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Spatial Modelling for Optimal Locations and Allocations of Schools in Educational Service Area Office-2, Nakhon Pathom Province, Thailand

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Abstract: To promote decentralisation and to increase the service efficiency of schools in an area, school maps must be created with the population demographics and distribution in mind. An effective tool that can be used to do this is the Geoinformatic System (GIS). This research's objectives are to construct proper school maps for the present (2007) situation, using the idealised model according to Hallak and using the p-median model. The area concerned is the Educational Service Area Office-2 in Nakhon Pathom Province in Thailand and the educational levels are primary, lower secondary and upper secondary. After schools maps are constructed from the relevant data using a GIS application, three efficiency assessments are made for each case: Assessments concerning the service area, the schools' service loading and the students' average travel distance to the nearest school. The present situation did best to minimise the number of no-service villages owing to the large number of schools. In the case of idealised and p-median models, increasing the travel distance limit that defined the service area boundaries helped reduce the number of no-service villages. The idealised and p-median models increase the school's service loadings while increasing the travel distance due to the small number of school sites generated by the models. However, the p-median model gave shorter travel distances than the idealised model did. After changing the population data by using a linear population growth projection for the years 2015 and 2020, it was found that the school maps generated by the p-median model had little change.

Key words: Location allocation, p-median model, geoinformatics, school service area, GIS

INTRODUCTION

In Thailand, the critical education reform programme was established in 1999 via the National Education Act to provide a 12 years free basic education to all children as part of reforming the existing inefficient education system (Office of the National Education Commission, 1999).

The official education services are presently separated into four categories: Early year education, basic education, vocational and technical education and higher education, all of which are under the responsibility of the Ministry of Education in association with several other agencies. Basic education with which this research is concerned is further separated into three levels: Primary (designated Prathom 1 through 6), lower secondary (Mattayom 1-3) and upper secondary (Mattayom 4-6). Since 2003, a 9 years compulsory education has been enforced, requiring all children to complete Mattayom 3. After the 1999 National Education Act, there have been changes to the structure of educational management and administration system. Total 185 educational service areas have been established as of 2008 in order to decentralise administrative responsibilities to the local level.

To ensure that all children receive education, school mapping strategies must be developed to determine optimal school locations. School mapping is used to plan school locations and management, ensuring the efficient and equal distribution of resources to develop schools. It has been strongly advocated by the International Institute for Educational Planning (IIEP) over the past 50 years (Caillods, 1983). In the countries where it is implemented, school mapping targets the provision of basic education to all children of school age, the optimum distribution of resources, the improvement of the ratio between costs and performance and the reform of structures, curricula and teaching methods. The Commission of Founding for Education Reforms states that when locating a school, one should adhere to the community density rather than to the sub-district or village borders.

However, school mapping in Thailand shows slow progress as there is a lack of proper assisting tools. Geographic Information System (GIS) technology with its high capability of storage and processing data is becoming a powerful tool for this task. This research aims

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to establish GIS-based databases for the location-allocation of schools, to identify optimal school locations using location-allocation models (idealistic and p-median models) and to compare the efficiencies of the present school map to the school maps derived from the models in terms of certain conditions: service area, service loading and travel distance.

The capabilities of GIS make it a promising tool in generating school maps to improve the education of children in an area. In recent years, several reports have been published about this usage. For example, Gilo (1997) has found that many schools in Tel Aviv, Israel need to be relocated due to access limitations, some schools' service areas force students to spend more time to reach their schools due to the service areas' sizes and new schools should be established to solve the problems.

The two models used are the idealised model according to Hallak (1977) and the p-median model. According to Hallak (1977), the ideal school service area should have a hexagonal shape to minimize the overlapping areas among schools close to each other. Whereas the p-median model is a location-allocation model in which the map is represented as a weighted graph and is usually used to determine the best locations to place a limited number of facilities (service points) in an area. Given the location of n-points that have known amounts of demand, the p-median model seeks to designate p of these points as facilities and allocate each demand to a facility, in such a way to minimise the total weighted distance between demands and facilities (Marianov and Serra, 2009). It could be represented mathematically as follows:

$$\text{Minimize} = \sum_{i\in I}\sum_{j\in J} w_i D_{ij} x_{ij}$$

Subject to:

$$\sum_{j\in J} x_{ij} = 1 \text{ for } \forall i \in I \quad (1)$$

$$\sum_{j\in J} y_j = p \text{ for } \forall i \in I \quad (2)$$

$$x_{ij} \leq y_j \text{ for } \forall i \in I, j \in J \quad (3)$$

$$x_{ij} \in \{0,1\}, y_j \in \{0,1\} \quad (4)$$

Where:

I = {1,...,M} is a set of demand points

J = {1,...,N} is a set of potential facility locations (service points)

P = {1,...,p} is a set of demand points

x_{ij} = 1 (if customer at demand point i allocated to service point j), otherwise $x_{ij} = 0$

y_j = 1 if a facility is established at location j, otherwise $y_j = 0$

D_{ij} = Shortest distance between location i and location j

w_i = Number of population at demand point i

The p-median model has been used to conduct researches on the location and allocation of facilities in residence areas, such as the location of hospitals in a city, along with a number of emergency ambulances each needs (Narula *et al*., 1974; Reilly, 1976).

MATERIALS AND METHODS

The study area is the Educational Service Area Office-2 within Nakhon Pathom Province, covering 4 districts: Bang Len, Nakhon Chaisi, Phuttamonthon and Sam Phran. All potential students are assumed to attend public schools only, as only the state-run primary and secondary schools are considered. The data includes district and tambon (sub-district) boundaries (Department of Provincial Administration 2009), the road network (City Planning Department, 2009) school data (surveys and Nakhon Pathom Education Service Area Office-2 2007) and village data (Bureau of Registration Administration 2009). The school data includes their geographic location, their names, the number of teachers, students and classrooms at each educational level, their area, their admission rate and other accessory data. The village data includes their geographic location, their names and their populations sorted according to age. The data is imported into a GIS database.

Procedure: First, the GIS database was constructed. The data was assembled from the sources mentioned and imported into the application with corresponding data formats. The database structure was constructed using the MySQL programming tool with three operating levels: The client, application and the server level. The future populations for each tambon in 2015 and 2020 were then forecast assuming uniform linear changes from 1998-2020 based on the records during the years 1998-2007.

The second part is the school efficiency assessment for the present situation. A map of schools and villages was generated. The efficiencies were evaluated in terms of service area, service loadings and travel distance. The service areas were defined by distance limits along the road network as follows: 1-5 km for the primary level, 3-7 km for the lower secondary level and 5-10 km for the upper secondary level. The distance limits were stepped up from the shortest distance to the furthest distance and new maps were created at each step. The Service Loading value (SL) of a specific school is defined as the ratio between the number of actual students enrolled at the school and the number of potential students (determined by age level) residing within the distance limit. Five classes of the service loading values are proposed in this research: Low, medium low, medium high, high and very high for each educational level. The optimum service loading values are in the range of 50-150% for primary and lower secondary schools and 30-50% for upper secondary schools, conforming to the attending rates given by the Ministry of Education (2008). The average travel distance was calculated by assuming that a student can attend the one school closest to their villages.

The third part is the assessment based on the idealised model. The preferred number of schools was determined by assuming a hexagonal service area. The areas are calculated from the preferred radii for each educational level. Applying it with the area of the districts, it was found that the preferred number of primary schools and lower secondary schools are both 50 for a 3 km service radius and the preferred number of upper secondary schools is 18 for a 5 km service radius. School maps were created from the numbers and new school locations which were selected based on the following criteria; is an existing medium or large school with moderate service loading, is in villages with high population density, has a high amount of potential students in its service area and gives a well-distributed map. The efficiencies were then evaluated similar to the efficiency assessment for the present situation.

The fourth part is the assessment based on the p-median model. Using the number of preferred schools obtained from the third section, potential sites were selected based on the above criteria. A map was then generated and the efficiencies were then evaluated in the same manner as the idealised model. The process was then repeated for the forecast 2015 and 2020 populations.

RESULTS AND DISCUSSION

Concerning the GIS database objective, the database has been developed so that a general client can search for school and village data in the database system using search keywords in the graphic user interface.

Present situation assessments: From the 2007 data, there were 143 public schools of interest in the research area. Total 104 have only primary level, 23 have both primary and lower secondary levels and 16 have both lower secondary and upper secondary levels.

Service area: When the distance limits that determine the service areas of the schools increase, the number to no service villages decrease while the overlapping areas increase. Most villages in the overlapping area are under services of 2-5 schools; however at distances >5 km, overlapping service areas of >5 schools appear. Using the state policy's preferred distance limits of 3 km for primary and lower secondary levels and 5 km for the upper secondary level, it is found that 11.06% of the villages are outside all primary school service areas and 49.43% are in overlapping areas. These numbers indicate that the locations are relatively adequate but the schools are too crowded. In contrast, the numbers of villages outside all lower and upper secondary areas are more than half of the villages (46.73 and 53.95%, respectively) but the numbers for those in overlapping area are relatively low (10.84 and 17.38%, respectively). This indicates that the current schools are well-located but more schools should be established. Another possible solution is to increase the travel distance instead of building more schools as it would be more convenient.

Service loading: It is found that higher distance limits lead to lower values of service loading. For example, the number of primary schools at the low-SL level is 14 at a 2 km limit but is 43, 79 and 101 at 3-5 km limits, respectively. Using the state policy's preferred distances, there are 43 primary schools (33.86%), 13 lower secondary schools (33.33%) and 2 upper secondary schools (12.50%) with low SL values. On the other hand, 16 primary schools (12.60%), 10 lower secondary schools (25.64%) and 5 upper secondary schools (31.25%) have very high SL values. These results might be due to the large number of primary schools (127 schools) in the area, making less attractive ones possess low attendance rates. High SL values of secondary schools reflect the capacity of these schools to attract students compared to other schools in the area. However, one must take into account the case of schools whose service areas overlap as these schools have to compete with each other to attract students. As a result, the SL values are lowered and could be underestimated. It should also be noted that in reality, students can attend any school regardless of the travel distance, increasing the difficulty in interpreting the SL values.

Travel distance: In this research, the assumptions detailed in the materials and methods section were used. An additional case is considered: A student must attend the closest school under the state's recommendation (zoning). It was found that the average travel distances were 1.62 km for primary-level students, 2.66 for lower secondary students and 4.80 for upper secondary students which are suitable for walking and cycling. However, the state-recommended schools give a significant increase in the students' travel distance. This indicates the inefficiency of the state's education zoning system.

Idealised model assessments

Service area: After new school maps were constructed according to the established criteria, the efficiencies were evaluated. Similar to the present situation, most villages in the overlapping areas are under services of 2-5 schools and the number of schools increase when the limited distance increases to >5 km.

Using the state policy's preferred distance limits of 3 km for primary and lower secondary levels and 5 km for the upper secondary level, it is found that 35.67% of the villages are outside all primary school service areas and 9.71% are in overlapping areas. Compared to the present situation, the percentage for the no-service area is significantly high due to the reduced number of schools (50 compared to 127) but the overlapping areas were dramatically reduced. Similarly, the number of no-service villages for the lower and upper secondary levels are about one third and one half of the total villages, respectively. Utilising a possible solution to the same problem as discussed in the evaluation of the present situation, increasing the distance limit, the number of no-service villages decreases to 6.32% for the lower secondary level and 18.28% for the upper secondary level as the overlapping area increases. This problem-solving strategy is therefore suitable if overlapping is less of a concern than no-service areas.

Service loading: Because there are fewer schools in the model than reality, all current students of the removed schools are assumed to transfer to the site closest to them. The percentages of schools with low SL values dropped dramatically compared to the present situation: 6% for primary schools, 26% for lower secondary schools and 0% for upper secondary schools. In contrast, there is an increase of schools with very high SL values: 28.0% for primary schools, 18.0% for lower secondary schools and 27.78% for upper secondary schools. This indicates the idealistic model's ability to increase the SL values of schools.

Travel distance: The average travel distance is 2.46 km for the primary level, 2.40 km for lower secondary and 4.19 km for upper secondary. The average travel distance for the primary level has significantly increased compared to the present situation due to the decrease of schools. However, the distances are still in cycling and driving distance. In addition, many students prefer walking through shorter routes that are not shown on the road maps. Regarding the secondary levels, the average travel distances were comparable to the present situation since the numbers of schools are near each other.

p-median model assessments: The average travel distances for the 5 lowest cases of each school level in each district are close to each other; however they vary across districts. Using the travel distance data, optimum school maps were constructed using the p-median application. Some schools were upgraded in the maps, for example, from primary to lower secondary to further satisfy the optimum criteria.

Service area: Like the present situation and the idealised model, the number of villages without school service decreased and the number of villages in overlapping areas increased when the limited distance increased with most villages in the overlapping areas being associated with 2-5 schools at once. Using the state policy's preferred distance limits, it is found that 38.60, 44.24 and 39.73% of the villages are in no-service areas and 15.80, 15.82 and 7.45% are in overlapping areas, for the primary, lower secondary and upper secondary levels, respectively. These numbers indicate that the selected school locations cannot provide services to the many villages outside the distance limits. As expected, the no-service problem can be solved if the distance limits are extended; the percentage drops to 8.58% for the primary level and 15.35% for the secondary levels.

Service loading: In this case, the same assumption regarding removed schools as discussed in the idealised model is considered. Using the state policy distance limits, regarding the primary, lower secondary and upper secondary schools, the percentage of schools with low SL values are 8.0, 18.0 and 5.6%, respectively. This indicates that the p-median method is satisfactory with increasing the SL of schools.

Travel distance: The average travel distances are 1.97 km for the primary level, 2.01 km for the lower secondary level and 2.91 km for the upper secondary level. Like the idealised model, the primary level value is high compared to the present situation but is still in the range of cycling and motor vehicles.

Compared to the idealised model, though, the values are significantly lower. The values for the secondary levels are even lower than of the present situations because the school map is constructed based on minimising the travel distances, the definition of the p-median model.

School mapping for future projections: A uniform linear model is applied to the population growths of each tambon in the range of years 1998-2020. The R^2 values range from 0.6075-0.9853. Using the projected population data for the years 2015 and 2020, new school maps were generated while assuming the number of school sites for each district be the same as those for the year 2007. It was found that the maps do not look much different from each other and some have the same school locations. This might be due to the use of the same set of sites and the small population differences.

CONCLUSION

Generally, the number of no-service villages decrease and the overlapping areas between service areas increase when the distance limits that define the service areas increase. Increasing the distance limit effectively solves the problem of no-service villages if the overlapping areas are less of a concern. Within the overlapping areas, some villages are associated with 2-5 schools at a time and the number of associated schools increases further with the distance limits.

When the state policy's distances are used in the assessments, substantial amounts of villages are found to be in no service areas. Furthermore, when the state agency's school zoning system is applied, the students' calculated average travel distances are higher compared to the distances obtained by assuming that students attend the schools closest to their villages. This reflects the inefficiency of the state's plans.

The idealised model and the p-median model were applied with the population data. These models decrease the amount of schools and establish new ones in remote areas. As a result, the service loadings of these schools increase. The travel distances increase too but they are still in the range of cycling and driving. The p-median model gave shorter distances than the idealised model. For the projected years 2015 and 2020, the school maps made using the p-median model had little difference from each other and from the year 2007.

However, this research has some shortcomings due to the assumptions used. The service loading values have to be used with caution as schools compete with each other in the case of overlapping service areas and students are able to attend any school available to them regardless of distance. The travel distance value considers only the road network and do not consider the possible short-cuts the students might take to school. Furthermore, the schools' individual limits in admitting students and the private schools are not considered.

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