GIS applications of slipperiness modelling

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INTRODUCTION

A need for winter maintenance to improve trafficability and also an increased risk for car accidents is the result of slippery road conditions. Where slippery roads develop depends on the meteorological conditions and since different areas differ in climate, the accident pattern and maintenance requirements will be specific for each part of the country. Pisano and Nelson (1998) point out that "poor allocations of road maintenance resources through excessive use of materials and labour at the wrong place and time increases costs while failing to minimise crashes and travel time". This further emphasises the importance of knowing the spatial distribution of slipperiness on roads. A number of slippery conditions can be defined depending on how they form and this creates a standardised classification. Data from a Road Weather Information System (RWIS) makes this possible and it gives many opportunities in spatial analysis of road climatology. For example:

- **Optimising the RWIS-station network**

  Instrumentation on individual stations for optimal detection of the types of slipperiness that occur at that specific place.

  Placement of each station, e.g. to detect a maximum number of types or one specific.

- **Planning the winter road maintenance**

  Knowledge of which types of slipperiness occurs where and how much, makes it easier to plan the maintenance need for different areas and times.

- **Planning of new road sections**

  In some areas a small change in the placement of a new road section makes a large change in the future road climate.

Planning of winter road maintenance can be optimised with knowledge about which type of road condition that is common in different areas. Several papers are written on the subject of defining a winter index to describe winter severity in different regions. Duaas et al. (1994) developed a method for allocating funds for winter maintenance. Cornford and Thornes (1996) showed a relation between winter indices and expenditure on maintenance. The purpose of constructing an index is generally to achieve a fair distribution of funding between the units responsible for maintenance.

The method described in this paper can also be used to plan the routes of new road sections. Fridstrøm et al. (1995) point out that weather conditions can play an important role in the accident-generating process and Schandersson (1998) showed an increase in accident risk during snowfall. By being aware of the most problematic areas, the most accident-prone and maintenance-requiring areas can be avoided beforehand.

This project is a further development of methods used in two former papers by Gustavsson et al. (1998) and Norrman (1999). Gustavsson et al. used a high frequency of low temperatures as a measure of unfavourable road climate, but the actual road conditions, e.g. wet or dry road surface, were not taken into account. Variations in topography and geography were used as input parameters in a model built for a Geographical Information System (GIS). Norrman (1999) suggests a classification of weather data into 10 types of slippery road condition. With knowledge of how the physical parameters, used in this classification, vary with topography and landuse, it is possible to show the spatial pattern of slipperiness. Regression analysis and GIS are used to make this model.

The structure followed during this paper is divided into three climate scales: Global, regional and local. A specific place has a latitude and a longitude that creates a certain winter weather. The road climate will in turn vary with regional factors, like distance to coast or elevation. These variations can be modelled, as described above, with a regression model. The remaining unexplained variation can be attributed to local factors. Weather stations in the Swedish RWIS are usually placed to show low temperatures during a specific weather situation, not to be representative for its surroundings at all times.

DATA

In the Swedish RWIS a large number of field stations are situated at roadsides, each equipped with sensors measuring air temperature (T_{air}), relative humidity (Rh) and road surface temperature (T_{road}). Observations are made every half an hour and the data is collected and stored in a central archive. Some stations also observe precipitation (P), wind speed (U) and wind direction. The dewpoint temperature (T_{dew}) is automatically derived from T_{air} and Rh.

Road conditions can be categorised according to a number of processes that give rise to different types of slipperiness, Norrman (1998). The author defines 10 situations classified by using data from a RWIS (Table 1).

Table 1. Classification of RWIS-data into ten types of slipperiness.

Type of slipperiness	Variables
1. Precipitation (rain/sleet) on a frozen road surface.	P T_{air} T_{road}
2. Precipitation (snow) on a frozen road surface.	P T_{air} T_{road}
3. Precipitation (snow/sleet) on a warm road surface.	P T_{air} T_{road}
4. Snowfall together with hoar-frost	P T_{air} T_{road} T_{dew}
5. Hoar-frost and low visibility	T_{road} T_{dew} Rh
6. Freezing dew followed by hoar-frost	T_{road} T_{dew}
7. Strong formation of hoar-frost	T_{road} T_{dew} Rh U
8. Weak formation of hoar-frost	T_{road} T_{dew} Rh U
9. Drifting snow	P T_{air} Rh U
10. Watercover which freezes	P T_{air} T_{dew} T_{road} Rh

All stations within the study area that have the required equipment for measuring these variables were selected. A total number of 27 met the criteria and they are quite evenly distributed throughout the area (figure 1). The RWIS data was gathered during the winter of 1996-97, from November to April. Topographical parameters that may have an influence on the spatial variation of these measured variables and that can be mapped from a DEM are chosen. Topographical factors are calculated from the global DEM *GTOPO30*, which has a resolution of approximately 1 km. A data base on landuse is available from *GRID-Arendal* on the internet and it has the same resolution as the DEM. The GIS software used is IDRISI, which is a raster-based system developed by Clark University (1995).

METHODS

An area of approximately 200 x 80 km was chosen on the Swedish south-west coast (figure 1). It is situated within latitudes 57.3°-58.1°N, longitudes 11.7°-15.2°E and has a varied topography with elevations from 0 to 370 m. The elevation increases with distance from the west coast. The climate of this area is under a strong influence of westerly winds, which will be reflected in, for instance, the distribution of precipitation.

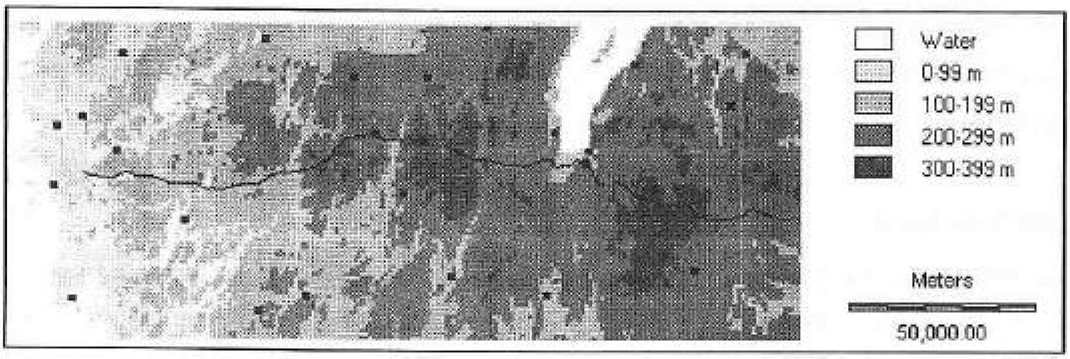

Figure 1. The study area with elevations, road weather stations (black squares) and a road section referred to later in the text.

The spatial modelling was performed in two steps, multiple regression and kriging with model variograms. The choice of these steps had two reasons, firstly to make a spatial analysis of the different types of slipperiness and secondly to make the interpolation easy with a reasonably good representation of the "real" distribution. The parameters used in the multiple regression were:

- Meters above the sea level (*masl*).
- Distance from the sea in kilometres (D_{Sea}). This is the Euclidean, as the crow flies, distance between each station and the nearest point on the coast. The square root of this variable was also used ($\sqrt{D_{Sea}}$).

- Distance from the large lake, Vättern, in kilometres (D_{Lake}). This is also the Euclidean distance between each station and the nearest point on the lakeside. The square root of this variable was also used ($\sqrt{D_{Lake}}$).

Multiple regression was applied on all 10 types of slipperiness.

Residuals from the regression are studied to interpret local variations in road climate. They are interpolated to a map by classifying landuse at each station and then giving pixels with the same landuse that specific residual. When stations with the same landuse have different residuals an average between them is used. Local and regional maps for each type of slipperiness are then added up. Some of, or all, types can be added up depending on the application. For example, Norrman and Eriksson (1999) found that the road accident rate varies between types. Since different types have a different impact, they should be weighted accordingly. Each accident rate can then be multiplied with each slipperiness map and then summarised.

APPLICATIONS

The stations are usually placed in typical environments, like where cold air pooling occurs or on hills, to give an early warning on deteriorating road conditions. It is important that the stations are placed and equipped in the best possible way. Road profiles of the slipperiness variations are extracted from the maps and shown in figure 2, the road is shown in figure 1. It is now possible to place the stations where a maximum number of occasions with slippery road conditions are detected. It is also possible to equip each station according to the types occurring at the site. It can clearly be seen in figure 2 that each type has a different variation along the road. Considering the variation of e.g. type 2 (snow on a cold road surface), it is crucial where a station is placed. Type 9 (drifting snow) does not vary much along this road so all stations will give equal information in this case. On the other hand, the temporal resolution is important for monitoring changes in weather and road conditions. For instance, when there is a front passage, it is good to have RWIS-stations at different sites to be able to follow the weather development even if the average slipperiness occurrence does not vary in the area.

A stations representativity can be analysed from the local placement map (topography and landuse). Here it is possible to see whether it is placed in the same type of location as nearby pixels.

The maps can be useful when planning winter road maintenance. Different types of slipperiness require different types of action. The ten types can, for example, be grouped into salting/gritting and ploughing categories. This would create means of spatial analysis of different maintenance needs.

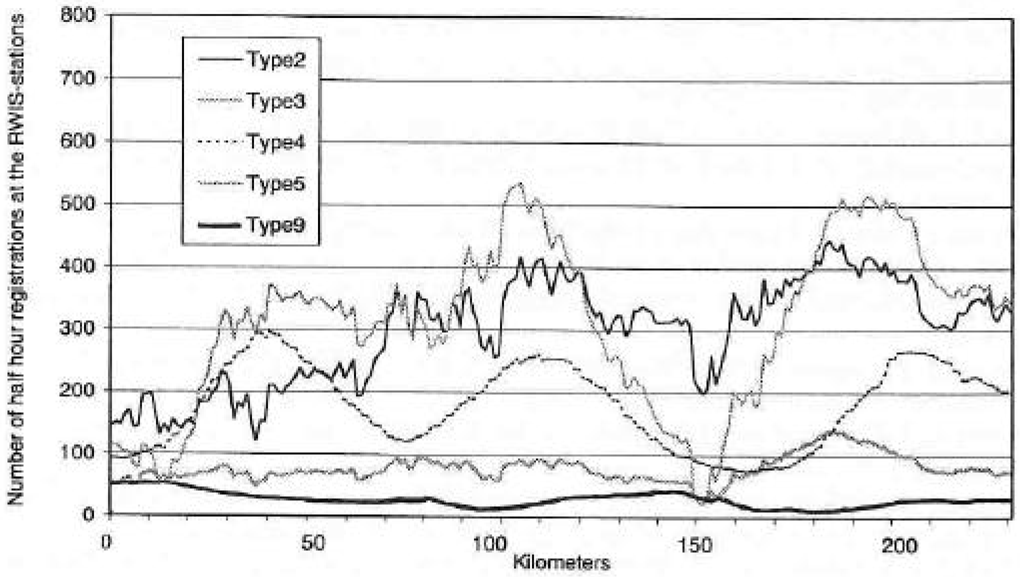

Figure 2. The variation of a selection of slipperiness types along a road (figure 1) in the study area. See table 1 for explanation of the type numbers.

Climate should be a more important factor when planning new road stretches, considering both a future accident risk and maintenance requirements. The road chosen here as an example runs from west (0 km) to east (230 km) through an area of a varied topography with elevations from 73 to 354 m. It is possible to use GIS to build corridors around planned road sections. The final slipperiness map can be seen as a friction surface where it is most unfavourable to place a road on the highest values (=high frequency of slipperiness). The corridor will be widest where slipperiness is least frequent and it makes the least difference how the road is placed. In a narrow corridor it can make a larger climatological difference the further the road is moved. Much money can be saved in the future if road climate is taken into account in the planning process, even if it does not come to the cheapest alternative to build.

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