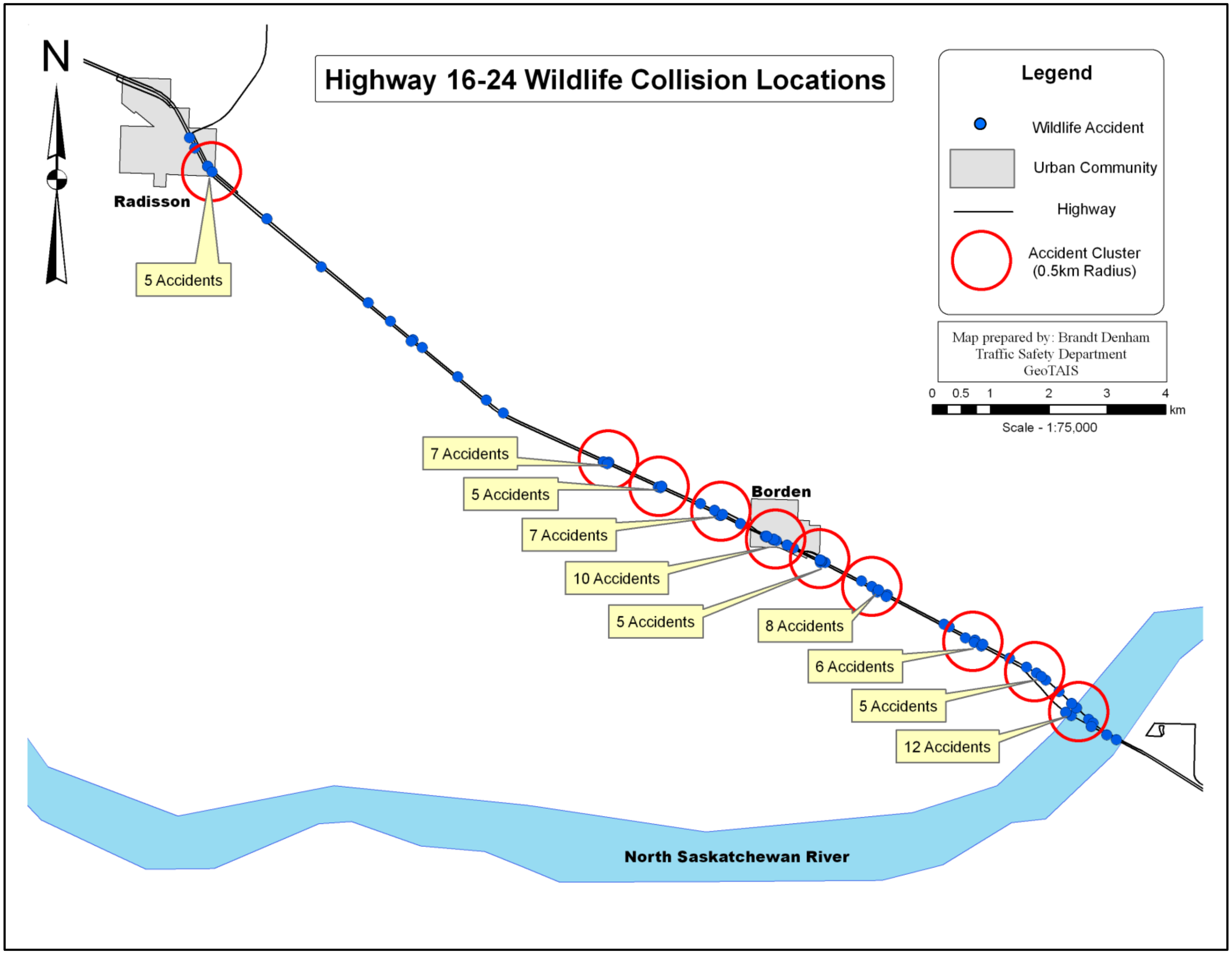

Figure 5 – Actual Wildlife Accident Locations on Highway 16, Control Section 24

Discussion

Many studies have used either Empirical Bayes methodology [12] or GIS methodology [13, 14] to aid in traffic accident analysis but few studies have combined them. The GeoTAIS system developed in this study is a powerful tool that offers a visual representation of data to help identify patterns and to associate high crash locations with other factors that are spatial in nature. Spatial features near roadway sites may influence the crash frequencies at particular locations which would otherwise be undetected in the absence of a tool like GIS. The GIS software will first be used to map hotspots based on their Performance Index at a provincial scale. The top sites will then be chosen for a closer and smaller scale view where exact accident locations can be plotted and analyzed. Areas of high accident density along these segments will then lead us to very specific areas to focus on for improvement.

The results from the Empirical Bayes rankings (Tables 2, 3, 4) clearly indicate how the segments with the highest accident frequency are not always the segments with the highest potential for safety improvement. In Table 2, one can see that the number 2 and number 4 ranked segments actually had higher accident frequencies than the number 1 ranked segment. The reason for this is that the number one ranked segment is performing worse than expected based on its characteristics when compared to the other segments. The pattern is evident from the other tables as well.

Table 4 illustrates a problem when extreme values are present. The number 2 ranked segment has an extremely long length (83.95 km) and an extremely low AADT (20 vehicles a day). Values like these are common with many of the gravel roads in the province. This segment only had 4 accidents over 3 years but gets ranked high because of its characteristics. Obviously a segment with only 4 accidents over 3 years will not be a priority so segments with low accident counts will likely not be considered and should perhaps be filtered out.

In the map of paved undivided highway sections in Figure 2, every major urban center has a hotspot segment close by. Saskatoon appears to have the highest abundance of hotspot segments extending out from almost every direction of the south half of the city, from west to south to east. Figure 3 shows the number 2 ranked divided highway segment extending out from the south side of the city as well. This makes for an obvious focus point evident by just a quick glance. Other hotspot cluster areas evident from this overview appear to be the northwest of Regina, south of Yorkton and the rural northwest. This type of overview makes it easy to narrow the focus by allowing for simple visual recognition of obvious spatial patterns.

The mapped results for the gravel highway hotspots in Figure 4 were less interesting than the other highway groups. The hotspots are scattered across the province and no immediately obvious spatial patterns are evident. As previously mentioned, many of the hotspots only appear because of extreme values which make the analysis of this highway group less useful.

The close up analysis of the top divided highway hotspot in Figure 5 shows how we can really pinpoint strategic locations for mitigation methods. At a glance we see that the lower half of this control section is riddled with wildlife accident clusters. The clusters lie on roughly a 5 km stretch of road from the bridge on the North Saskatchewan River to just north of the town of Borden. This now becomes a much more manageable area (5 km narrowed down from 19.26 km) with very high potential for safety improvement. This type of analysis can be done for all of the top hotspot picks and then used to help decide which segments have the most feasibility for implementing safety measures. Other spatial factors could also be considered and layered onto the map in this type of analysis such as vegetation, water bodies and protected areas.

Conclusions

The goal of this project was to find specific locations on Saskatchewan highways that exhibit high potential for safety improvement with regards to wildlife accidents. This was successfully accomplished by combining the state of the art techniques of Empirical Bayes network screening and GIS analysis. The Empirical Bayes method provides a reliable means to narrow down the search for safety improvement potential while GIS analysis helped pinpoint exact locations and spatial relationships. The results of Empirical Bayes network screening can be ranked and shown on paper (Tables 2, 3, 4) but it also helps to observe the data visually with the use of GIS software. The GeoTAIS software offers an interactive environment which can display the data on a map at any scale. At first, an overview of the data (Figures 1, 2 and 3) helps to quickly identify areas of interest and from there we can zoom in to take a look at actual accident locations and their spatial patterns. The result is a fast and efficient way to assess areas of high safety improvement potential. While our application was directed towards wildlife accidents, the same methodology could also be applied to other types of traffic accident analysis.

References

1. Insurance Information Institute, 2010. *Deer-Vehicle Collisions Are On the Rise; Make Sure You Have Comprehensive Coverage On Your Auto Policy*. Retrieved March.1, 2011 from http://www.iii.org/press_releases/deer-vehicle-collisions-are-on-the-rise-make-sure-you-have-comprehensive-coverage-on-your-auto-policy.html

2. L-P Tardif & Associates, 2003. *Collisions Involving Motor Vehicles and Large Animals in Canada*. Retrieved March.1, 2011 from http://www.wildlifeaccidents.ca/docs/D6ACDB93DFABC8C6.pdf

3. L-P Tardif & Associates, 2006. *Update of Data Sources on Collisions Involving Motor Vehicles and Large Animals in Canada*. Retrieved March.1, 2011 from http://www.tc.gc.ca/media/documents/roadsafety/Collisions_large_animals-vehicles_June_8_final_report_e.pdf

4. TAIS, 2011. Traffic Accident Information System database. Traffic Safety Program Evaluation, Saskatchewan Government Insurance. Regina, Saskatchewan.

5. Statistics Canada, 2010. Quarterly Demographic Estimates. Retrieved March.1, 2011 from http://www.statcan.gc.ca/daily-quotidien/101222/t101222a2-eng.htm

6. Saskatchewan Ministry of Highways, 2011. Common Questions. Retrieved March.1, 2011 from http://www.highways.gov.sk.ca/common-questions/

7. Jo J., Lee J., Ouyang Y., 2011. *Integrated Decision Support for Roadway Safety Analysis*. Journal of Computing in Civil Engineering 25:1, pp 50-56

8. AASHTO *Safety Analyst*, 2011. Network Screening. Retrieved March.1, 2011 from http://www.safetyanalyst.org/screening.htm

9. Environmental Systems Research Institute (ESRI), 2010. *Types of Geodatabases*. ArcGIS Desktop 9.3 Help. Retrieved April.11, 2011 from http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?id=2480&pid=2474&topicname=Types_of_geodatabases

10. Wang X. and Abdel-Aty M., 2006. *Temporal and spatial analyses of rear-end crashes at signalized intersections.* Accident Analysis and Prevention Vol.38, pp 1137-1150

11. Bamfo J. and Hauer E., 1977. *Two tools for finding what links the dependent variable to the Explanatory Variables.* In Proceedings of the ICTCT 1997 Conference, Lund, Sweden.

12. Powers M. and Carson J., 2004. *Before-After Crash Analysis: A Primer for Using the Empirical Bayes Method*. Montana State University, Department of Civil Engineering.

13. Mitra S., 2008. Enhancing Road Traffic Safety: *A GIS Based Methodology to Identify Potential Areas of Improvement*. Retrieved March.1, 2011 from http://leonard.csusb.edu/research/documents/1018FinalReport.pdf

14. Liang L., Ma'some D. and Hua L., 2005. *Traffic Accident Application Using Geographic Information System*. Journal of the Eastern Asia Society for Transportation Studies Vol.6, pp 3574-3589.