# Geographical Access to Services, Health (GASH): Modelling Population Access to New Zealand Public Hospitals

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**Abstract.** This paper demonstrates a method for estimating the geographical accessibility of public hospitals. Using Geographical Information Systems, cost path analysis is used to determine the minimum travel time and distance to the closest hospital via a road network. This analysis is applied to approximately 36,000 small areas in New Zealand allowing geographical access to be linked to local populations. Statistics can be generated on what is the total time spent traveling or the total distance traveled if everybody visited a hospital once. These statistics can be generated for different management areas and enables comparisons to be made between regions. This accessibility model is intended for decision support for planners assessing the distribution of hospital services. It can also be easily adapted for other services such as access to General Practitioners and cancer screening centers. A difficulty with calculating travel times is determining the travel speeds for different roads. Road layers often contain information that describes the road characteristics and additional information on the bendiness of the roads can be obtained from calculating the sinuosity of the roads. A process for calculating sinuosity and estimating road travel speeds is described. This study has shown that the northern and southern parts of New Zealand have high average travel times to hospital services.

## 1. INTRODUCTION

The retention of ‘local’ hospital services has been a contentious issue in most countries including New Zealand (Barnett 1984). Local retention of services is a geographical access issue, and the major tension is between the cost of providing hospital services from small relatively isolated facilities and the advantages in providing fewer large facilities with the capacity for providing more complex services. Locating health services, particularly hospitals, is always going to be contentious because facilities are visible symbols of local empowerment. Modeling allows planning and policy development to consider a range of factors in the decision-making process, including where disadvantaged subpopulations may be under-serviced and/or whether there is identifiable inequities in geographical access.

Recent improvements in computer power and the availability of GIS data layers has opened up new opportunities for modeling accessibility. Even though least-cost path algorithms, such as those applied here, have been available in commercial GIS since the late 1980s, the application of these algorithms to large national data sets has only recently become feasible. This paper demonstrates how GIS can be used to model travel distance and time to public hospitals in New Zealand using 43 hospitals and approximately 36,000 small areas (meshblocks) in New Zealand. This travel is based on using a private car traveling on a road network. The approximate travel time and distance from each meshblock to the closest public hospital will be calculated. This paper will describe an Arc/Info process to do this, comment on experiences, and demonstrate applications of such a result.

The benefit of having travel time and distance to the closest hospital for each meshblock is that by multiplying the travel distance or travel time by the population of each meshblock, it is possible to calculate the approximate total and average travel time and distance if everybody visited a hospital once. These statistics can be tabulated for different management areas such as District Health Boards or Territorial Local Authorities and provide a comparison of hospital accessibility for different regions of New Zealand. These indices of hospital access can be formulated in many different ways so that demographic groups in more need of health care, such as the elderly and the very young, are given extra weighting. These indices can be used to determine the social equity of the distribution of public hospitals in New Zealand.

Hospitals are not homogeneous in the services they provide. The hospitals used were based on a "Hospital Service Plan" (Ministry of Health 1998). Only hospitals classified in the service plan as sub-acute, secondary, lower-level tertiary or higher-level tertiary were used in the analysis. The total number of hospitals was 43 and their locations were manually entered. Accessibility to the closest hospital was first calculated for all the hospitals and subsequently calculated for only hospitals classified as secondary and above, and then just tertiary hospitals. The accessibility to different types of services can then be assessed. The development of this accessibility model is based on many assumptions that are described and substantiated in this paper.

## 2. BACKGROUND INFORMATION

It should be emphasised that geographical accessibility is but one of many dimensions in the accessibility of health care. Other dimensions of accessibility, identified by the World Health Assembly (1979), are financial, cultural and functional dimensions.

Even, just considering the geographical access dimension, numerous models can be constructed. In addition to cost path models, such as used in this study, gravity and distance decay functions have been used to model spatial interaction and produce indices of accessibility (Fotheringham and O'Kelly 1989). Additionally, density models have been used to show population to hospital ratios for given areas. However, because densities tend to be extremely small, i.e. there are a large number of people served by few hospitals, density modelling has limited applicability for most geographical access modelling.

Previous studies overseas have attempted to model geographical access to health services. Earickson's (1970) study of access to hospitals in Metropolitan Chicago was limited by the available computing capacity of the time, and this study was complicated by factors such as race and religion as determinants of hospital choice and access. Religion and race in 1970s Chicago overrode, and even negated simple considerations of travel time in the study. As these factors have little or no influence on an individual's access to present-day New Zealand public hospitals, they have not been considered in this study. Although the methodology for calculating travel distances is not clear, it appears to be based on extrapolations of socio-economic data, and survey results of actual travel.

Walmsley and McPhail's (1976) study into the New South Wales (Australia) hospitals briefly mentions the effect of travel distance on how often patients avail themselves of outpatient services (p36). Again, the methodology of calculating distances is not clear, but it is based on a town-to-town scale. At this coarse resolution, it is unlikely that computer-based calculations would be necessary.

In New Zealand, Critchlow Associates (1995, 1996) undertook two consultancies for the Central Regional Health Authority and the Southern Regional Health Authority that calculated the travel times to public hospitals within each of the commissioning regions. It classified the road network into three speed categories, based on existing Department of Lands and Survey Information road records. Public transport was also incorporated into the database. While these models provided a useful indication of access to public hospitals at a regional level, the passage of time and further restructuring of the public health sector since their publication has diminished their applicability.

Lovett et. al. (2000) used GIS techniques to calculate accessibility to a range of primary health services (GPs, pharmacies and dental services) in East Anglia, UK. Separate travel times for both public transport and private car were included. The study used weightings for five different road types that would influence travel speed. It incorporated data on the actual GP that each patient was registered with, rather than assuming that patients would always choose to use the closest medical practitioner.

## 3. MODELLING MINIMUM TRAVEL DISTANCE TO CLOSEST HOSPITAL

This paper will demonstrate a geographic model based on cost path analysis to produce layers showing travel time and distance to the closest hospital. The advantage of this approach over gravity modelling is that the concepts of the model are easy for decision makers (who may have very little technical understanding) to grasp. Many people, when thinking about accessibility to hospitals, would consider how far it is to the closest hospital both in terms of distance, cost and time.

Three inputs were used in the analysis: a national road network, meshblock centroids, and hospital point locations. Fortunately, the NZ Government has recently relinquished its demand for royalties for access to the national 1:50,000 topographic data set, which means that a comprehensive road network of NZ is now available to all researchers. This road network contains various information on road characteristics but does not contain information on travel speed or time for each road segment. To calculate travel distance, road segment length is required and this is easily computed with GIS.

The meshblock centroids were generated from Statistics New Zealand’s Meshblock areas. Meshblocks are the smallest areas used in the distribution of census data and there are approximately 37,000 in the 1996 census release with a median population of 90 people per meshblock (Statistics New Zealand 2001 – http://www.stats.govt.nz) The unique identification number for each meshblock links these small areas to population census data, which facilitates demographic analysis.

The network analysis capabilities in *ARC/INFO* were used to calculate accessibility. The key command used was called *nodedistance*, which computes the distances between all possible combinations of origin and destination nodes. This command uses a least cost path algorithm, which is based on an algorithm generally credited to Dijkstra (1959). The algorithm is described in Arc/Info user manuals (ESRI 1992). In this study, the nodes closest to the meshblock centroids were the origin nodes and the nodes closest to the hospitals were the destination nodes. The nodes closest to the meshblock centroids and hospitals were identified using the *near* command, which also calculates the Euclidian distance to the nodes.

The *nodedistance* command provides a table of minimum distances via a network between all possible combinations of origins and destinations. It also provides identification numbers of the origins and destinations for each record and the Euclidean distance.

The *nodedistance* function does not only identify distances but can also be used on any specified field, such as travel time. To identify the closest hospital for a given meshblock centroid the statistic function in Arcinfo was used to identify the minimum distance for each origin to the closest destination.

The minimum distance to the closest hospital for each centroid was calculated by summing the network distance (obtained from the *nodedistance* command and subsequent statistics) plus the distance from the centroid to the closest road node (obtained from the *near* command) plus the distance from the hospital to the closest road node (also obtained from the *near* command).

The calculation of minimum travel distance to the closest hospital is easy to understand and Arc/Info provides some powerful commands that make this possible. This process produces many output tables and the most difficult part of developing this process was linking all the tables through common identification fields so that the identified closest hospitals and their distances can be linked back to the meshblock centroids.

The process for calculating the minimum travel time to the closest hospital is similar to the minimum distance process except road travel time was used instead of distance. The difficulty with this process was determining what the travel times were for travelling along the road segments. The method for calculating this is described below. The travel times from meshblock centroids and from hospitals to the closest road node were calculated using distance (obtained from the hospital-distance modelling process) and a travel speed of 50 km/hour.

First, all hospitals (sub acute and above) were treated the same and the analysis calculated the travel distance and time to the closest hospital for each of the 36,000 meshblock centroids. The processing time was approximately 6 hours using two 750 MHz CPU standard desktop PC computers. Accessibility to different degrees of hospital service was subsequently calculated by using just secondary and above hospitals, and then just tertiary hospitals.

## 4. ROAD NETWORK TRAVEL TIMES

The estimated road network travel times were based on whether the road was inside or outside an urban area, whether or not it was a motorway, the number of lanes, the surface, and the bendiness (sinuosity).

Urban roads were identified from integrating the road network with a Landcover layer (Thompson 1998). Motorways were identified by using the field "*name*" and searching for the name "Motorway", and also by manually locating "open speed limit" roads in the Wellington and Auckland urban areas. The number of lanes a road has and the road surface were provided with the road layer.

Sinuosity index have been used in hydrology for describing the meandering of river channels. A simple formula for sinuosity is observed length divided by expected straight-line (direct) length (Haggett and Chorley 1969 p58). GIS easily provides observed lengths of lines. The straight-line length was calculated for each road segment by creating a new road layer that was a generalization of the original road layer. This generalization involved removing vertices from the road arcs so that there was only one vertex per 500m. This had the effect of straightening the road segments. The lengths of the straightened road segments were then calculated and joined to the original road network using arc Ids. The sinuosity index was calculated by dividing the original length by the straight length. If a road was originally straight, then the sinuosity index will be 1. If a road is bendy then the sinuosity index will be above 1. A very bendy road that turns back on itself (hairpin corners on a hill) may have a high sinuosity score of 4. A sinuosity threshold of more than 1.02 was used to identify bendy roads. This threshold was determined by graphically viewing the sinuosity indices of roads in New Zealand and comparing this with the author's personal experience.

The estimated travel speed for each road segment was calculated as follows:

- Sealed urban roads - average speed: 30km/hr
- Urban motorway- average speed: 80km/hr
- Non urban, 2 lanes, sealed, straight roads- average speed: 80 km/hr
- Non urban, 2 lanes, sealed, bendy roads- average speed: 60 km/hr
- Non urban, 1 lane, sealed, straight roads- average speed: 70 km/hr
- Non urban, 1 lane, sealed, bendy roads- average speed: 40 km/hr
- Metalled straight roads- average speed: 50 km/hr
- Metalled bendy roads- average speed: 30 km/hr

This classification of road speeds is more detailed than that used by Critchlow Associates (1995), which was based on only three classes of roads speed - 80km/h for motorways and high-speed rural roads, 60km/h for slow rural roads, and 35km/h for urban and minor rural roads. The travel time study of GPs in East Anglia (UK) (Lovett et al, 2000) used 12 classes of travel time, but because traffic and road conditions are different in the UK, it is not valid to compare them with NZ roads.

The road segment travel times were calculated from arc lengths and estimated travel speeds. It needs to be emphasized that the road segment travel times are estimations only. The travel speeds for different road types are not based on scientific empirical evidence but instead on approximations based on personal experience. This process does not take into account urban expressways where average travel speeds could be more than 30km/hr. It also does not consider the effects of traffic congestion and difficult intersection. The network distance and travel times ignore one-way streets.

Many meshblock centroids are located on offshore islands or out at sea. These centroids are used to represent people on boats or isolated islands. The distance to the closest hospital from these centroids is based on the euclidian distance to the closest road and the network distance along the road to the closest hospital. Sometimes the closest roads to these centroids were roads on islands that did not connect to roads near hospitals. This caused a problem that was resolved using two approaches. First road networks on large islands were connected to the main road network by an arc that represented a ferry service route. The travel times for these ferry routes were then estimated from timetable schedules. The second approach was to then delete all roads that were not connected to the main road network in the South or North Islands. The *Trace* and *Nselect* commands were used to identify these roads.

## 5. RESULTS

The travel distance and time to the closest hospital for each meshblock centroid is represented in Figures 1 and 2. These figures show the raw data that results from the analysis. This data can be aggregated to many different regional management units, such as Territorial Local Authorities or District Health Boards (DHB). Figures 3 and 4 show the average travel distance and time for each DHB.

A more meaningful representation of this data would be to also consider the spatial distribution of the population, because there are many areas in New Zealand that have low population densities. Population census data is aggregated to meshblocks therefore it is easy to obtain the population for each meshblock and multiple this by the travel time and then compute the total and average travel time for each District Health Boards (DHB). Figures 5 and 6 show the results of this analysis. Figure 5 essentially shows the total amount of time spent travelling in each DHB if everybody needed to visit the closest hospital once. These statistics, based on the population distribution, provide a means of comparing accessibility of different regions throughout New Zealand.

It is also possible to compare the accessibility of elderly people or different ethnic groups. It can be safely assumed that elderly people need to visit hospitals more frequently than other age groups. When calculating total travel times it is possible to put extra weighting on elderly people. Extra weighting could also be put on travel that takes more than an hour to the closest hospital since this extra time can be critical to a patient's survival. The "golden hour" is a threshold that ambulance officers often talk about. Using such weightings and statistics, it is possible to examine and display the social equity of hospital services.

The analysis process not only calculated the distance and time to the closest hospital but also identified the name of the closest hospital based on both distance and time (sometimes these were different). The number of visits each hospital would receive if everybody visited the closest hospital once can be easily tabulated and a catchment area for each hospital can also be mapped.

The analysis results and applications so far have been based on all the hospitals. Travel distance and time to just the tertiary hospitals, and secondary and above hospitals has also been generated using this process. The total and average travel times for all hospitals, secondary and above, and tertiary hospitals is shown in Table 1. This is a national figure for New Zealand and represents the total and average travel times if everyone had to visit these types of hospitals once. As expected the larger hospitals are less accessible.

**Table 1:** The total and average travel times to the closest hospital for all of New Zealand (by hospital type)

| Hospital Type | Total Travel Time (hours) | Average Travel Time (minutes) |
|---|---|---|
| All | 1,265,756 | 20.9 |
| Secondary and Tertiary | 1,546,876 | 25.7 |
| Tertiary | 5,486,933 | 91.0 |

The raw data produced from the cost path analysis can be applied in many different ways when combined with population data to produce many interesting maps and statistics, however, it is not appropriate to present many maps in this paper. The intention of this paper is to describe the process used to create the base results, rather then demonstrate applications. An atlas depicting accessibility of different types of hospitals services, and at a range of scales, can be easily generated from the results.

## 6. DISCUSSION AND CONCLUSION

Geogaphical access models have enormous potential for informing policy development and grounding debate on how to achieve social equity of hospital access. Models are a critical resource that can be used by health service planners to prioritise the location and allocation of health services. The modelling is fairly straightforward and new health services can be processed and existing service access models can be reprocessed quickly on a desktop computer, even for large data sets.

This GIS accessibility model does not take into consideration all factors relevant to prioritising hospital locations. Planners have to consider economies of scale, previous capital development (sunk costs) associated with existing hospitals, supporting infrastructure, and access to medical employees. Planners may also want to consider travel costs associated with public transport. The travel times associated with roads, although based on cost path analysis, also included assumptions that have not been verified empirically, and can therefore only be used as

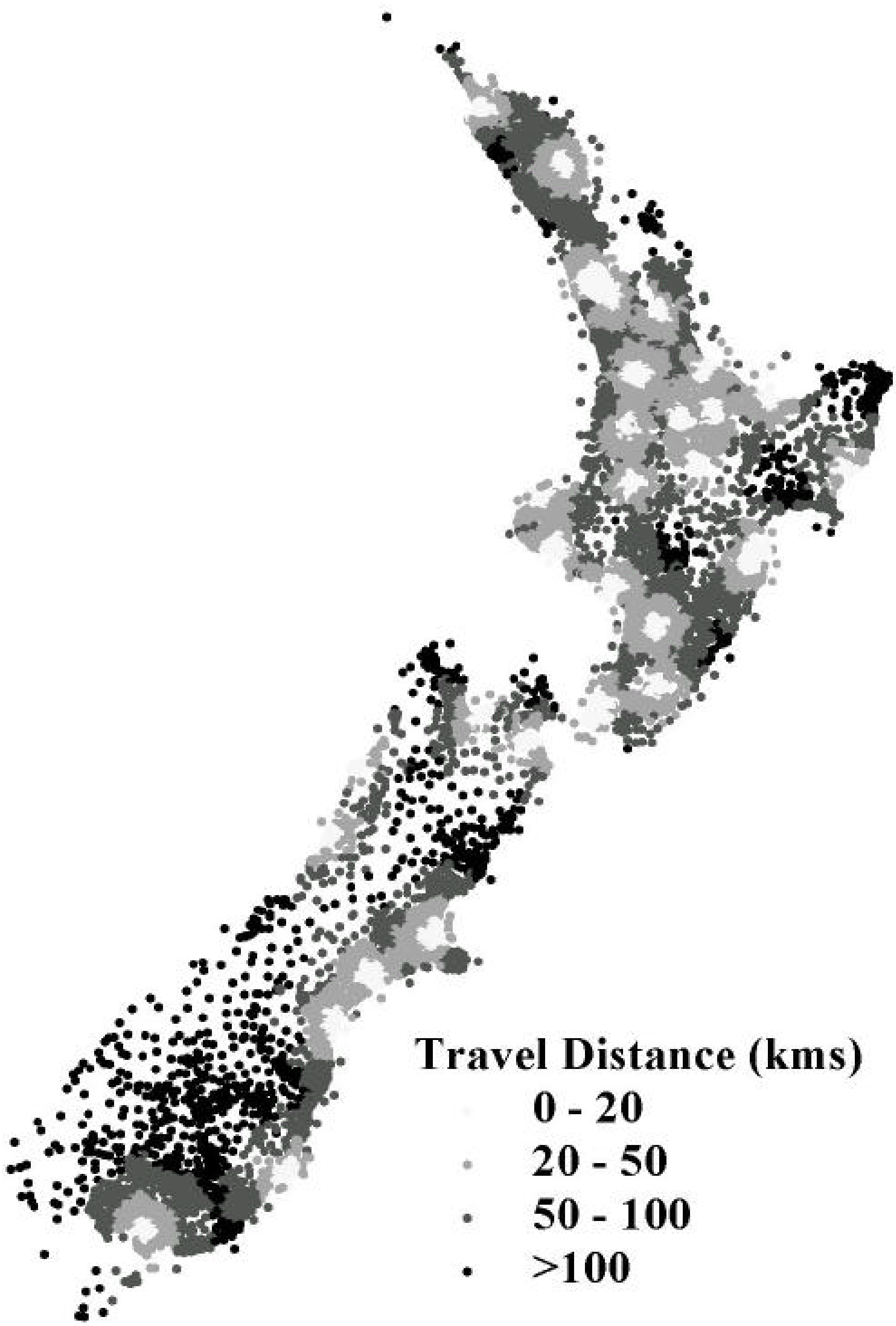

**Figure 1:** Travel distance to the closest hospital by meshblock centroid


**Figure 2:** Travel time to the closest hospital by meshblock centroid

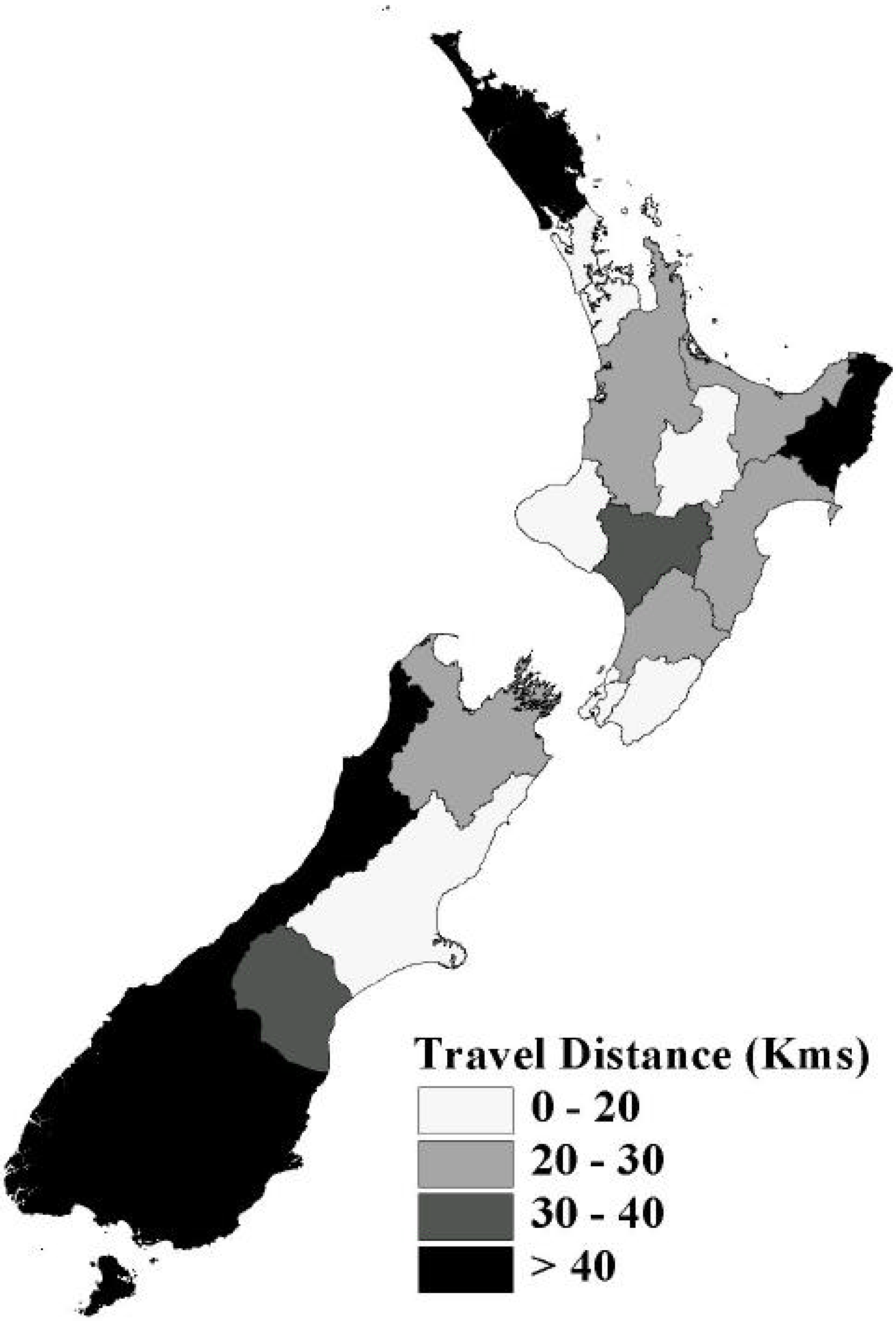


**Figure 3:** Average distance to closest hospital by District Health Board based on the location of meshblock centroids


**Figure 4:** Average time to closest hospital by District Health Board based on the location of meshblock centroids

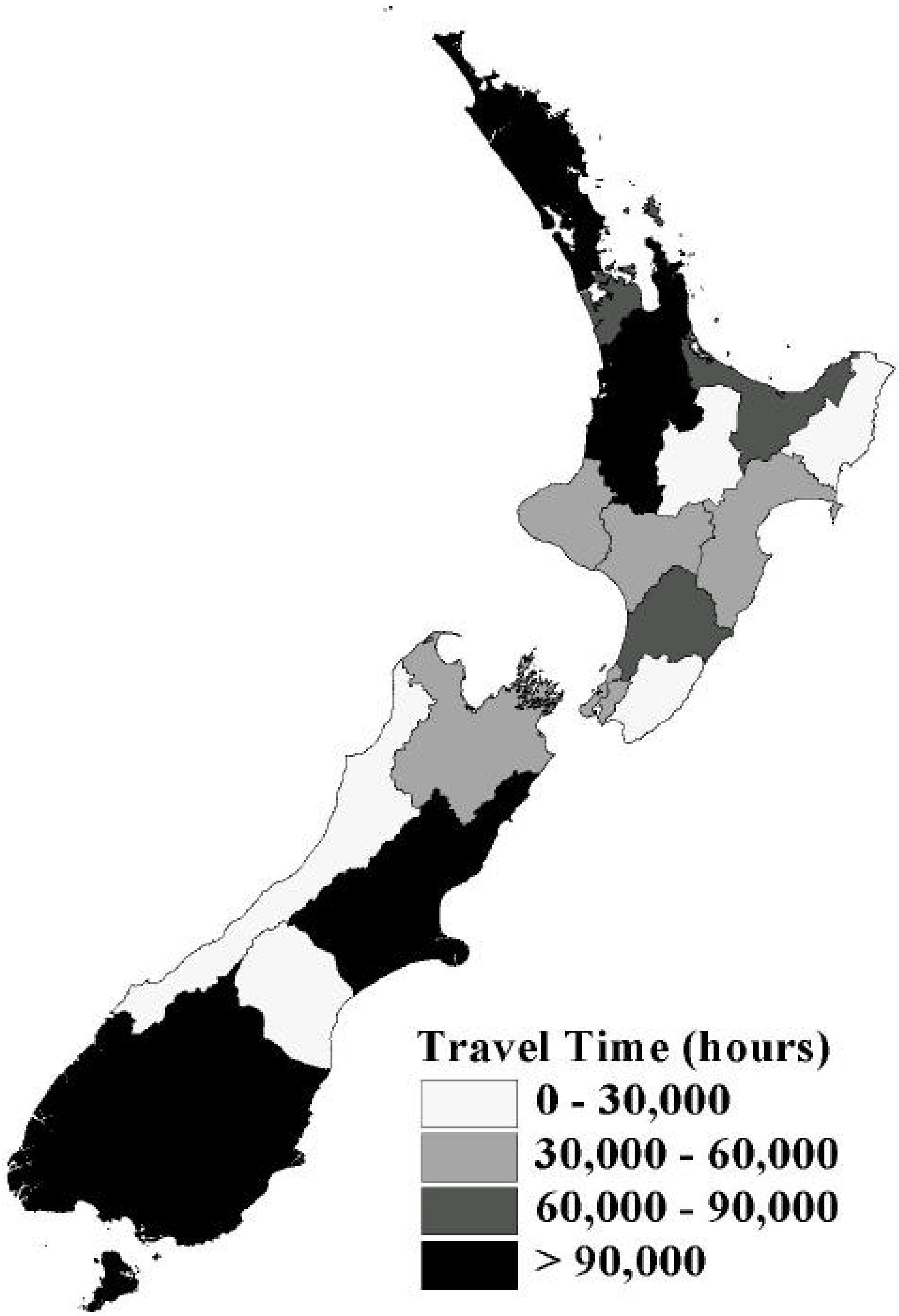


**Figure 5:** Total time spent travelling if everyone visited the closest hospital once (by District Health Board)


**Figure 6:** Average time spent travelling if everyone visited the closest hospital once (by District Health Board)

a guide. Further empirical research is required to improve information on road travel speeds. Nevertheless, GIS accessibility models do provide decision support and a relatively consistent method.

This study shows that GIS can be used to assess accessibility over large networks using thousands of demand points and 43 supply points. This research has raised the awareness of many public servants of what can be done with GIS, and many are now thinking of other services that should be analysed for accessibility using this approach. With health services alone there are many such services - mental health centres, GPs, Eye specialists, Oncologists, etc. Planners are now starting to think of the importance of maintaining geographical databases relating to such services.

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