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Spatial Zoning of School Location-Allocation in Greater Auckland, New Zealand

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Abstract

This paper focuses on the use of network analysis to allocate the location of secondary schools in North Shore City of Greater Auckland in New Zealand. For simplicity, eight state and three private secondary schools in the North Shore City were only examined. One of the main issues of the study was finding the travel distance and the travel time of the existing schools zones. Another issue was using an established database to show that a suitable zone is one which have a travel distance within 1500/2000/3000 meters and travel time within 30/40/60 minutes from a given school. Three procedures were implemented. These were: copying certain coverages to a needed workspace, displaying and correcting the location of existing secondary schools, and using Allocate command in GIS to define the school zones according to the previous criterion. By using the allocate function, the study came up with three different patterns of school zones. Two new schools were also allocated based on distance between adjacent zones. These suggested schools were due to the long distances/time that students living in some areas have to pass while traveling to their schools. It was concluded that GIS capabilities proved to be effective in examining school zones in North Shore City as well as other locations in different countries.

Introduction **

Greater Auckland, New Zealand has a population of more than 1 million residents. It is divided to four major administrative cities namely North Shore City, Waitakare City, Auckland City and Manukau City. Tens of primary, intermediate and secondary state schools are scattered all over Greater Auckland. This paper is interested in examining the issue of school zoning. However, for simplicity, eight state and three non-state secondary schools in the North Shore City will be only discussed.

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** The reason for choosing North Shore City as a study area is justified by the fact that the researcher had lived there for several years. That residency was followed by frequent visits to the area.

North Shore City (NSC) has a population of about 200,000 inhabitants. It extends from Devonport in the south to the rural and tree-clad hills around Albany in the North. There are eight state secondary schools serving all communities in the NSC. These schools are: Birkenhead (Birkdale) College, Glenfield College, Long Bay College, Northcote College, Rangitoto College, Takapuna Grammar School, Westlake Boys High School and Westlake Girls High School. In addition to this, there are three non-state secondary schools namely Carmel College, Hato Petera College, and Rosmini College. Although each school has its own catchment's area they attract students from other places.

In the past, the Ministry of Education through a demographic program decided that for a particular community a needed school depended on the population of that community. When zoning was introduced it was to restrict the movement of people so that each school will have an equal opportunity to be attended by its own communities, and that some schools that were perceived to have better education would not be overcrowded compared with other schools. In other words, zoning was implemented to make education even across the country, so each school has its share of clients. In this case enrolment could be controlled more effectively.

When the Ministry of Education abolished zoning in schools about 15 years ago, they didn’t set up a whole new scene of education. They gave parents a major role to decide where their children might go for studying. So the removal of zoning caused a problem straight away. Actually, in the last 15 years, the New Zealand population became more mobile. Standard of living became higher with many families having 2 cars: one became a taxi to shuttle children to schools, while the other was used for other needs. The result was depriving a child in his community from attending the school of his community due to the restricted enrolment policy and the restricted size of classes. Consequently, children who were not allowed to study in their community had to go somewhere else. The writer believes that this was totally wrong because originally schools were put to serve their own community.

Another phenomenon resulted from abolishing school zoning was that some schools were becoming more elite than others in that their children were from areas of high standard of living. On the other end of the scale, schools in the lower socio-economic areas were left with children who could not afford to move away from that area. So the rich became richer and the poor became poorer.

This research, therefore, aims to use location- allocation modeling as a GIS tool along with other capabilities to solve the problem of children forcing themselves to another area and preventing the residents of that area from getting the education they want. Although North Shore City was selected as the study area, It is believed that the procedures that were used here may be applied to other parts of Greater Auckland or anywhere else (Fig. 1).

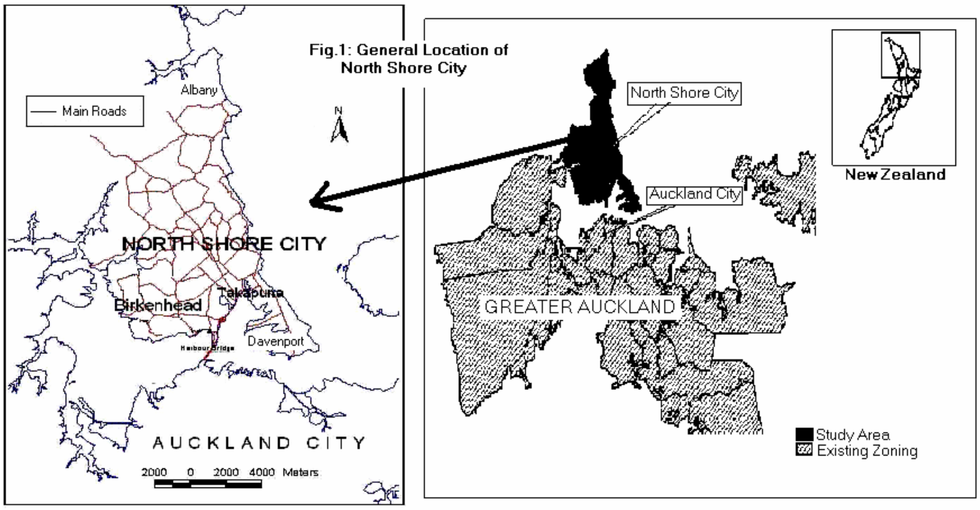


Fig.1: General Location of North Shore City

Aim of the Study:

The aim of this study is to integrate location-allocation modeling with other GIS capabilities to come up with a framework that may help decision makers in having plans for school zoning as well as to help students' parents in deciding the optimum school location their children would go to. New schools based on certain criteria will be suggested.

Research Key Issues:

The specific key issues for this research are:

- Building the database by copying files and coverages (mainly coastlines, road network and main roads), editing data, and inputting additional data (particularly locations of state and private secondary school).
- Analysis of the data to establish a database for school contributing area boundaries.
- Finding the travel distance and travel time of the existing school zones.
- Use the established database to achieve the following criteria: a suitable zone is one which have a travel distance within 1500/2000/3000 meters and travel time within 30/40/60 minutes from a certain school.

This study is significant in that it deals with a practical issue related to the daily behavior of students from the study area. The challenge is that the basic location-allocation tool is capable of creating and representing various zonal systems depending on a certain criteria set such as center capacity, local demand, travel time, crossing main roads, and use of buses or trains.

Data Sources:

1. The needed coverages were copied from material available in the Department of Geography, University of Auckland database under the following subheadings:

   - A Guide to Geography Spatial Data Holdings

   - Address - matched Streets of Auckland (by area).

2. Locations of the existing secondary state schools in the study area were obtained from several Auckland atlases.

Theoretical Framework:

The theme of location-allocation can be considered a significant topic in spatial analysis aiming to solve problems of matching supply and demand by incorporating certain objectives and limitations. Recently, GIS packages mainly ARC/INFO used some of the algorithms as tools for application. It is believed that location-allocation modeling is a complex network analysis aiming to determine the locations of existing and planned facilities, as well as the allocation of demand to these facilities (1).

The private sector uses many location-allocation examples. It can be assumed that a company runs self-drink distribution facilities to support supermarkets. The objective in this case is to minimize the total distance traveled, and a two-hour drive distance limitation may be imposed on the problem. A location-allocation tool is to match the distribution facilities and the supermarkets while meeting the objective and the limitation at the same time.

Location-allocation is also a vital issue in the public sector. For example, a local school board may decide that (1) all school-age children should be within 1 kilometer of their schools and (2) the total distance traveled by all children should be minimized. In this case, schools represent the supply and school-age children represent the demand. The objective of this location-allocation analysis is to provide a fair service to a population, while maximizing efficiency in the total distance traveled (2).

Working in a location-allocation environment requires inputs in supply, demand, and distance measures. The supply consists of facilities or centers at point locations. The demand may consist of points, lines, or polygons, depending on the data source and the level of spatial data collection. Distance measures between the supply and demand are often presented in a distance matrix or a distance list. Distances may be measured along the shortest path between two points on a road network or along the straight line connecting two points. In location-allocation analysis shortest path distances are likely to produce more accurate results than straight line distances (3).

Perhaps the most important input to a location-allocation problem is the model for solving the problem. Two most common models are *minimum distance* and *maximum coverage*(4). The minimum distance model, also called the p-median location model, minimizes the total distance traveled from all demand points to their nearest supply centers(5). The p-median model has been applied to a variety of facility location problems, including food distribution facilities, public libraries, and health facilities. The maximum coverage model maximizes the demand covered within a specified time or distance(6). Public sector location problems, such as location emergency medical and fire services, are ideally suited for the maximum coverage model. The model is also useful for many convenience oriented retail facilities, such as movie theaters, banks, and fast food restaurants.

Both minimum distance and maximum coverage models may have added limitations or options. A maximum distance limitation may be set on the minimum distance model so that the solution, while minimizing the total distance traveled, ensures that no demand is beyond the specified maximum distance. A desired distance option may be used with the maximum coverage model to cover all demand points within the desired distance(7).

It is noteworthy that location-allocation models have been an important topic in geography and operations research since the seminal work of Cooper (1963) and Hakimi (1964) in the 1960s. Computer programs for location-allocation have been widely available since the early 1970s (8). The role of the computer in transforming raw data into useful information became necessary since then. By integrating GIS technology and computer-based Decision Support Systems, a framework for spatial decision support was established. Actually, a shift towards GIS location analysis was advocated by several authors in the late 1980s and early 1990s(9).

M. Grothe and H. Scholton (1993) used GIS as a tool for spatial assignment problems in the facility location planning. They illustrated the potential benefits of GIS technology as a decision support tool. Their concentration was on the role of catchment's areas in solving facility location assessment and optimization problems in urban areas. Methods for modeling catchment areas using a demand-oriented approach was examined and included in a design of Facility Location Assessment and Optimization Systems (FLAOS).

The overall objective of Grothe and Scholten was to illustrate that GIS Technology can be used effectively to support decisions associated with facility location assessment and optimization problems. To meet this overall objective they had the following framework:

- An overview of facility location theory and the identification of a conceptual framework for catchment area definition.
- Development and implementation of instruments aimed at modeling catchment areas to support facility location assessment and optimization.
- Application of FLAOSs in facility location problems.

Two application examples with the use of FLOAS were briefly outlined by Grothe and Scholten. The first example developed a FLOAS for facility location problems in the Dutch banking sector, while in the other example the FLOAS concept was applied in the field of residential zoning for elderly. The authors analyzed the access of the elderly to retail facilities and care service centers. With the use of buffering and overlay operations they were able to determine attractive and less attractive areas in the district. The final zoning map showed which site is most appropriate for new developments.

Since 1995, several researchers focused on location-allocation models to determine optimal locations for private and public sector facilities such as warehouses, factories, retail stores, ambulance depots, police stations, fire stations, and schools, as well as optimal allocations of 'customers' to these facilities(10). According to Waters (1999), these models were routinely incorporated into Geographical Information Systems in Transportation (GIS-T) files. Church (1999), provided detailed and up-to-date discussions of location-allocation modeling within a GIS context.

Many of the most important breakthroughs in the location-allocation literature were presented at the so-called ISOLDE (International Symposium on Locational Desions) conferences that began in Bannf, Alberta, Canada, in 1978 and were held around the world since then. The proceedings for these conferences were somewhat brief, although the most significant papers are usually published in special issues of operations research journals and more recently in the journal *Location Science.*

Packages such as TransCAD allow for a variety of goals to be optimized in facility location problems including: minimizing the average cost of service (often referred to as the *p*- median problem); minimizing the maximum cost of service (the *p*- centre problem) ; maximizing the lowest cost of service (for noxious facilities); and maximizing profit [11].

Most applications involved situations where both customers and facilities were point entities within the GIS, but Miller (1996) extended the model to include all nine point/line/area customer-facility combinations within a GIS framework. Lasse-Jensen (1998) explained how various school districts in selected regions of Copenhagen may be assessed using location-allocation modeling tools of victor-based geographical information systems. He showed how the consequences of suggested redistricting projects may be analyzed and how 'best solutions' in terms of school locations, capacity and district boundaries may be pointed out.

Lasse-Jensen discussed location-allocation modeling in connection with the process of assigning children from their residential location to the nearest school for a selected area of Copenhagen. According to Lasse-Jensen this kind of spatial analysis provided the means for quantifying the relation between school location and capacity on the one hand and the demand and the demand for seats in the surrounding areas on the other hand. His general goal was to maximize accessibility by minimizing the total travel distance for all pupils while at the same time ensuring that no pupil has to travel an excessively great distance to attend school.

From the above-mentioned literature, it is concluded that the use of network analysis to allocate the location of resources or services through the modeling of supply and demand in a given network is a major concern for GIS specialists.

Methodology of the research:

The following processing procedures for the study were:

1. Copying the needed coverages to a created workspace.The coverages were:

   - School locations
   - School areas (including coastlines)
   - Road network
   - Main roads.

2. Displaying the location of existing secondary schools, and correcting four locations that were mislocated on the original file. These schools are:

   - Long Bay College
   - Rangitoto College
   - Takapuna Grammar School

- West Lake Boys School.

3. Use Allocate command in Arc/Info to define the school zones according to the following criteria:

   (a) A suitable zone is one that has a distance of 1500 meters around a certain school, and 30 minutes of travel time to a school.

   (b) A suitable zone is one that has a distance of 2000 meters around a certain school and 40 minutes of travel time to a school.

   (c) A suitable zone is one that has a distance of 3000 meters around a certain school, and 60 minutes of travel time to a school.

- The allocate command was also used to determine travel distance and travel time of the existing school zoning.

In order to implement the Allocate function, the following steps were completed:

(1): Defining "the Centre File" which included:

- cover - id

- route - id- item (Table 1)

- maximum - impedance - item:

- length of road (travel distance) in meters.

- travel time (i.e. the length of the road divided by walking speed) in minutes.

The attributes of centers were contained in a user-created INFO file called a centers file, which was analogous to the stops file used in pathfinding. Like stops, centers were referenced by the User-ID of the node where they were located. Centers files contained the following items below. The centers file and items were specified with the CENTERS command.

Table 1: Center-file structure for North Shore schools

School-id	Nthroad-id	Route-id	School Name
1	24937	28160	Birkenhead College
2	20602	27483	Glenfield College
3	27563	28491	Northcote College
4	7895	25959	Rangitoto College
5	26378	28466	Takapuna Grammar School
6	20058	27416	Westlake Boys' High School
7	24622	28102	Hato Petera College
8	20779	27506	Westlake Girls' High School
9	22740	27812	Rosmini College
10	19984	27405	Carmel College
11	266	25040	Long Bay College
12	3983	25432	Proposed
13	11965	25959	Proposed

Nthroad-id (cover – id)

The Nthroad-id is an integer item that contained the node-IDs of the centers in the coverage. This item was required in the centers file. Cover represented the network coverage name. This item name is mandatory.

Route-id (route - id- item)

The Route-id item contained the User-IDs of the routes that will receive the results of the allocation. The name of the route-system to which the routes will be written is specified with the NETCOVER command.

(2): Preparing the network coverage and output route-system with NETCOVER command. Usage:

NETCOVER <cover> <route-system> {Append Init}

(3): Determining the maximum - impedance i.e. the maximum cumulative impedance of the least-cost path between any location on an allocated arc and the centre. In this research four figures for e maximum - impedance were used. These are: 2000 meters, 1500 meters, 40 minutes, and 30 minutes.

(4): Locating two new suggested secondary schools based on distance between adjacent zones.

(5): Displaying all zoning results in ArcView.

Discussion of the Results:

This study has examined the zoning system in North Shore City. By using the Allocate function this study revealed different patterns of school zoning in the study area (Table 2). These patterns are summarized as follows:

1. Zones with optimum travel distance of 1500 meters and travel time of 30 minutes. This turned out to be the case for the following schools: Hato Petera College, and West Lake Girls'High School (Fig. 2).

Table 2: Optimum school zones according to maximum travel distance and maximum travel time

School id	School name	Maximum travel dist. (meters)	Maximum travel time (minutes)
7	Hato Petera College	1500	30
8	West Lake Girl' School	1500	30
3	Northcote College	2000	40
9	Rosmini College	2000	40
1	Birkenhead College	3000	60
2	Glenfield College	3000	60
4	Rangitoto College	3000	60
5	Takapuna Grammar School	3000	60
6	West Lake Boys' School	3000	60
10	Karmel College	3000	60
11	Long Bay College	3000	60

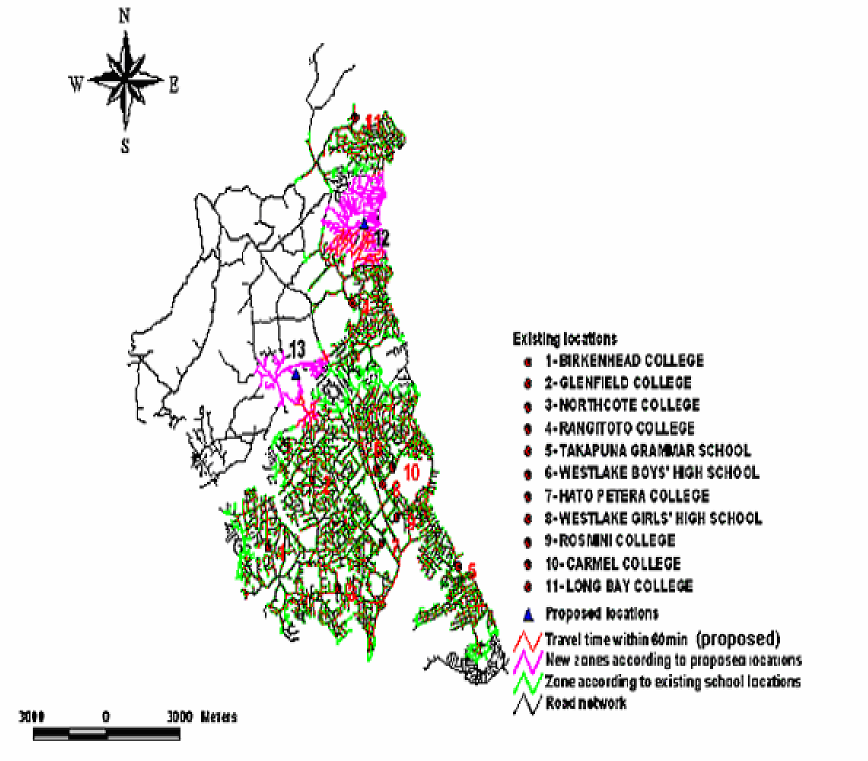
2. Zones with optimum travel distance of 2000 meters and travel time of 40 minutes. This turned out to be the case for the following schools:

   Northcote College and Rosmini College (Fig. 2).

3. Zones with optimum travel distance of 3000 meters and travel time of 60 minutes. This turned out to be the case for the following schools:

Birkenhead College, Glenfield College, Rangitoto College, Takapuna Grammar School, West Lake Boys'High School, Carmel College, and Long Bay College (Fig. 2).

Fig. 2: Existing and Proposed SchooL Lcations In North Shore City



The research also revealed that certain areas in North Shore City badly need the establishment of new secondary schools. This is due to the long distances/time that students living in these areas have to pass while traveling to their schools. Therefore, the study suggested two new school locations based on distance factor. These locations were one between Long Bay College and Rangitoto College and the other between Rangitoto College and Glenfield College (Fig. 2).

It should be mentioned that one major problem appeared during the implementation of the research. This problem was related to running the Allocate command that needed both a centre file and network dataset. After these files were prepared, running the command was successful.

Concluding remarks and suggested further research:

Recently the service sector has been facing drastic changes. Various developments in socio-economic conditions and technology have had strong impacts on the activities on public and private service facilities including schools catchment areas. These changes need a constant monitoring in order to optimize the relationships between demand and supply. In this context the geographic location of a school is of crucial importance as demand and supply differ in space.

This paper illustrated that location-allocation models can be used effectively to support decisions of facility location assessment and optimization problems. It should be mentioned, however, that some issues affected the findings of the research. These issues are inaccuracy of data sources, combining of school locations with route network, and travel time.

Inaccuracy of data sources consists of inaccuracy in both spatial data and tabular data. Errors in spatial data were found when comparing the provided coverage with the base map. However, when a school location was allocated in a wrong place in relation to the base map, it was possible to correct. In this study, for example, the locations of four existing secondary schools, namely Long Bay College, Rangitoto College, Takapuna Grammar School, and West Lake Boys School were misallocated on the original file. Fortunately, the researcher was able to correct these locations. Moreover, tabular data concerning supply seats, demand seats, and student population within every existing supply zone was not available. These parameters may be affective in determining school zoning.

Combining of school locations with route network was another cause of inaccuracy for school zoning boundaries. This is illustrated by the fact that some points representing school locations did not overlap with some related nodes of the road network. Therefore, the nodes of the road network which were closest to these school locations were adopted as actual locations and were used in the center file for preparing network data to run allocate function.

As for the travel time it was calculated according to the estimated working speed of the students. In this research, the walking speed was assumed as 45 meters per minute. Consequently, the travel time equaled the length of the road segment divided by walking speed. As a result, the networks of travel time were presented as school zones when using allocate function. In this context, the boundaries of each school zone show the broad idea of maximum travel time within the zone. However, because of walking speed variation it may not be considered a constant value.

Nevertheless, in spite of the above limitations, planners and decision makers can benefit from the resulted boundaries of school zones. Once other information such as supply seats, demand seats and student population are available then a better decision support system may be established.

The present writer would like to make it clear that two methods for school zoning in the study area could be used. One method is based on drawing a buffer zone around a school location. The other method uses allocate function in GIS Arc/info based on network data. The buffer zone method specifies the school locations and produces buffer zones around these locations in terms of specific distances i.e. 1500 meter or 2000 meter. Each buffer zone has a radius equal to the specific distance that will be used for overlay with a route network.

The allocate function method assigns network links to centers as school locations. A route along the assigned arcs is created in the network coverage. The new network is produced based on both center file and maximum impedance such as specific travel distance and travel time i.e. 1500 meter, 2000 meter, 30 minutes, and 40 minutes. As a result, a separate route network for each school location is created and every location on the resulting routes is within a specific value of travel distance and travel time. After that the boundaries of each zone is separated by the system.

The school zoning boundaries produced by the buffer zone method is mostly inaccurate due to the fact that the overlap area between adjacent zones is big particularly when school locations are dense. The allocate function, on the other hand, proved to be a valid method for school zoning based on network environment such as network coverage (road network), impedance distance (travel distance or travel time), and center file (school location). Consequently, a separate route network for each school location is established and every location on the resulting routes is within a specific value reflecting the travel distance or the travel time of a school.

The writer would like to emphasize that the decision maker should be careful in dealing with the idea of spatial optimization. This is because that when a model is solved optimally, that optimal solution may be inferior when another objective or criterion is introduced. This means that optimality can be defined for only what has been explicitly included in a model. To support the search for solutions that meet the needs of the decision maker, it is important to produce close-to-optimal solutions which were the case of the present study.

Nevertheless, this study shows how a decision maker may use GIS to solve spatial problems concerning school locations and allocation to produce information that is relevant to the task of providing good service to students attending a given school. It is shown how better delimitation of school zones may reduce the maximum distance to a school by the use of allocation modeling. The study also demonstrated how an optimum/semi-optimum location for a proposed new secondary school might be computed.

Once again, this study did not incorporate student addresses and school capacities in its analysis. It may be possible to obtain better and more accurate results if these additional factors are taken into consideration. However, GIS capabilities proved to be valuable in examining school zones in North Shore City.

تحديد النطاقات المكانية للمدارس في مدينة أوكلند الكبرى بنيوزيلندة

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ملخص

يركز هذا البحث على استخدام تحليل الشبكة من أجل تحديد مواقع المدارس في ضاحية " نورث شور " التابعة لمدينة أوكلند الكبرى في نيوزيلندة . وعلى الرغم من وجود عشرات المدارس في منطقة أوكلند الكبرى إلا أن الدراسة قد اقتصرت فقط على ثماني مدارس حكومية ومدرستين غير حكوميتين جميعها ثانوية في ضاحية " نورث شور " . ولقد كان أحد الأهداف الرئيسية لهذه الدراسة ايجاد مسافة الطريق والزمن المستغرق والمتعلقين بنطاقات المدارس الحالية. وهنالك هدف ثان يتلخص في بناء قاعدة بيانات واستخدامها في تبيان أن

النطاق المدرسي المناسب هو ذلك النطاق الذي تكون فيه المسافات المناسبة هي 1500 و 2000 و 3000 مترا ، وتكون فيه الفترات الزمنية المستغرقة هي 30 و 40 و 60 دقيقة من المدرسة المعينة على التوالي . وقد تم تنفيذ ثلاثة أساليب مرتبطة بمنهجية الدراسة هي : نسخ غطاءات معينة إلى ملف خاص ، وعرض وتصحيح مواقع المدارس الثانوية القائمة ، واستخدام أمر " التخصيص " لتحديد النطاقات المدرسية وفق المعيار المذكور أعلاه. إنه باستخدام وظيفة "التخصيص" الكائنة في نظم المعلومات الجغرافية والآنفة الذكر فقد توصلت الدراسة إلى ثلاثة أنماط مختلفة للنطاقات المدرسية . هذا ، وقد تم اقتراح إنشاء مدرستين جديدتين بالإستناد إلى المسافة بين النطاقات المجاورة . وقد عزي اقتراح تلك المدارس إلى المسافات والأوقات الطويلة التي ينبغي على الطلبة القاطنين في مناطق معينة أن يقطعوها أثناء ذهابهم إلى مدارسهم . وخلصت الدراسة إلى أن إمكانات نظم المعلومات الجغرافية قد أثبتت كفاءتها في تحديد النطاقات المدرسية في منطقة الدراسة ، وأن المنهجية المتبعة يمكن استخدامها في مناطق أخرى من أوكلند الكبرى جنبا إلى جنب مع مدن أخرى في مختلف الأقطار.

* **The paper was received on June 8, 2004 and accepted for publication on May 10, 2005.**

Notes

(1) Lo and Yeung 2002.
(2) Chang 2002
(3) Chang 2002
(4) Ghosh et al. 1995; Church 1999.
(5) Hakimi 1964.
(6) Church and Revelle 1974.
(7) Chang 2002.
(8) Rushton et al. 1973
(9) Densham and Rushton 1988; Densham and Goodchild 1989; Armstrong and Densham 1990; Beaumont 1991; and densham 1991.
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(11) Caliper Corporation (1996) *Routing and logistics with TransCAD 3.0*, Newton, Caliper Corporation..

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