Optimum route location model for an all-weather road on the east side of Lake Winnipeg

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Abstract: Development of all-weather roads in remote areas presents many problems. This is well illustrated by this study which attempts to determine the best road corridor for the east side of Lake Winnipeg. This corridor must connect the various resource-bases in native communities. This study also investigates the key engineering, environmental and social factors affecting road development to the region. They should not be considered in isolation from one another, as they are interrelated.

Any all-weather road development requires an environmental assessment of some form. Usually such developments are designed with engineering standards in mind, with little heed given to the environmental and social impacts in the early planning stages. The development of optimization models using Geographic Information System (GIS) can assist in the placement of a road by reducing human conflicts and environmental impacts.

The objectives of this study are twofold: firstly, to design an optimum path road network model for the east side of Lake Winnipeg, and secondly, to demonstrate the effectiveness of a GIS model in providing a corridor with the least cost of engineering, and minimal environmental and social impacts.

Introduction

Development of all-weather roads in remote areas presents numerous problems and conflicts. The east side of Lake Winnipeg is a remote region of dispersed, isolated, small communities which currently rely on temporary, weather-dependent transportation systems. Transport Canada (1987) has recommended an all-weather road facility to assist in the placement of interim improvement facilities, which is to consider environmental and cultural factors.

The Provincial Overview Plan of 1987 (Manitoba Natural Resources, 1987) emphasized the need for multi-use corridors in this region to reduce the overall impact. "It is realized that some zones in the plan area are very sensitive to transportation corridors, the paramount importance of these corridors to isolated communities located within and beyond the plan area should not be neglected."

Any all-weather road development would require an environmental assessment of some form. These types of developments are generally designed to meet efficient engineering standards, with little consideration of environmental or social impacts in the early planning stages. The development of optimization models can assist in establishing a road alignment that would reduce potential conflict and environmental impacts. All-weather roads will link communities and facilitate the exchange of industrial goods, but they can also have a negative impact on caribou calving areas, hunting and fishing in the area.

The purpose of this study is to develop and demonstrate, on a micro- computer based system, an optimum route location model for initial siting of a corridor for road development which takes into account engineering, social and environmental considerations. This model could take into consideration lessons learned from Conflict Regulation by Boulding and Wehr (1979) for improving the overall efficiency and accuracy of conceptual plans. Another objective is to demonstrate the effectiveness of a GIS model in providing a corridor at the lowest cost while minimizing environmental and social impacts. Such a model will provide a beneficial mechanism for resolving conflicts in road development by attempting to take into account the majority of concerns and interests. It has three principal components: road engineering, environmental, and social criteria. Each component is broken into a number of layers which form the raw data for the model. The data is derived from existing maps, satellite imagery and community meetings.

Study Area

The study area chosen is from the east side of Lake Winnipeg east to the Ontario border and from Hollow Water north to Pigeon

River (Figure 1). The east side of Lake Winnipeg is one of the few remaining regions under developed regions of Manitoba, with most of it accessible only by winter road, boat, or plane. This region of Manitoba is part of the Canadian Shield and is characterized by uplands with exposed bedrock and broad low lying areas. Muskeg and other types of low lying land predominate near the shore of Lake Winnipeg, while areas of bare rock are common along the Manitoba and Ontario border. There are pockets of lakes throughout the region. The region's rivers and lakes drain west into Lake Winnipeg. The shallow soils are a mixture of grey luvisols, organic and rock land covered by boreal forest composed mainly of black spruce, white spruce, jack pine and other coniferous species. The main inhabitants are Aboriginals, Metis, and a few white inhabitants. The total population of around 11,000 people. The majority of the area is Crown Land, which falls under provincial jurisdiction. The Indian Reserve land currently falls under federal jurisdiction.

There are pockets of lakes throughout the region (Table 1). The economy is primarily subsistence with some commercial activity. The unemployment rate is well over fifty percent and the region relies heavily on transfer payments and on southern subsidy (Manitoba Natural Resources, 1987). The population in the region is rising at a rate exceeding three per cent per year. The region may not have the capacity to support the population without continuing subsidy and southern goods (Table 1).

The east side of Lake Winnipeg is in a period of transition. However, the cumulative impact on the environment can be minimized with proper planning and decision making. The use of GIS, mapping database, and Remote Sensing, may help with these processes.

Methods of Analysis

Modelling refers to the processing of duplicating processes and conditions in order to provide new information about the physical and sociological processes that make make up our world. Route location models have been used for many years. Roberts and Suhbier (1964) used preselected alternate routes and evaluated them

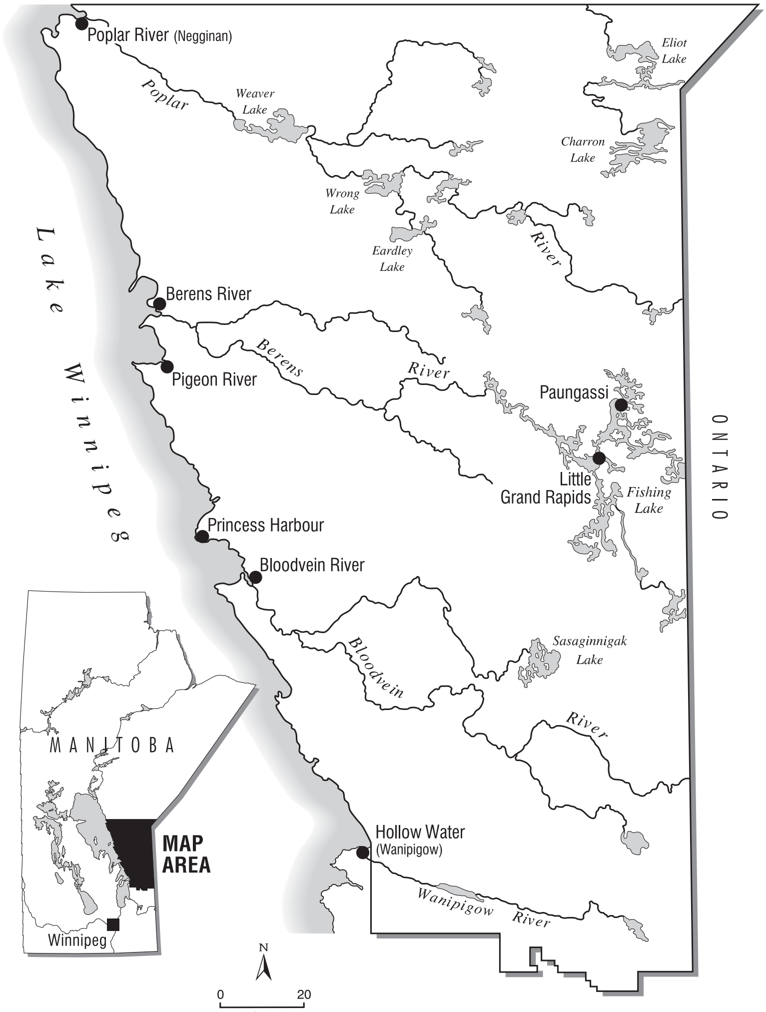

Figure 1: *Location of the sudy area.*

Table 1: *Native communities on east side of Lake Winnipeg.*

COMMUNITIES	POPULATION	INDUSTRY	DOMINANT LANGUAGE
Bloodvein	494	1,4,7,8,12	English
Little Grand Rapids	943	7,10,1,4	Saulteaux
Paungassi	L.G.R.	7,10,1,4	Saulteaux
Berens River	874	1,4,9,13	English
Poplar River	620	1,4,8	Saulteaux
St. Theresa Point	1720	1,8,7,4	Cree
Wasagamack	765	1,6,7,8	Cree
Population Total	+5416		

Economic Activities
1. Fishing
4. Forestry
6. Hunting
7. Trapping
8. Construction
9. Commercial Industries
10. Guiding
12. Band Administration
13. Government
14. Arts and Crafts

with respect to several cost variables. This allowed for the rational selection of the best alternative.

Turner and Miles (1971) determined that there are many factors affecting the location of a road: route-dependent factors such as user costs, aesthetics, and the cost of structures. The first set of factors may be associated with the generation of alternatives while the second may be associated with the evaluation of alternatives to find an optimum route.

Both Minamikata (1984) and Nieuwenhuis (1986) developed a raster grid cells method to evaluate road costs. Douglas and Henderson (1988) expanded on these methods, developing a multi-parameter method which used a minimum total rating to obtain the optimum path. The criteria used were topography, land ownership and hazards. They suggested other criteria might be used such a location of sand and gravel, water and railway crossings.

The available database for the present study is derived from a variety of sources including satellite (supervised imagery), computer data bases, map data, statistical data and personal interviews. The map data available includes a mineral potential map (Azis, et al. 1972), land use zones map (Wall 1976), biophysical map of a portion of the region, fishing lodges and outcamps map (Indian and Northern Affairs 1984), topography map (Walton 1988) and surficial deposit map. Each of these sources is input as raw data into the model. The raw database is reclassified into three major categories, namely: engineering, environmental, and social; and various subcategories/classes according to criteria set out in the optimum path/corridor for the road model. The economic criteria in this model are meant to examine the route of least conflict, although this may not be the least expensive route. The following is a brief description of the major categories and subcategories, along with their scores of the data base selected for the all-weather model;

1. Engineering criteria consists of:
- The percentage slope is classified and assigned a score (weighted value) of 0 value to regions of 0 - 10% slope, 5 value to 10% to 20% slope, and 10 value to 20 and up slope.
- Surface deposits are classified and assigned score of 10 for no deposits, 5 for potential deposits and 0 for commercial deposits.
- Hazards will form the third overlay based on existing barriers to road development. Water bodies or thick forest cover are classified and assigned a score of 0 for no barrier, 5 for partial, and 10 for complete cover barrier.

2. Environmental criteria consists of:
- The east side of Lake Winnipeg offers an opportunity to look at environmental factors which might be affected by the development of a road into a remote area. For example, a wilderness park affords some protection to the region.
- Land use zones are classified and assigned a score of 0 for land readily traversed by a road, while a score of 10 represents regions which should be left alone.
- Natural lake use zones are classified and assigned a score of 0 for a diverse biophysical zone and a score of 10 for a homogeneous zone.

3. Social criteria consists of:
- Lodges/fishing camps classified into and assigned a score of 0 for within 1.00 km buffer, 10 for > 1.00 km away from business

location. Fishing is a primary livelihood and is affected by a road development. While a buffer zone of 1.00 km is recommended around a fishing camp to protect the fishery, freezer plant locations should be placed close to the newly developed road (Manitoba Hydro 1989).

- Communities/residential areas are classified into and assigned a score of 0 for within 1.00 km buffer, and 10 for >1.0 km outside communities. They may provide the destination points for the road. In certain instances it is not desirable to be linked to the south, but regionally integrated (Chorley et al. 1967).
- Existing and potential mine sites are classified into weighted values of 0 for within 1.00 km and 10 for 1.00 km outside a mining area. The road may be able to link areas of potential mining to the region (Romanowski 1986).

The IDRISI software package (Clark University 1987) was used to process the above overlays as well as for importing and converting vector data into raster formats. As a raster based system it provides map overlays easily as well as execution of the model.

The Geography Information Model is designed to incorporate the majority of the factors listed above into a route selection model for the east side of Lake Winnipeg. The goal of the model is to find the optimum all-weather road route, bearing in mind all the related engineering, environmental, and social concerns (Eastman et al. 1993). From the engineering perspective, the most suitable location for all-weather roads is associated with no barriers while unsuitable is associated with barrier areas. To meet the environmental and social concerns, all-weather road routes are protected with a buffer zone of 1.00 km within the engineering suitable area. The total index factor is used to narrow down the suitable corridor for building all-weather roads. Land with the lowest index value is recommended for building. All of the individual layers, in this instance, are treated as equivalents (Barry, et al. 1985). It is also possible to set up a participatory setting where individuals involved can be assigned a relative importance factor. These factors are then weighted according to the results of the participatory group (Arnoff 1989).

Douglas and Henderson's (1988) work created a least cost road suitability map equation based on each grid cell – having a total grid cell value from 0 - 100. The same results can be obtained using an IDRISI Cost module based on creating a cost surface in relation to a source point or cell, and identifying the current endpoint for the road just north of Hollow Water (see Figure 2). This seemed an appropriate starting point as environmental damage has occurred by development of a logging road.

"The Cost Module generates a distance/proximity surface where distance is measured as the least effort in moving over a friction surface. The unit of measure is 'grid cell equivalents' (gce)" (IDRISI 1996, p. 38). The COSTGROW option was used to deal with complex surfaces of the study region.

The Pathway Module (together with the cost surface module) is used to produce the least cost optimal road. This module requires the destination target cells be indicated as points or lines on an image. A road network cannot be created without repeating the procedure a number of times, because it simply finds a single least cost path to one target. The procedure must be used several times with individual targets to arrive at optimum paths to a number of locations. The width of the path is one grid cell.

Results

Using the Pathway Module a path was created from the source point north of Hollow Water to Hollow Water. It was found to be extremely close to the road created by a lumber company. A second cost surface map was created with Little Grand Rapids as the source point using the same suitability map. The cost surface was input into the Pathway Module to derive the least cost path to Poplar Point. It was used a second time using the pathway from the source point north of Hollow Water to Poplar River. Figure 2 shows the final map representing a possible road network.

The resulting road network map takes a path close to the edge of Lake Winnipeg to link native communities. The link to Little Grand Rapids and Pauguassi seems to avoid the park lands and does not cross through caribou calving areas. The actual road corridor would come later after further intensive investigation by the local authority of the region as recommended by Simpson and McKecknie (1987). However, the initial process can involve all

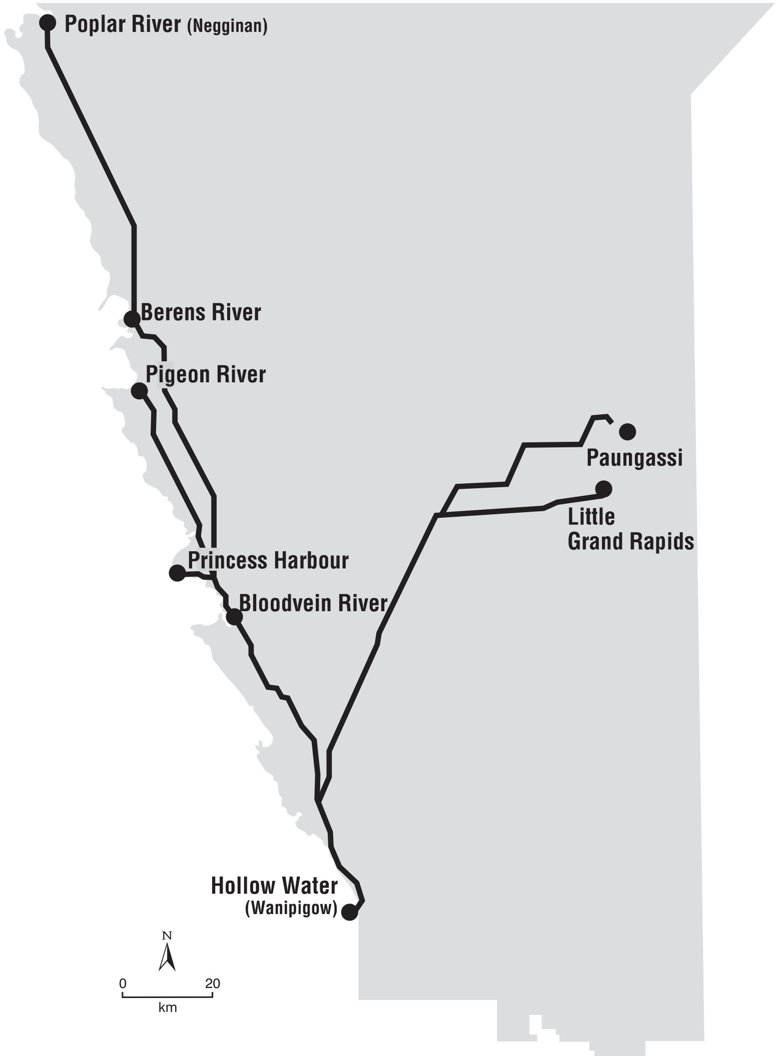

Figure 2: *Location of proposed roads.*

parties in the process of social and environmental assessment prior to ground evaluation.

Conclusion

In this study, a holistic approach to modelling a suitable corridor for all-weather road development was explored. It incorporated engineering, environmental and social aspects of the region. This type of model can take into account competing interests for a particular parcel of land.

Each portion of the development on the east side of Lake Winnipeg has multiple effects both direct and indirect. they are also cumulative in nature (Canadian Environmental Assessment Research Council 1987 and 1988). Recently the cumulative effects associated with complex developments have been recognized as a major challenge. Many of them can cause irreversible social, economic, and environmental effects. To assess such effects we must adopt a more comprehensive holistic approach to the environment. Each activity can not operate independently of the other. Predictive/simulation models similar to the present study can assist in achieving the most suitable development.

The tools of GIS and Remote Sensing are playing an integral role in this type of modelling, both in a predictive and historical perspective. This type of information will allow for the evaluation and prediction of change.

The east side of Lake Winnipeg holds the promise of some development. If developments such as multi-use corridors and roads are properly planned they will have a positive impact. The model is used to create the most suitable path between two points or a point and a road. Further work needs to be carried out to create a road network module which could form an extension of the Pathway module. This is a limitation of the current IDRISI program models, because they cannot handle the creation of a network. IDRISI also has limited capability in handling the input of routes through a region and determining optimum paths. However, the model can input environmental assessment audits. In fact, it may be in this way that one can further improve the overall model's effectiveness in planning road corridors.

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