If all ambulances could fly: putting provincial standards of emergency care access to the test in Northern British Columbia

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This article has been peer reviewed.

Introduction: Geographic access to emergency treatment remains an important public policy concern as rural emergency medical systems respond to various pressures to centralize services. Geographical Information Systems (GIS) are effective tools to determine what proportion of a given population is adequately served by existing or proposed service distributions.
Methods: This study compares 2 GIS approaches to determining whether recent standards of emergency care access established by the British Columbia Ministry of Health Services are being met in Northern British Columbia. In particular, we compare results obtained using the more commonly used straight-line, or "as the crow flies," method with those obtained using a more sophisticated method that estimates travel time using digitally referenced road network data.
Results: Both methods reveal that provincial standards of emergency access are not being met in Northern British Columbia.
Conclusion: In terms of comparing the 2 approaches, the network technique indicated a lower level of access and was more accurate in identifying populations residing inside and outside the "golden hour" of emergency care.

Introduction : L'accès géographique aux soins d'urgence demeure une importante préoccupation sur le plan des politiques publiques au moment où les systèmes médicaux et d'urgence des milieux ruraux répondent à diverses pressions pour centraliser leurs services. Les systèmes d'information géographique (SIG) sont des moyens efficaces de déterminer le pourcentage d'une population donnée qui est adéquatement desservie par des services existants ou proposés.
Méthodes : Cette étude compare deux méthodes de SIG pour déterminer si l'on satisfait, dans le nord de la Colombie-Britannique, aux normes récentes sur l'accès aux soins d'urgence établies par le ministère des Services de santé de cette province. Nous comparons plus particulièrement les résultats obtenus par la méthode plus couramment utilisée de la ligne droite ou «à vol d'oiseau» aux résultats obtenus par des méthodes plus complexes qui estiment le temps de déplacement à partir des données référencées numériquement d'un réseau routier.
Résultats : Les deux méthodes révèlent que l'on ne respecte pas, dans le nord de la Colombie-Britannique, les normes provinciales sur l'accès aux services d'urgence.
Conclusion : Sur le plan de la comparaison des deux méthodes, la technique du réseau routier a indiqué un niveau moins élevé d'accès et s'est révélée plus exacte pour identifier les populations résidant à moins d'une heure ou à plus d'une heure de route, une heure constituant l'«étalon-or» du temps d'accès maximal pour les soins d'urgence.

INTRODUCTION

Geographic access to emergency treatment was a critical issue in the 1940s and 1950s when many rural hospitals in Canada were built using a mix of federal, provincial and local funds. More than 5 decades later, this issue is again a key concern as the viability of many rural facilities is threatened by persistent physician shortages, population decline, and centralization exercises carried out by provincial governments or delegated authorities such as regional health boards. A number of provincial governments have established guidelines intended to ensure hospital emergency department and dispatch centre closures are done in a manner that guarantee rural residents remain within specified maximum distances or travel times to the nearest emergency treatment site.[1–4] Too often, however, the issue of accurately measuring distances, travel times, and population distributions is overlooked.[1–3]

Geographical Information Systems (GIS) are effective tools to determine what proportion of a given population is adequately served by existing or proposed service distributions.[5–8] Two types of approaches can be employed to estimate travel time using GIS.[9,10] One approach is based on the shortest route (i.e., by road) (referred to henceforth as the "shortest-route" approach or analysis) between point of origin and destination following representations of road networks, thus requiring sophisticated data and analytical techniques.[5–7,11] The second approach uses "as the crow flies" measures of distance to estimate travel time.[12–14] The "as the crow flies" (i.e., straight-line) measure of distance has less stringent data requirements and is easier to program, but is also less accurate because it does not consider actual travel paths.[9] Currently, the latter technique is more widespread, and its use is supported in the literature by studies that demonstrate a high degree of correlation between results using either method.[15] There are concerns, however, that the straight-line method may not be as effective in rural areas that have more limited road coverage, and where variable road conditions, climate and topography present barriers to physical movement.[5,10,11,14,15]

These concerns apply to our study area, Northern British Columbia (BC), which we define as the jurisdiction governed by the Northern Health Authority (NHA).[16] The geographic size of the study area is over 600 000 km^2, which represents 60% of BC's total land mass, and is the largest territory covered by one regional health authority in Canada. Throughout this vast area, there are approximately 300 000 residents who are unevenly distributed in numerous small communities, of which only one community has a population exceeding 50 000 (Fig. 1).[17]

The BC Ministry of Health Services (MHS) and Planning (2002) defines their standard of emergency access as 98% of a regional authority's population residing within 60 minutes' travel from home to an emergency treatment site — a variation on the "golden hour" concept.[1] The 2002 report, cited above, claims that Northern BC meets provincial standards of emergency care access. However, the straight-line method that is used to support the MHS analysis is based on crude estimates of travel time and population distribution.[12,13] In addition, the report in question included a number of facilities that do not appear to provide ongoing emergency treatment capability. Notwithstanding concerns about the scientific basis of the golden hour principle,[18,19] our main concerns are that the relationship between distance and travel times is analyzed directly rather than approximated, and that the mapping of population distributions relative to travel-time criteria is carried out in the most rigourous manner possible.

The first objective of this study was to retest the provincial guidelines using straight-line estimations, but with higher spatial resolution data, more up-to-date population figures, and including only facilities that offer 24/7/52 (24 hours a day, 7 days a week, and 52 weeks a year) emergency treatment. The second objective was to employ the more rigourous method of calculating travel times based on actual transportation networks, and compare these results to the straight-line analysis to determine whether the more sophisticated method is warranted to examine emergency care accessibility in Northern BC.

Data and methods

In accordance with the MHS definition of emergency services, we chose to exclude facilities that, as of June 2004, do not remain open or provide on-call

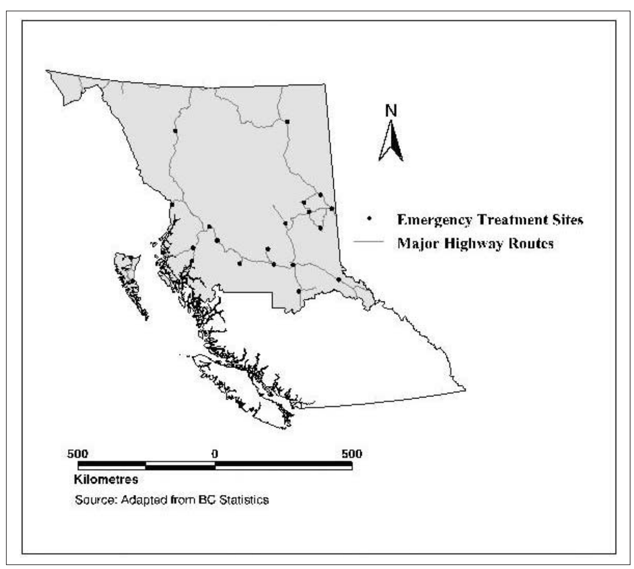

Fig. 1. Northern Health Authority, British Columbia, Canada, 2004.

services 24/7/52.[1] Hospital data were collected from the Canadian Healthcare Association's *Guide to Canadian Healthcare Facilities*, 2002/03.[20] From this document we compiled an initial list of 19 facilities operated by the NHA that were classified as providing 24/7/52 emergency service. An additional 3 facilities were added to our list following phone calls to all smaller facilities in the region that had not reported this attribute in the directory. As a result, our study included a lower number of facilities than the 35 listed in the Ministry's report. Each eligible facility was manually geo-referenced based on the street address of the facility.

Block level population data for the study area were downloaded from Statistics Canada using GeoSuite 2002.[21] Blocks are defined as the "area equivalent to a city block bounded by intersecting streets."[22] The points representing block centroids (i.e., the geographic centres of the block polygons) contain the attribute of total population. The block scale was chosen because it is the finest scale at which population estimates are available, and because there is no suppression or rounding of population data. Postal code data for the entire study area were obtained online from the Canadian Census Postal Code Analyzer 2001 database.[23] The postal code polygons were used to adjust population estimates obtained from the block level data using the shortest-route analysis technique.[24]

Route network data that included all roads in BC were obtained from DMTI Spatial Inc.[25] According to DMTI's data standards, speed limits for each road segment were estimated based on road type and proximity to population density based on the 1996 Census of Canada. Ferry routes, trails and temporary roads were listed at 10 km/h, gravel roads in sparsely populated areas and ramps at 50 km/h, and major or arterial roads and secondary highways in sparsely populated areas at 60 km/h. Road types that were assigned a speed limit of 80 km/h included gravel roads in populated areas, major/arterial roads in populated areas, secondary highways in populated areas and primary roads. Expressways had an estimated speed limit of 100 km/h. As with any model input, GIS data were reviewed thoroughly to confirm that there were no non-standard outlier values (e.g., we discovered that the speed rates for ferry routes had to be revised to conform to DMTI's own standards).

The facility table, postal code table and block data table were imported into ArcView v. 3.2, a GIS program,[26] and event themes were created. This means that the latitude and longitude coordinates in the 3 tables were converted by the software into 3 GIS point layers, in which each point represented the location of a facility, the centroid of a block, or a postal code area.

We conducted a straight-line analysis by creating 50-km buffers around the 22 hospital points in ArcView. This means that each facility became the centroid of a circular "polygon" with a 50-km radius. (An object in a vector-based GIS, such as ArcView, is technically a string of x,y coordinates joined together by straight lines. Even radial buffers, therefore, which appear on a computer monitor or in print as circles, are correctly referred to as "polygons.") The block centroids that were contained by the buffered facility polygons were then clipped, or selected from the point layer set, allowing us to sum the population within the 50-km buffers.

To conduct the shortest-route analysis, we first imported the road network data and the block data table into a Web-based network calculator program called the Distance Analyzer Interface (DAI)[27] developed at the University of Northern British Columbia (UNBC). The DAI allows the user to import attribute data and query the network calculator for distances or travel times. The DAI calculated 1-hour travel time from each of the 22 hospitals along every possible route. The results were examined on an interactive map-viewing page created in the GIS laboratory at the UNBC with funding from the North West Data Sharing Network,[28] and then exported as a shapefile for analysis using ArcMap, a commercial GIS program.[29]

Next, a 1-km buffer was created around the road segments, resulting in a new GIS polygon layer. The blocks contained partially or entirely within the buffered route layer were selected using the "Select By Location" tool, and a new table was created. The selected block populations were then summed to give the total population within 1 hour of emergency hospital care.

We further fine-tuned the shortest-route analysis by employing postal code data to account for situations where blocks were only partially contained by the route buffer. Postal code areas are higher resolution than blocks, but do not have population data associated with them. In ArcView, a BC block data table was joined to a table of all NHA postal codes to create an event theme. This results in a set of postal codes containing population statistics. The postal code locations that fall within the buffered route layer can then be separated from this set using a procedure in ArcMap referred to as a "clip overlay." Each point contained in the route polygon was selected, and a new table representing all postal codes within 1 hour of emergency services was created. As an illustration, suppose a block containing 10 postal code polygons was partially contained by the route buffer, and 6 of these postal code polygons were located within the route buffer. In this instance, 60% of the population in the block would be considered within the golden hour, rather than the entire population of the block, as estimated without the postal code adjustment.

In order to estimate the improvements in measurement accuracy made when employing the shortest-route analysis compared with the straight-line approach, 3 measures were reported. The *rate of false positives* is the population that resides inside the 50-km facility buffer identified by the straight-line technique, but that were identified as residing more than 1 hour from emergency treatment according to shortest-route analysis, expressed as a percent of the total positives identified using the straight-line technique. The *rate of false negatives* is the population residing outside the 50-km facility buffers that was identified as residing less than 1 hour from emergency treatment according to the shortest-route analysis, as a percent of total negatives identified using the straight-line technique. Finally, the *rate of misclassifications* is the sum of false positives and false negatives as a proportion of the total study population. Population estimates of false positives and false negatives were obtained using the "Select By Location" tool in ArcMap.

Results

The results of the straight-line distance analysis indicated that 18 222 people in Northern BC, or 6.4% of the population in 2001, live farther than 1 hour from emergency care. Using shortest-route analysis and the route buffer technique without adjusting for partial coverage, the number of residents living outside the golden hour increased to 29 388, or 10.4% of the population. By further fine-tuning the network method using postal code locations, the population residing outside the golden hour rose to 30 322, or 10.7% of the population.

In terms of quantifying the improvements in accuracy that resulted from using the shortest-route analysis, we estimate that 17 620 of the 265 041 residents reported to be within the golden hour using the straight-line method would, in fact, have to travel more than 1 hour to the nearest emergency centre. This is a rate of false positives of 6.6%. We also estimated that 6454 of the 18 222 residents reported to be beyond the golden hour using the straight-line method would have to travel less than 1 hour for emergency treatment, or a rate of false negatives of 35.4%. In total, the rate of misclassification using the straight-line method was 8.5% (i.e., 24 074 of 283 263 Northern BC residents).

Fig. 2 provides an illustration of the difference that the shortest-route analysis makes, showing the lack of precision associated with the straight-line approach in identifying how many people reside within a 1-hour automobile trip of the Lakes District Hospital in Burns Lake, BC. In this case, the shortest-route approach identified 2260 of 6961 residents (32.5%) within a 50-km radius of the hospital who are more than 1-hour from the hospital when the actual road network was used to calculate travel time, as indicated by the area route polygons.

Discussion

Our findings suggest that Northern BC is significantly underserved in terms of 24/7/52 emergency care, and that the provincial MHS had substantially underestimated the number of residents outside the golden hour by using less rigourous data and methods of GIS analysis. The findings are even more striking considering the generous interpretation of the golden-hour concept employed to conduct the shortest-route analysis (i.e., 60 min of travel one way, with no consideration of the time needed for an ambulance to respond to an emergency call). Although the standards outlined by the BC MHS are only guidelines and not considered mandatory, they do raise an important question: What would it take to meet these guidelines in Northern BC? Given the results of our analysis, it would seem that

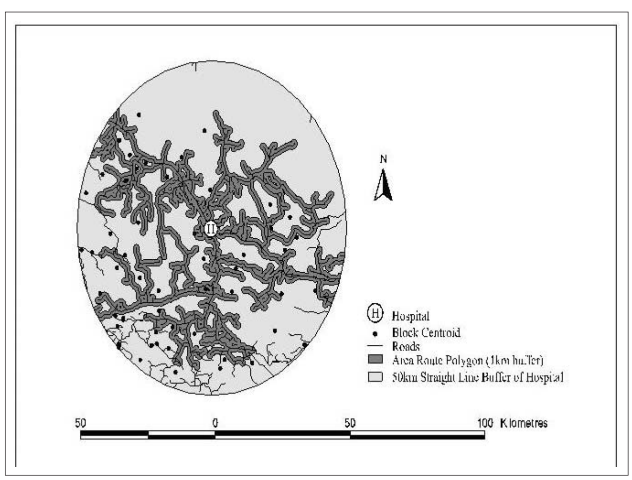

Fig. 2. Identification of "false positives" using shortest-route (by road) analysis within a 50-km aerial buffer around Lakes Distric Hospital, Burns Lake, BC, 2001 Census data.

adequate delivery of emergency services would require substantial reinvestment in Northern BC to address substandard access.

Our results clearly show several benefits to employing shortest-route analysis. Most importantly, the more rigourous analysis suggests that nearly 25 000 residents had been misclassified using the straight-line approach. This number includes approximately 18 000 people who are within a 50-km radius of an emergency treatment facility, but whose travel to the facility is estimated to take more than 1 hour due to road conditions. In the example cited above using shortest-route analysis within a 50-km buffer around the Lakes District Hospital in Burns Lake (Fig. 2), nearly one-third of the population identified as within the golden hour using the less accurate straight-line method were considered to be more than a 1-hour drive using the shortest-route analysis. In effect, the nearly 18 000 individuals identified as "false positives" reside on the low-density fringe of the region's largest urban settlements, highlighting important consequences in terms of the costs and logistics of service delivery when low-density residential development is allowed to occur within or just beyond municipal limits.

The shortest-route approach is useful for more than identifying gaps in access; it also provides more accurate information with which to make decisions about emergency health service planning. For instance, results such as those reported here would add credibility to requests for additional funding in demonstrably underserviced areas. The results produced from the DAI and GIS overlay techniques could be used to pinpoint existing treatment centres presently without 24/7/52 emergency capacity that could be upgraded in order to meet the provincial emergency access guidelines. It could also be used to determine an optimal distribution of a specified number of ambulance stations for which funding has been secured. Likewise, the analysis presented in this paper should be regarded as concrete evidence of the added costs of allowing low-density housing to occur on the fringe of urban settlements, and point to the need for greater coordination between health authorities and municipal and regional levels of government. Finally, the detailed information generated using GIS and shortest-route analysis could be linked to clinical outcomes data as a means of estimating the risk of additional distance or response times for specific conditions or types of trauma at the regional and sub-regional levels.

Additional advantages of GIS and shortest-route analysis techniques are their adaptability. For example, the methods employed in this study can be adapted to account for seasonality, temporary geographic barriers and changing road conditions. Likewise, the analysis can be revised to capture variability in the supply of eligible treatment locations, such as during periods when a community hospital's emergency department is closed due to temporary physician shortages. Such considerations are particularly important for emergency health care in rural and remote regions like Northern BC.

Using the most accurate methods available for calculating travel time and population distribution is imperative when considering access to such a vital service as 24/7/52 emergency care. This is especially the case in rural and remote settings where greater transportation and service provision challenges are the norm. Shortest-route approaches are more costly and complex to develop, but the results of our analysis demonstrate the considerable benefits that these techniques have over more commonplace straight-line GIS methods. We argue that policy regarding health service delivery and accessibility in rural and remote areas would be better informed by the use of shortest-route analysis.

Limitations

The analysis treats all emergency treatment sites as equivalent in terms of service capabilities, which is unrealistic given the differences in size and staffing of facilities throughout the study area. There is no indication, for instance, of temporary emergency department closures that are known to affect smaller facilities in rural and remote settings.

The road network data supplied by DMTI Spatial Inc. has 2 potential shortcomings. First, the coverage in very remote parts of Northern BC is often inadequate. However, this had a very limited impact on the overall results considering that the compact nature of smaller and remote settlements, the small populations involved and the fact that a number of very remote settlements are well outside of the golden hour whether or not the road network data coverage representing these areas is comprehensive. The second shortcoming is the travel speed attributes, which correspond to posted speed limits rather than emergency response conditions. We determined that the slower speed limits are justified as approximating unexpected delays that may be encountered on any given ambulance response, as well as compensating for the inflated estimation of the golden-hour concept employed by the BC MHS.

Another concern is that the estimation of route network travel time using the DAI does not necessarily stop at 60 minutes, but instead "back tracks" to the vector node nearest to, but not beyond, the point at which a 60-minute trip is completed. There is potential for the nodes to be distributed at a lower density in more remote areas, which may result in a larger margin of error in approximating 1 hour of travel.

Finally, when performing buffer routines there is always the question of how to handle situations in which a polygon, such as a block or postal code, is only partially contained. There is no standard procedure for handling these cases. Our approach with the straight-line buffer technique was to include block polygons only if the block centroid was contained. We did so because blocks are typically small in area, but we acknowledge that they are comparatively larger in less dense settings. When conducting the shortest-route analysis, the blocks contained by the 1-km road buffer were counted as within the 1-hour travel time, regardless of whether the centroid was also contained. The use of postal codes to adjust for the area of the block outside of the buffer addresses some of these concerns, but assumes a uniform distribution of population within blocks. It should be noted that the postal code adjustment only resulted in a reduction of 934 residents (less than 1%) of the 253 875 initially regarded as within 1 hour of emergency treatment. This low level of adjustment attests to the small area size of blocks, and hence their utility for this sort of analysis.

Acknowledgements: We thank Seamus Carroll and Aaron Koning for their programming efforts and expertise in the development of the Distance Analyzer Interface.

Financial support for this research was obtained from the British Columbia Rural and Remote Health Institute, University of Northern British Columbia (UNBC), and a research grant from the Northern Land Use Institute at UNBC.

Competing interests: None declared.

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