Using census area in site location selection in planning: ambulance locations in Niigata, Japan

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1. Introduction

Site location is an important aspect of spatial planning in public health and decisions about the allocation of resources have respond to changing population numbers and distributions. For example, the aged are disproportionately high users of ambulance services (Clark and Fitzgerald, 1999) and are more likely to require ambulances for life-threatening emergencies (McConnel and Wilson, 1998). In many developed countries the population is predicted to age severely. For example, in Japan people over 65 years old currently make up 20% of the total population but, are predicted rise to about 40% in 2050 (Ministry of Internal Affairs and Communications, 2008). There are many other examples of the need to respond to the changing spatial demand for resources in public health and in other arenas (education, social services, natural hazard risk management, etc). The price for ignoring changing demographies and the associated shift in resource needs is a failure to positive deliver health outcomes (service accessibility, service delivery, etc) in which may be statutory - the implications for getting it wrong are severe. The challenge to spatial planners is to be able to continue to deliver efficient public services that meet the needs of current and future populations, which are accessible for important social groups.

This paper describes the development of a generic method for optimising current and future site location using a modified genetic algorithm (GA), linked to a network analysis of census data and EMS case data. The case study optimises the location of ambulances stations over a set of existing possible sites as ambulance arrival times are a crucial factor in patient survival for severe emergency cases (Snyder et al, 2007; Stiell et al, 1999; Feero et al, 1995) especially when the response time was less than 4 to 5 minutes (Blackwell and Kaufman, 2002; Pons et al, 2005).

2. Methods

2.1 Genetic Algorithms

GAs are search and optimisation algorithms (Goldberg, 1989) that simulate the process of genetic mutation and selection in biological evolution. They are used when the number of possible solutions to a problem is too large to be evaluated within normal constraints. For example, consider a $1km^2$ area with a possible location in each 10m cell and an objective to identify the best 25 locations evaluated against some criteria. There are 10,000 possible locations from which to select a set 25, requiring 4.4 e+35684 permutations to be evaluated, which would take too long to compute by brute force. GAs are particularly suited to answer site location questions in relation to accessibility. A set of potential of solutions (or 'genes') is created, called a 'chromosome'. Pairs of chromosomes make 'individuals' and are evaluated based on some 'fitness' criteria. If the criteria are met genes are interchanged to breed another generation of solutions in a 'crossover'. This process creates new individuals from successful parents and continues for a predetermined number of cycles or until some convergence criteria are met. In order to protect against stagnation or in-breeding, mutation is introduced at regular intervals to add some random genes. GAs breed solutions by creating 'fitter' offspring with some mutation to ensure diversity: hence the analogy with natural selection.

2.2 Data

Current population data was obtained from the Japanese 2005 census. Future population data was projected using a cohort estimation method with the population estimation model developed by the National Institute of Population and Social Security, Japan (Kaneko et al, 2008). A local fertility rate of 1.22 for Niigata City was used to estimate future populations.

Data for 21,211 pre-hospital emergency medical services (EMS) records attended by an ambulance in Niigata, a city in Japan, for the period April to December in 2007 were geocoded and used for this study. These were used in 2 ways:

1) to develop a predictive relationship of EMS cases from census data variables with a multivariable regression analysis;
2) to provide a count EMS cases in each of the 2072 census areas in Niigata from a point-in-polygon operation.

The end result was that the census areas were attributed with current EMS cases and predicted EMS cases for 5 year intervals from 2015 to 2040 based on the based on projected population and consistent socio-economic variables in the census small areas using the predicted model.

In Japan there is a one-tiered EMS system provided by the fire department (Tanigawa K, Tanaka, 2006) and ambulances are located in fire stations. In Niigata there are 35 fire stations as potential locations for ambulances. Currently 27 ambulances are operated from 27 fire stations.

The road network for Niigata was provided by Increment P Corporations, Japan.

2.3 Analysis

First a network analysis was then run to generate a matrix of distances between each potential supply point (35 ambulance stations) and each demand point (2072 census areas).

Next the GA was run to identify the optimal location of 27 ambulances. The fitness criteria used to was to evaluate the outputs of the GA was to minimise the person distances based on the network distance weighted by the number of current and predicted future EMS cases.

The nearest ambulance station from the optimised location was identified for each census areas to determine the ambulance 'footprint'. The demand for each station was also calculated based on the number of cases and the distances involved in reaching them

3. Results

3.1 Current Locations

The grouping genetic algorithm identified the optimal set of 27 ambulance locations based on the network distance between each census centroids and weighted by the number of emergency cases. Of the 27 locations, 23 were existing stations but 4 were not, indicating that some improvement in ambulance accessibility could be achieved with some re-allocation of resources.

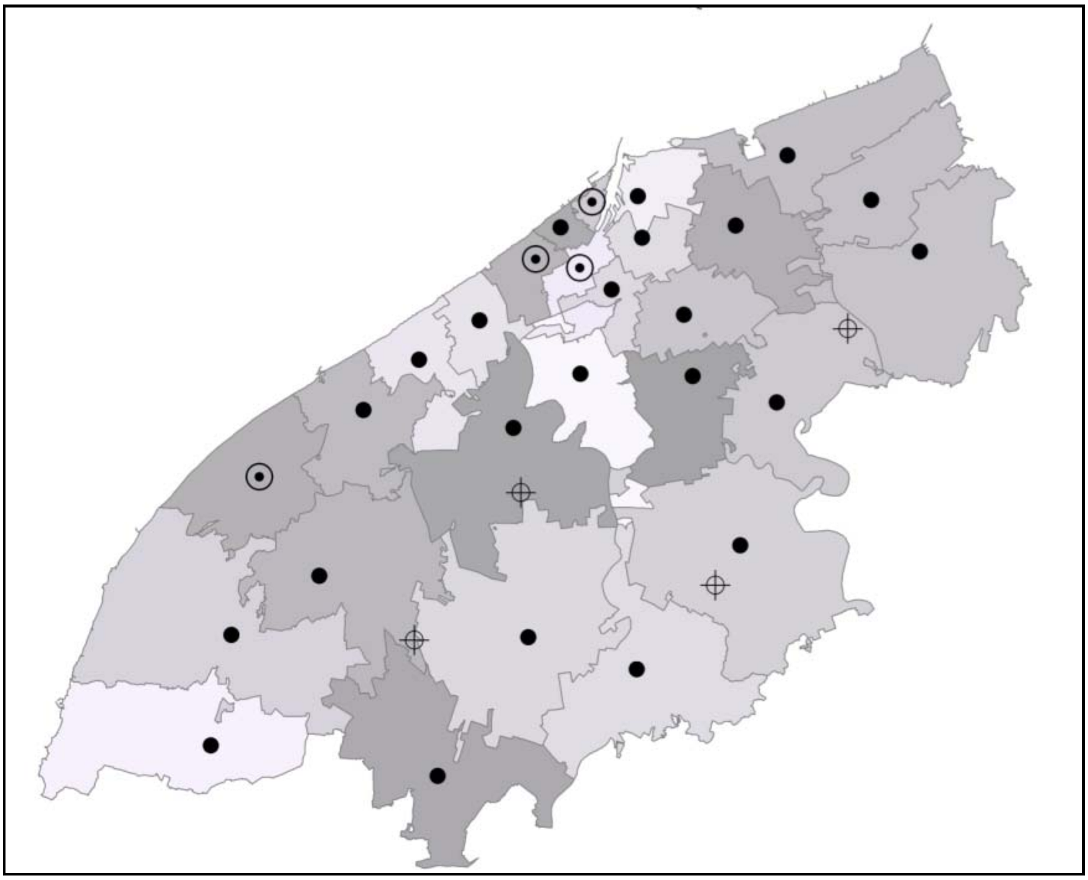

Figure1. Optimal location of 27 ambulance stations based on predicted emergency cases for 2030, (•) indicates optimal locations that are the same as current locations, (⌖) current sites not selected by the optimisation and (⦿) new locations.

Travel times cases from the set of optimised locations to the 21,211 emergency were compared with those from current ambulance locations. The average ambulance response time was reduced by 57 seconds from the current ambulance locations to the optimised ambulance locations (5 minutes and 21 seconds and 4 minutes and 24 seconds respectively).

3.2 Future Locations

The grouping genetic algorithm identified the optimal set of 27 ambulance locations based on the network distance between each census centroids and weighted by the number of predicted emergency cases. Of the 27 locations, 22 were existing stations but 5 were not, indicating that some improvement in ambulance accessibility could be achieved with some re-allocation of resources. The major differences between the current and future ambulance demand is the reduced concentration of ambulances in the urban centre (Northern area near to the river) and the concomitant increase in EMS cases and ambulance demand in the peri-urban areas for 2030

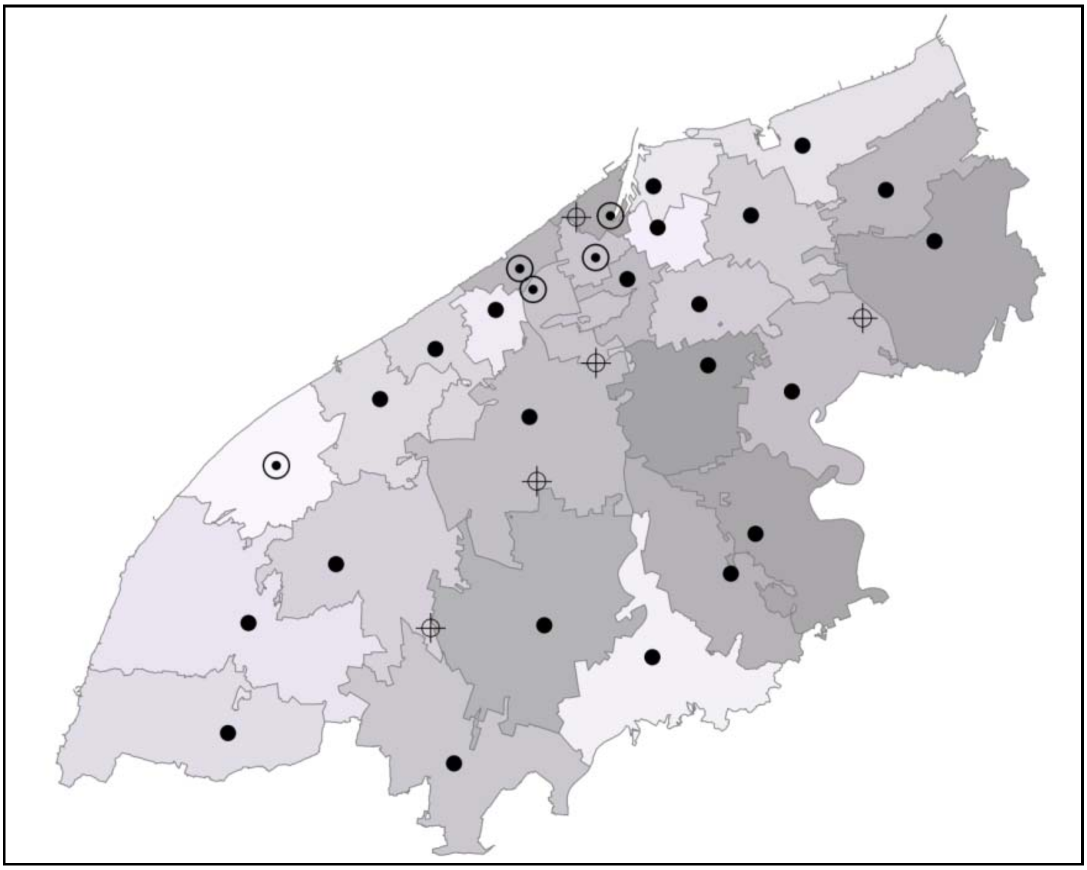

Figure 2. Optimal location of 27 ambulance stations based on predicted emergency cases for 2030, (•) indicates optimal locations that are the same as current locations, (⌖) current sites not selected by the optimisation and (⊙) new locations.

4. Discussion

The method described in this work is generic and could readily be applied to optimise retail outlets by considering market footprints, for example. A number of aspects of this work are relevant to the Geocomputation and public service planning communities. First, Optimising over network distances can provide a more realistic analysis of optimal access to different goods or services. It allows disparities between different spatial and social groups to be examined and provides potential solutions. Second, the approach is relatively simple, combining a GIS network analysis of distances between different sets of points with demographic data to create a weighting that can be adjusted depending on the objectives of the study or the phenomenon under investigation. Third, the approach allows the planners to evaluate and compare current and future demand for resources.

5. References

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