

입지최적알고리즘 평가를 위한 GIS VISUALISATION 기법의 이용

APPLICATIONS OF GIS VISUALISATION TECHNIQUES TO EVALUATE LOCATION OPTIMISATION PERFORMANCES

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Key words: GIS, Model solution performance, Location optimisation, Visualisation techniques

I. Introduction

Many literatures have discussed performance of location optimisation algorithms and concerned with the designed of what is terms a location optimisation algorithm for location analysis. However, there are few literatures that explore interactive relationships between visualisation and location optimisation within GIS. Not much is known about which visualisation techniques are suitable for representing best solutions of which location models in different location problems, and how to compare solution performance of the location algorithms tested. Traditional researches in location optimisation and analysis have been explored to obtain an ability to handle large problem sizes efficiently, or robustness and near optimal performance with flexible handling mechanisms of objective functions, or data errors and scales of data effects in location analysis, or automatic choice from among alternative solution procedures, or good user interfaces. Among these features, visualisation issue have been neglected although various visualisation techniques have been implemented in Geographic Information Systems (GIS) systems. Visual interactive methods within GIS can be an alternative solution approach to location optimisation performance analysis and could provide many attractions to spatial planning such that the visualisation result can be performed well to identify those areas on a map where the solution works least well, or poor despite the algorithmic sophistication used. This also allows a useful tool for end users to identify both good and poorly serviced locations simultaneously. Consequently, the end users applying suitable visualisation techniques within their location optimisation algorithms can recognise appropriate optimisation solution process for their location problem that how best optimal solution can be obtained, and may expect a location optimisation system as a modest GIS itself.

Therefore, this paper aims to investigate appropriate visualisation techniques to evaluate location optimisation performances within GIS location analysis. To tackle this research objective, 2-D and 3-D visualisation functions and their visual results are compared to identify its strengths and weaknesses for location optimisation visualisation. As location solution heuristics, p-median location problem and two optimisation heuristics are explored. To discuss this research objective, Section 2 addresses the approaches of GIS visualisation techniques to represent relevant geographical data and evaluate spatial optimisation analysis, in particular for location optimisation problems. Section 3 develops p-median location problem and its solution model with the optimisation algorithms, and Section 4 describes assessment procedures of the solution performances undertaken within a GIS system. Section 5, in turn, presents various 2-D and 3-D visualisation results to emphasise the visualisation effects for the location problem. In conclusion, this paper discusses the potentials of these visualisation approaches as a new research theme for the next GIS generation.

II. Visualisation, GIS, and location optimisation

1. Visualisation in GIS

Visualisation is a cornerstone of scientific progress and closely related to spatial scientific technology progress, such as digital cartographic techniques, digital data handling, and management. In terms of the relationship between digital data management and geographical analysis, visualisation of geographical data can take an importance place within geographical analysis. This also provides clear evidence of why GIS has enjoyed great attention from commercial organisations. The interaction between GIS and scientific visualisation finds support in the use of maps and other graphical displays as outputs from GIS systems to isolate and describe patterns in spatial distribution (Hearnshaw and Unwin, 1992).

Thus, a visual contact and display provide useful tools to understand geographical data used in the geographical analysis and analyse geographical problems in spatial decision making process (Dorling, 1993). For the relationship between geography and GIS, many research contribution have been achieved within which a range of academic approaches have been appeared in the literatures (Hearnshaw and Unwin, 1992; Armstrong et al. 1992; Dorling, 1994). Most recently, visualisation and GIS has influenced on the organisation of spatial facility planning and spatial decision support systems (SDSS) using multi-criteria analysis methods (Malczewski et al. 1997).

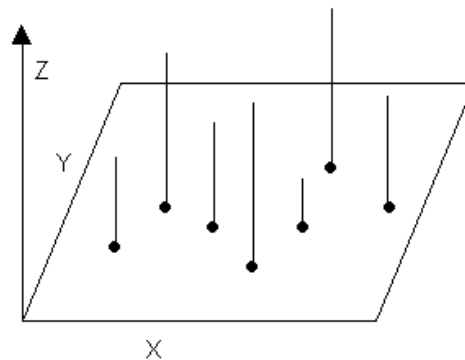
As visualisation can be an important issue in GIS, location optimisation and visualisation can have several kinds of research implications and potentials associated with GIS applications because visualisation can aid the exploration and comparison of optimal solution results and the evaluation can be enhanced by such visualisation. However, this research topic has been neglected in location optimisation and GIS. Major trends of location optimisation to date have focused on the sophistication of the optimal solution techniques without taking into account visualisation effects. In GIS location analysis, most of the parts have been presented using data manipulation (i.e. spatial data query) and solution display (i.e. buffering and overlay) without optimal searching process. These simple display functions cannot support the identification of the solution differences of two location optimisation techniques in a problem space. Although some 2-D based GIS spatial analysis functions have been provided for assisting the solution performance analysis (i.e. spatial interpolation of ArcView), the functions have limited capabilities to detect the significance of different solution performance. As a simple example, the representation of different optimal locations in a map is not enough to interpret the solution performance of location optimisation techniques. To date, there have not appeared research attempts to integrate the visualisation approach and location optimisation solution interpretation. For this reason, this paper explores the integration scheme based on visualisation aspects because in current GIS technologies, visualisation is one of the most beneficial parts for displaying location analysis results.

2, Visualisation and location optimisation

Most commercial GIS systems have been designed to deal with 2-D spatial objects by depicting spatial objects as class, ratio, and labels. Some display functions such as density, contour lines and isolines have been used to describe the volume of two-dimensional objects on a 2-D map and they can be used to portray location variation of location optimisation by classifying the solution degree or solution quality (i.e.

shading of solution quality on a map). 3-D techniques have been also developed for representing spatial data to 3-D shapes, surface modelling, and real-time perspective viewing. By using the techniques, GIS can create and visualise spatial data into a three dimension to provide insight, real trends, and support problem solving. <Figure 2-1> illustrates an imaginary 3-D form of spatial objects that Z value represents an attribute value of each spatial object at a spatial location (X and Y coordinate).

<Figure 2-1> A imaginary 3-D form of spatial objects



Exploration of optimal search methods and the comparison of best solutions for a location model can be enhanced by various visualisation techniques (Densham, 1994). Armstrong et al. (1992) depicted various cartographic visualisation methods useful for location-allocation models. They introduced valuable uses of cartographic displays for supporting locational decision making. Densham (1996) demonstrated several integration strategies of visual interactive modelling and location algorithms in GIS environments. As GIS has advanced and hardware and CPU processing speed in computing technologies have developed rapidly, the visualisation function has come to be recognised as an important part of GIS functionality, especially when building a robust spatial decision support system (SDSS) (Densham, 1991). Arentze et al. (1996), however, criticised the inflexible use of traditional SDSS approaches that fail to provide a highly interactive problem solving environment for facility location planning and proposed an interactive view approach for SDSS for which a dynamic visualisation mechanism should be developed.

If location optimisation processes are illustrated in GIS, many advantages of visualisation are expected for interpretation of the location solution results. At first, visual contexts and cartographic symbols support the solution description of location optimisation. The visual context and cartographic symbols can help GIS analysts to understand the complex procedures and algorithmic solution processes during the optimisation process. It also provides an effective communication with analysts and decision makers as an efficient function of SDSS. Secondly, a useful visualisation can create valuable information for decision-makers to enhance the impact of alternative urban planning policies and development strategies (Webster, 1994). A

good visualisation technique may support planners and analysts to consider other alternatives. This means that cartographic representation of location optimisation problems provides a superior method of communicating the results to decision makers. Thirdly, good visualisation helps to understand the conflict between the best solution(s) and the worst solution(s) in location optimisation process. To visualise the best solution in a location problem space, a centre-region display method can be used through the combination of area shading and point symbols to show the service regions (demand locations) and facility locations for a location solution. The point symbol represents facility locations and colour or shading pattern describes the service areas of those facilities or the relationship of location-allocations of the facility (centre) and demand factors. A number of alternative techniques have been investigated and exist to visualise solutions to location problems. Armstrong et al. (1992) provided a wide range of various cartographic visualisation displays for location-allocation solutions.

III. Location problem and solution algorithms

1. P-median problem

For the location optimisation problem, this paper implements p-median problem that searches for optimal facility locations to meet minimised travel costs from their customers to the facility. This location problem has been one of the widely used geographical location optimisation problems over several decades, and it has a long research history in geography (e.g. Abler et al., 1977; Gould, 1985; Robinson, 1998). The problem form can be described as follows; -

$$(1) \quad \text{Minimise } \delta = \sum_{i=1}^n \sum_{j=1}^p w_i c_{ij} \lambda_{ij}$$

where w_i is weight of demands such as population or total customers in a area, and c_{ij} is travel cost between demands and central facilities. For the travel cost, this paper employs Euclidean distance function: n is the number of demand (customers), and p is the number of facilities to be located on a plane: i is the demand location and j is the facility location, and λ_{ij} is allocation decision variable (1 if assigned, or 0 if not). Thus, this constraint assumes that all demand be assigned to the closest facility.

2. Solution algorithms

To solve the p-median problem, this paper develops two optimisation algorithms, Cooper algorithm and Genetic Algorithm. For the first algorithm, Cooper's alternative heuristic and search algorithm (Cooper, 1963, 1964, 1968) are developed, and as a benchmark technique, a canonical Genetic Algorithm (GA) is exploited that was developed by Goldberg (1989). Cooper algorithm employs alternative partitioning search technique in optimisation procedure, which produce efficient computational performance for large scaled complex location optimisation problem.

Alongside the conventional heuristic, genetic algorithm (GA) can be used to compare solution quality for the location problem. GA is an advanced algorithm to search for global optimal solution for optimisation problems. It is extremely simple to apply and various variants can be readily devised (Davis, 1991). GA is a search technique analogous of the process of natural biological evolution, whereby good genes survive in their local environment and breed for next generation. Other poorer performers die out. In the present context, this evolution ability to adapt to the local environment is measured by how well the resulting parameterised p-median models fit the data on which it is to be calibrated by a search technique (e.g. Houch, et al. 1996).

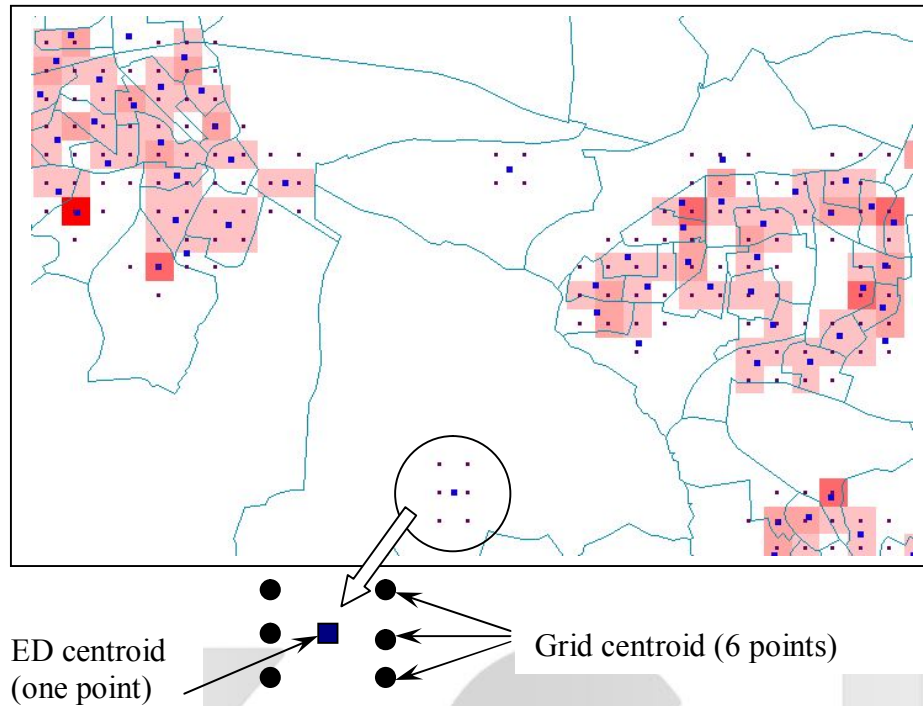
In this paper, a basic canonical genetic algorithm (GA) developed by Goldberg (1989) is developed for the location problem. In the basic GA, each parameter in the p-median problem represents coordinate information of candidate facility location, and the parameter is represented by a binary bit strings. The bit strings representing the candidate location are concatenated together and subjected to genetic operators. For the p-median problem, the solution process of the GA is divided into two steps; location and allocation. At the allocation level, a location optimisation algorithm, which is either conventional optimiser or genetic algorithm, can be adopted to solve the general assignment of centre and demand allocation. To obtain a solution in the allocation step, the solution is converted to the fitness value for evolution selection process in the GA. Then, this evolutionary process can be used to search for the best or global optimal value by exploring the whole location area and this distinguished search performance contributes to the formulation of a robust location optimisation algorithm.

IV. Data and assessment

1. SURPOP data

To undertake the optimisation problem solving process, this paper employs grid based population centroid information extracted from Surpop census data for Leeds-Bradford area. The Surpop system provides a set of estimated population for 200 meter grid cells derived from the 1981 and 1991 UK census data in Great Britain (www.census.ac.uk/cdu/surpop). Selected census variables (e.g. total resident numbers) and data can be downloaded for user-defined geographical areas in various output formats, suitable for the use of GIS software (i.e. raster data for Arc/Info grid) or ASCII text format. <Figure 4-1> illustrates the Surpop population grid data with Enumeration District centroids. Instead using EDs, this paper uses each grid cell's centroid as potential demand points. In addition, the grid data format can be a good GIS representation format, providing a good surface visualisation basis for the benchmark test and produce more accurate population distribution, compared with the ED centroids (Martin and Bracken, 1991).

<Figure 4-1> The Surpop population grid data and ED centroids



2. Assessment procedures

There are several different conventional ways of assessing performance of location optimisation problems such as plotting objective function values, mapping solution polygons, presenting tables of computing time against problem size, and etcetera. However all these approaches disguise the reality of the differences on the ground that interpret how to compare spatial results from different location optimisation algorithms. A better methodology to overcome the limitation of conventional methods would be as follows. At first, GIS produces a candidate spatial solution to cover the study region with either a fine grid or with a fine set of data points for which data are available. These could be at a finer resolution than was used to produce the spatial optimisation. Next, GIS visualisation function calculates the objective function surface for this grid and produces a three dimensional surface. Then, these procedures are repeated for different number of centres. These all steps are animated on a map within a GIS system. During these processes, the surfaces from a base set of results showing differential performances are subtracted to profile the “deprived” areas which defines poor accessibility areas in the study region.

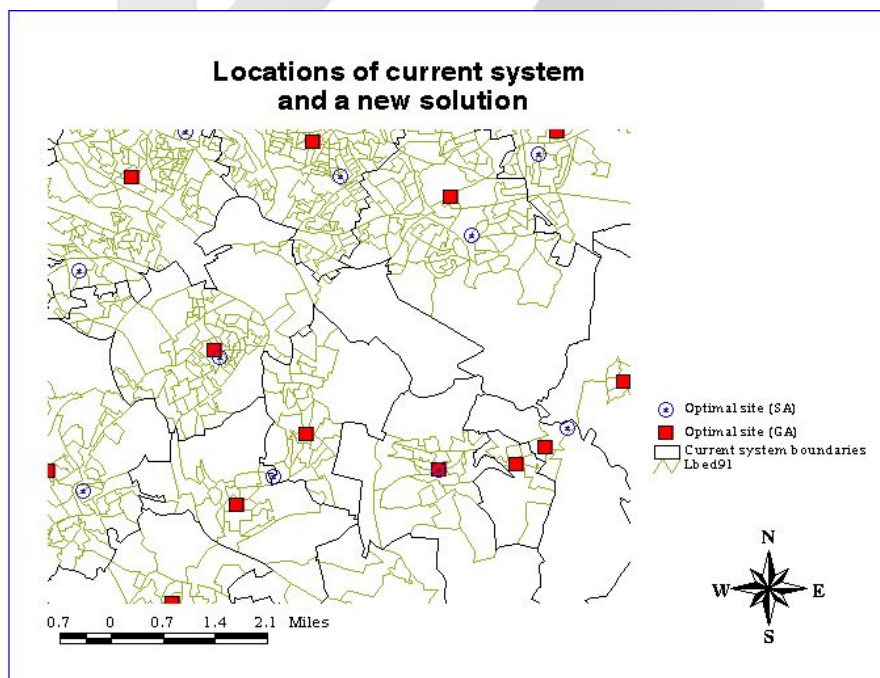
V. Visualisation approaches for location optimisation problem

1. 2 Dimensional visualisation

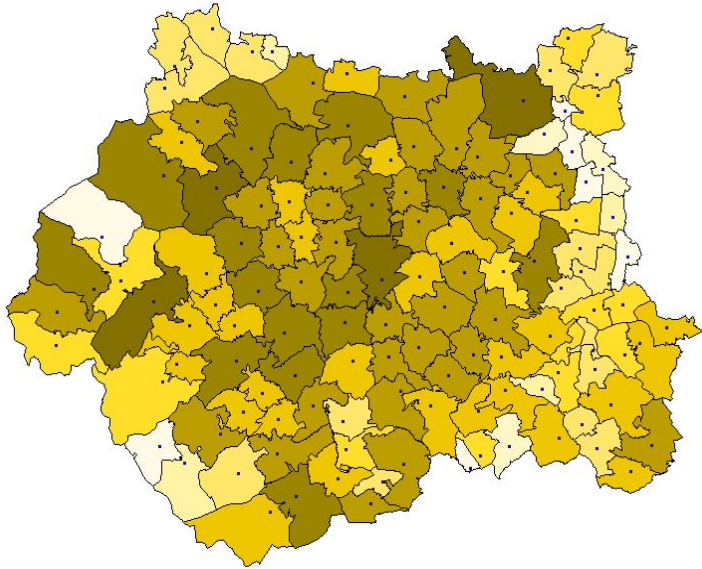
In location optimisation evaluation, 2-D visualisation approach is a simple and effective way to map demand and supply factors of location problem. A centre-region display method is a useful to present service regions and facility locations. Point symbols in the map can display optimal facility locations and colour or shading patterns in polygons portray the optimal solution of those facilities such as minimised travel distance from the facility to service areas.

A simple way of this method to display optimal centre locations of current algorithm (e.g. Cooper algorithm) and a new algorithm (e.g. Genetic algorithm) is illustrated in <Figure 5-1>. This figure presents the different location distribution of the optimal facilities between these two techniques. The different locations also generate solution variation in each solution algorithm for which shaded polygons can be used to indicate catchment areas that are served by the optimal centres. <Figure 5-2> illustrates the optimal centre locations and shaded catchment areas that present the optimal solution variation.

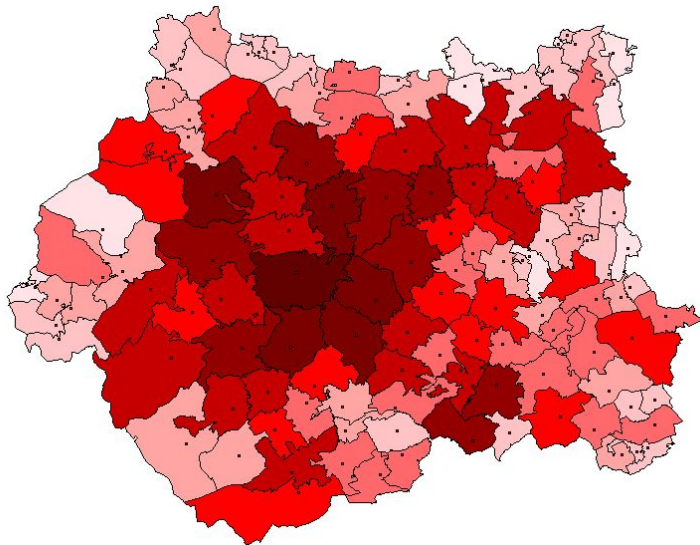
<Figure 5-1> A map showing the differences in locations of current system (Cooper algorithm) and a new solution (GA technique)



<Figure 5-2> Maps displaying optimal locations and solution variations



a) Optimal centres and service areas of Cooper algorithm



b) Optimal centres and service areas of Genetic algorithm

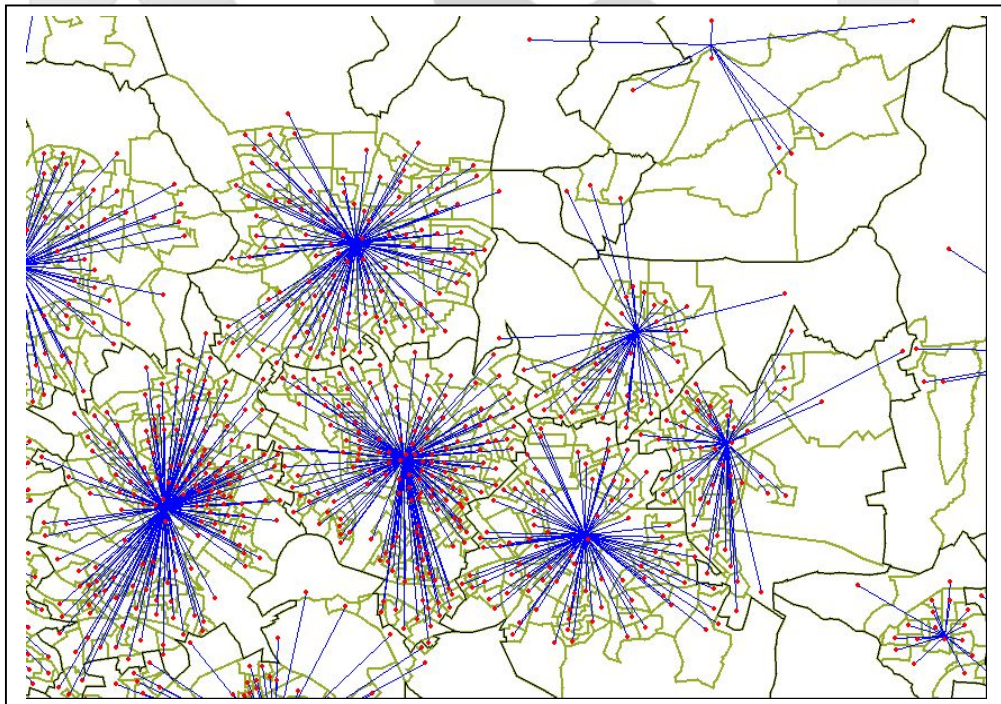
As another 2-D visualisation technique useful to location optimisation, spider lines can be applicable to illustrate the location patterns of optimal centres and allocated demands. <Figure 5-3> illustrates two spider line maps of the location problem that show location and allocation patterns of the optimal centres. To create the spider lines, this paper uses an avenue script of ArcView GIS that provides a quick visual display on a map.

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<Figure 5-3> The optimal location representation using the spider lines



a) Optimal centres and assigned demands (Cooper algorithm)



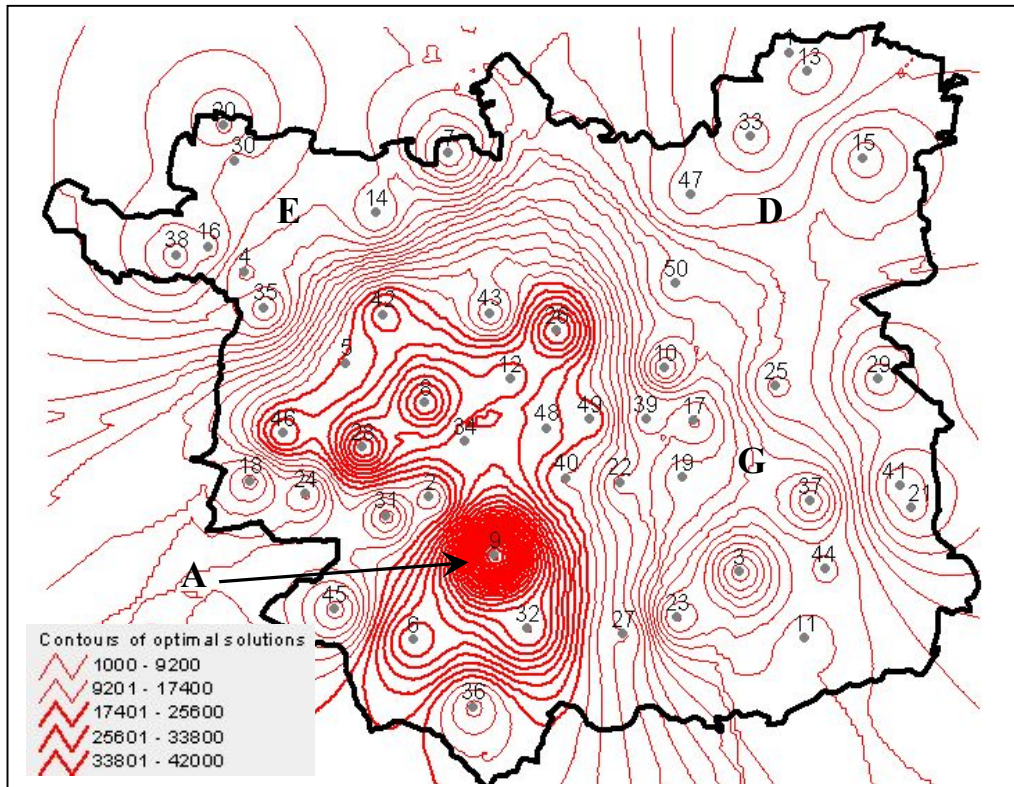
b) Optimal centres and assigned demands (Genetic algorithm)

However, the spider line display has limited capability to visualise the comparison of solution differences when applied into a large location problem such as with several hundreds centres and thousands of demand points. In this case, geometrical similarity of the allocated regions needs to be identified and the usefulness of the location pattern detection is restricted to the problem where each facility serves a relatively small number of demand locations. The spider display also causes visual confusion at the border areas where spider lines are converged. Consequently, it makes difficult to identify the 'marginal difference' in large-scale problems and furthermore, would cause instability of location optimisation evaluation in large location problem representation.

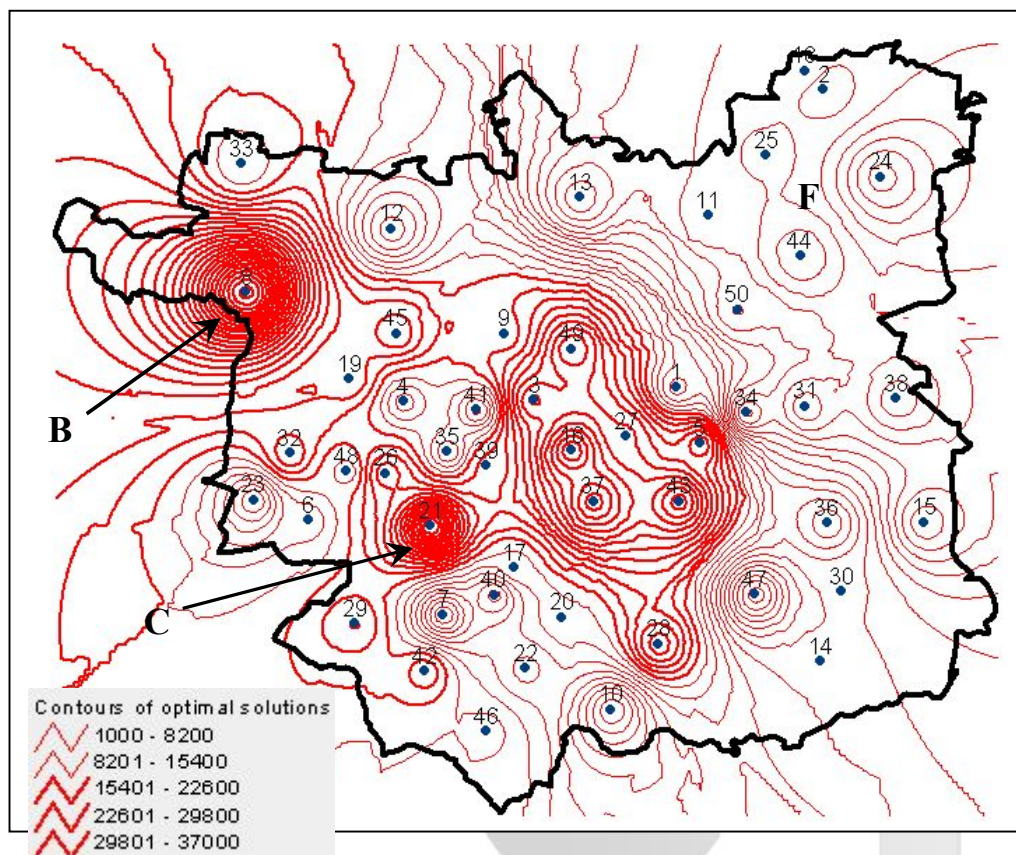
In addition, it is necessary to identify those parts on the map where the solution works well or badly and which also allow both good and poorly serviced locations to be identified simultaneously. This solution is identified by the optimal solution variation that is represented as a Z value in 2-D visualisation. Since the Z value is usually a continuously varied over space, the value is usually grouped into a class. This can be achieved by shading Z -value classes or labelling the isolines which divide them. To display this variation on a map, Figures <5-4> and <5-5> show a 2-D isoline contour view that represents the optimisation solutions of the Cooper algorithm and Genetic algorithm.



<Figure 5-4> 2-D contour line view representing the optimal solutions of the Cooper algorithm

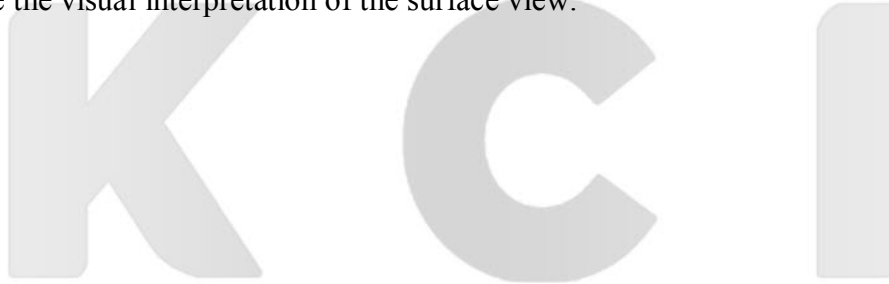


<Figure 5-5> 2-D contour line view representing the optimal solutions of the GA

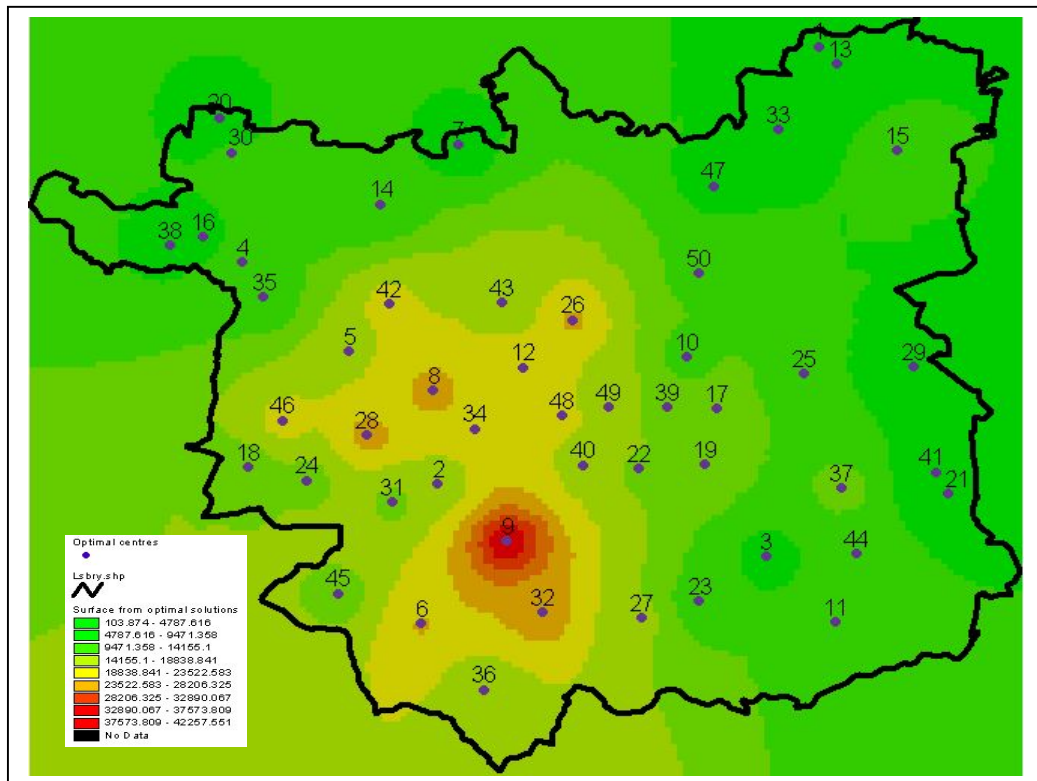


Although each isoline represents all contiguous accessibility with the same value or magnitude of the optimal solution, it is difficult to use the 2-D contour line to represent a clear or sharp break in the Z values at a region where the lines indicate significant changes of the location phenomena. The thickness of contour lines is also limited to the scales grouped and too many lines converging at a region causes a merged line set. For example, in Figures <5-4> and <5-5>, regions A, B, and C show the crude visualisation for the contour line views, where it can be assumed that the optimal solutions change rapidly towards the peak or deepest valley. The representation of dispersed optimal solution Z value is also a problem in 2-D visualisation map. It is not easy to detect variations in how much the Z values are changed. In the regions where large intervals occur or where contour boundaries occur at valley to hill or vice versa (see for example, regions D, E, F, G), the small difference is omitted and it is not possible to detect the differences easily.

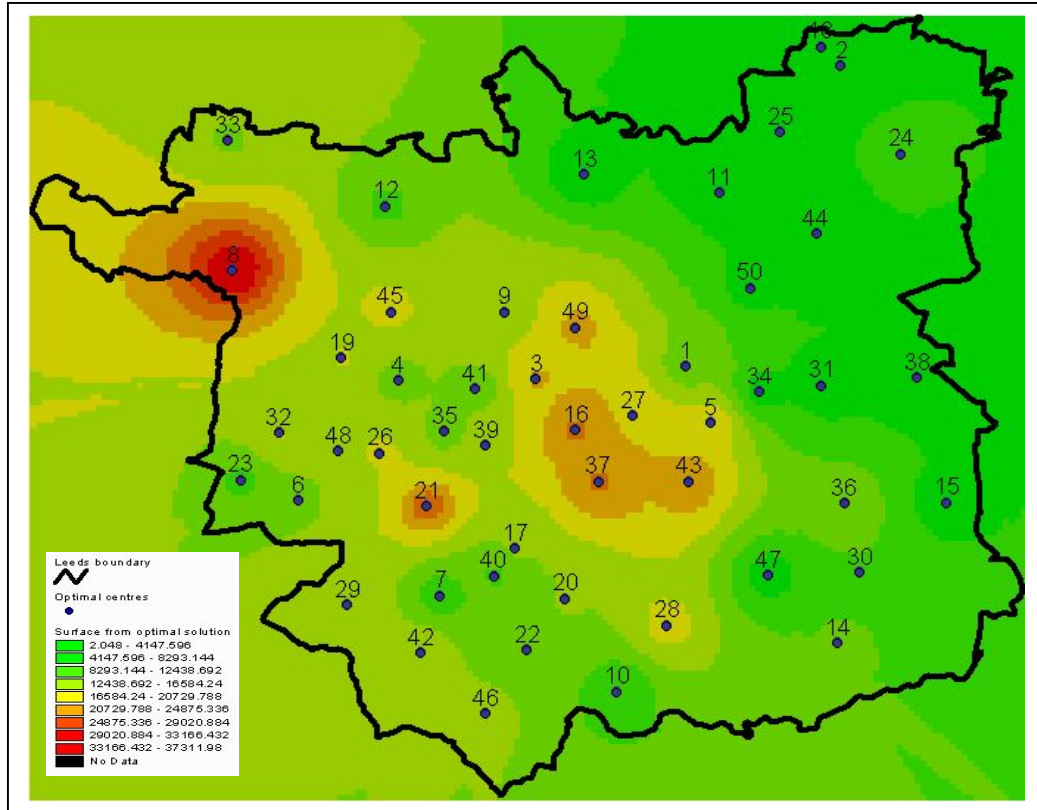
To reduce the visual problem of the contour line compactness, 2-D surface displays can be useful. Grid surface is a proprietary GIS spatial data format to represent geographical phenomena continuously varied over space. Figures <5-6> and <5-7> present 2-D surface views of the optimal solutions of the two algorithms. The surface view can aid the observation of landscape changes of the Z values and of the solution variation with different colours. The overlay of a set of finer contour lines can also improve the visual interpretation of the surface view.



<Figure 5-6> 2-D surface view of the optimal centres location and their solution of the Cooper algorithm



<Figure 5-7> 2-D surface view of the optimal centres location and their solution of the Genetic Algorithm



Whilst the spider lines and surface views can provide good potential applications of cartographic visualisations, the 2-D techniques are restricted to visualise the problem space where the best and worst optimal solution regions should be compared simultaneously. The 2-D display methods may be only suitable for displaying the solution results of *a single optimisation technique*. It is hard to describe visually the extent to which different optimisation techniques can generate different optimal solution values for the same region. For example, if a point or zone is identical to the best optimal site with *different best solution values* by two optimisation methods, it is hard to represent the solution differences of the best solution for the centre under the display of the 2-D contour lines and surface map.

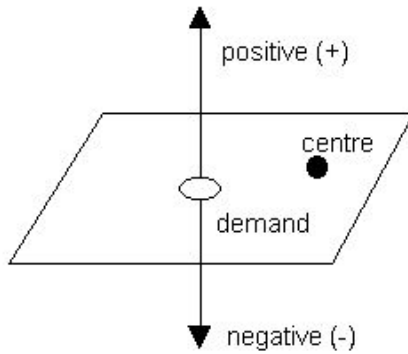
2. 3 Dimensional visualisation

As optimal solution is sensitive to the search performance of optimisation techniques (i.e. algorithmic intensity, robustness, and computational dependency), the visualisation comparison is an important factor for location optimisation in GIS. Sometimes, several centres locate at the same position regardless of local or global search manner. In this case, traditional 2-D contour and surface maps cannot perform well to identify which areas are better or worse by which algorithm except through simple labelling of the value. However, this labelling method is not effective for large problem spaces, where specific ranges of optimal values converge in a small region such that the 2-D isoline map generates a poor visualisation resolution. Therefore, traditional 2-D visualisation ways may not be useful to compare the results of the location model. The benchmark test requires a good 3 dimensional analysis to compare the different location optimisation objectives dynamically.

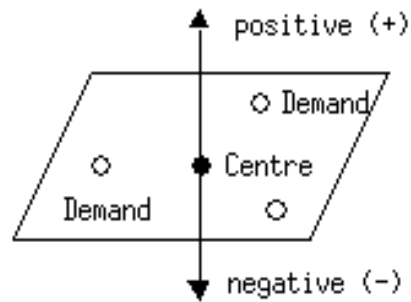
<Figure 5-8> shows a simple diagram of the 3-D based comparison for the p-median problem. There are two kinds of 3-D visualisation for the comparison of the algorithm solution. The first type is the computation of the accessibility of the demand part and the second part is the computation of the allocated facility centre part. If both the Cooper and Genetic algorithms generate an optimal centre at the same location where different accessibility results are computed, the demand can be positive to the GA and negative to the Cooper algorithm, or vice versa. For this case, in supply part, each optimal facility has different solutions and this is emphasised by a positive and negative 3-D visualisation. It can be easy to imagine that the positive and negative comparison is identified in large problem space and sizes and that 3-D visualisation effect is more emphasised.

<Figure 5-8> Diagram of 3 dimensional visualisation

(a) Visualisation of demand part



(b) Visualisation of Supply part



Index: if minimisation function is applied,

0 (no difference): exactly same location-allocation relationship

> 0 (positive): worse location-allocation relationship

< 0 (negative): better location-allocation relationship

In the context of the location optimisation, each location object such as optimal centre and demand should be represented in a single valued function,

$$(2) \quad Z = f(x, y)$$

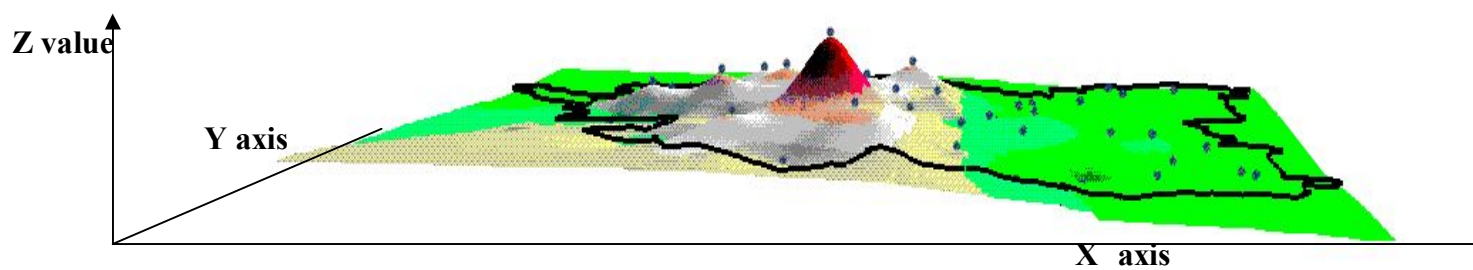
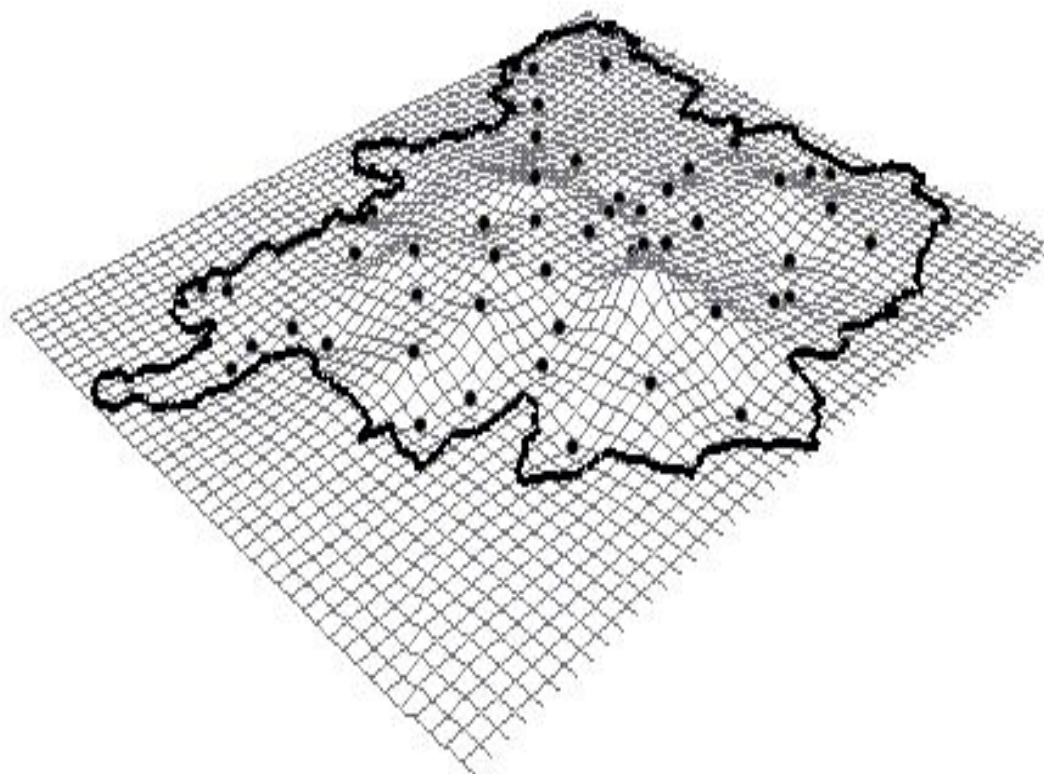
where Z is the optimal solution value for the optimal centre (= Euclidean distance * weight (population) / total weight in the study area) or accessibility (Euclidean distance between demands and the nearest centre) or total travel distance value for each demand (= distance * weight, population at a demand point, zone, Surpop Grid). X and Y are the geographical coordinates of the two objects, centre and demand in the location-allocation optimisation.

To represent the Z value effectively on 3-D format, ArcView 3-D extension (ESRI, 1996) uses an isometric model to represent mesh line illustration, which appears as a 3-D visualisation. However, it should be noted that in theory, the ArcView extension has not reached to real 3 dimensional visualisation levels that take into account of both perspective view and multiple direction of the Z value of spatial objects. In terms of the perspective representation, the 3-D extension cannot support the identification of real 'far and near view' of spatial objects at a position. There are some technical points remained to be a real 3-D visualisation for the extension. However, this paper keeps the process and definition of the ArcView functionality, which has already customised into the GIS software.

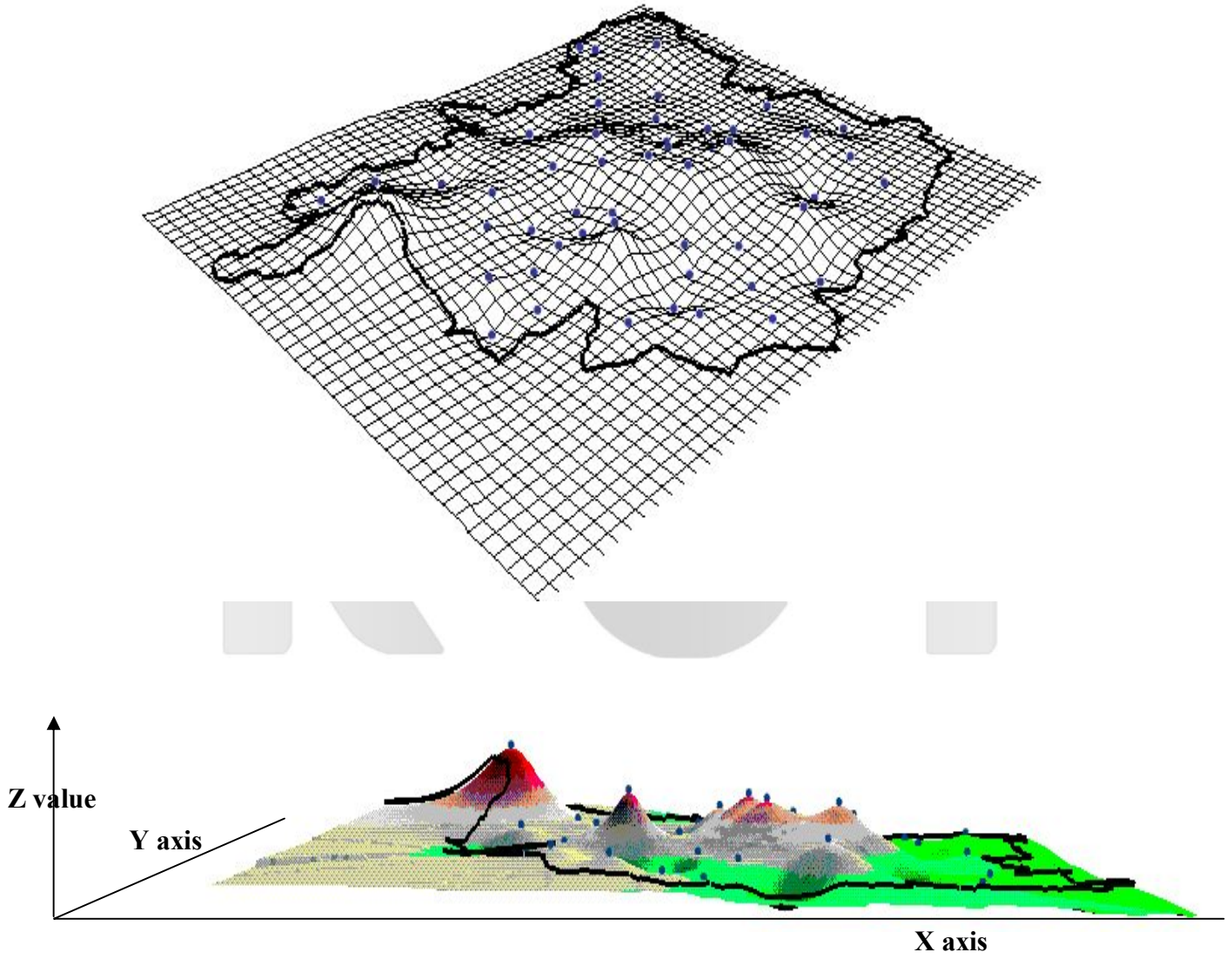
For the p-median model, Figures <5-9> and <5-10> illustrate the 3-D visualisation examples that display optimal solution variations of the two algorithms using mesh line and graduated colouring views. On the maps, it is easy to detect the area where one algorithm obtains better accessibility than another algorithm, and its solution variation can be easily estimated. That is, the representation makes easy to identify the optimisation solution changes around best optimal centres. In addition, the better and poorly serviced areas can be easily mapped on the 3-D views, which help analysts to draw solution landscape clearly. The 3-D maps of <Figure 5-11> also aid to detect solution variation of optimal centres, which illustrate the positive and negative relationship more clearly than the mesh line approach. For example, if solution difference shows positive relationship such as hill and peak, the area regards as worst for the GA and vice versa for the Cooper alternative heuristic.

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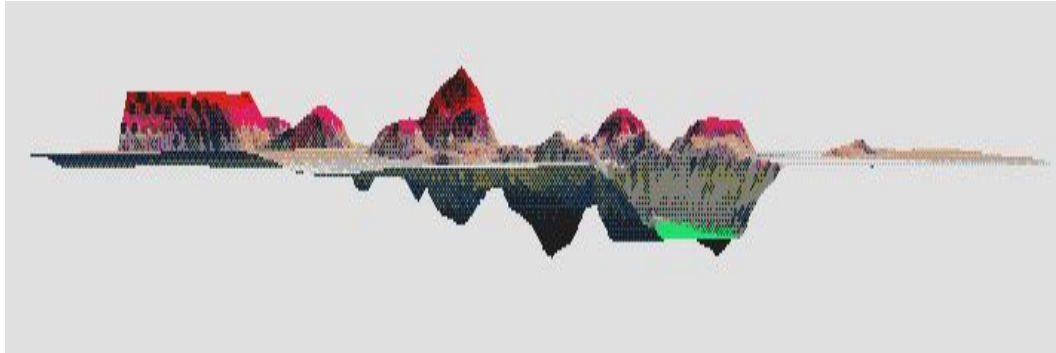
<Figure 5-9> The 3-D views of 50 centres optimal solution variation by the Cooper alternative heuristic (supply aspect)



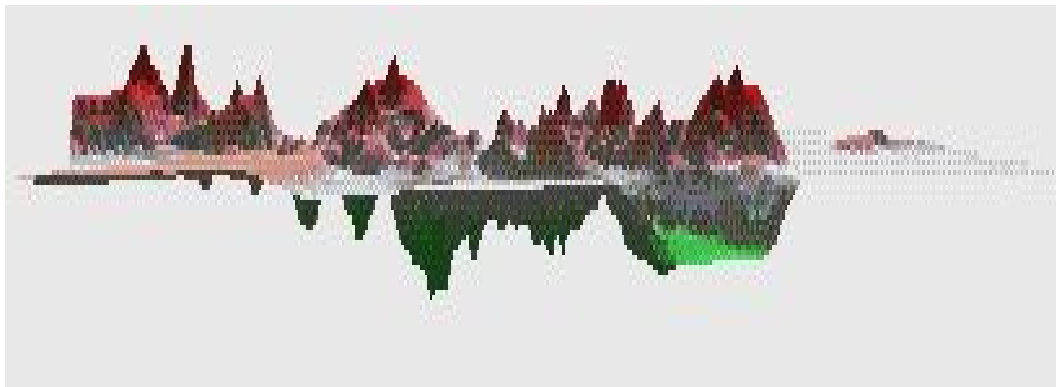
<Figure 5-10> The 3-D views of 50 centres optimal solution variation by the genetic algorithm (supply aspect)



<Figure 5-11> The 3-D views of the optimal solution variations of the GA and Cooper alternative heuristic



(a) A ground view of accessibility solution variation



(b) A ground view of total travel distance solution variation

VI. Conclusion

Many GIS applications have often represented their spatial information with various dimensional visualisation formats from basic 2-D to 3-D visualisation in order to illustrate complex spatial solution results. To display optimal solutions of location optimisation problems, this paper explore visualisation approach which is advantageous to detect the areas where good or poor serviced demands are located and where the accessibility trends to the optimal centres are changed. Visualisation techniques in GIS can bring effective way to search good, bad, and poor accessibility areas. This benefit of representing solution variation on a map provides an insight of understanding location optimisation problem. It also supports the detection of solution variation at a specific targeted area and its visual examination could support to search for alternative optimal locations in decision making process. In addition, various cartographic visualisation mapping can re-enforce the cartographic SDSS building in a GIS in relation to location analysis and optimisation problem solving. Therefore, visualisation issue should be an important task for developing location optimisation research.

However, the identification of the potential of the visualisation approach in location optimisation also proposed several further works. At first, visualisation is a crucial role in gaining new insights and understanding of the structure of location optimisation problems. Thus, their utilisation scopes should be expanded towards various situations and solution analysis topics. Secondly, the development of the visual skills of decision-makers can help the decision-makers to recognise meaningful alternatives and strategies during the optimisation solving process. These visualisation techniques for the location optimisation may be regarded as tools for exploring the problem and the set of alternative locations. The visualisation and its analysis can be used to analyse the data used on the optimisation problem, to identify the best solutions, to explore the set of efficient solutions, and to order alternatives. Finally, the visualisation issue should be, therefore, an integral part of location optimisation and furthermore, be interactive decision supporting approaches in GIS.

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초록

입지최적알고리즘 평가를 위한 GIS VISUALISATION 기법의 이용

김영훈

지리정보시스템 (Geographic Information Systems)의 공간분석에 있어서 최적 입지의 평가와 판단은 중요한 공간의사 결정의 한 부분이다. 이를 위해서 현재까지 지리정보의 공간분석 연구에서 많은 기법들과 모형들이 개발되어 왔다. 또한 각종 지리정보들의 형상화와 시각화를 위한 각종 지도화 기법들도 지리정보 시스템내에서 활발히 이용되고 있다. 이러한 공간분석 결과의 효과적인 지도화와 시각화는 지리정보시스템을 이용하는 의사결정에 많은 이점들을 제공할 수 있다. 또한 공간 문제 해결에 이용되는 각종 분석 모형과 알고리즘의 결과를 지도상으로 얼마나 효과적으로 지도화할 수 있는지는 효과적인 입지 의사 평가 및 결정에 중요한 요소가 될 수 있다. 이러한 중요성에도 불구하고, 대부분의 GIS 입지 분석 및 모형 연구들은 분석 기법의 계량화와 우수한 알고리즘의 개발에 치중되어 왔으며, GIS 내의 최적화 분석 결과의 지도화 및 시각적 기능과의 통합에 대한 통합 연구는 상대적으로 소홀해 왔다.

즉 각 지역간에 발생할 수 있는 상이한 최적 접근도의 변화와 분석 모형의 상이한 분석 결과를 시각적으로 동시에 표현하는 것은 GIS 내의 입지 분석 및 모형 연구에 필수적인 한 부분이라고 할 수 있다. 그러므로, 본 연구에서는 이들 연구의 한 부분으로써, 입지 분석 기법 및 모형들이 제시하는 결과를 비교 분석하는데 있어, 어떠한 시각화 기능들이 효과적으로 이용될 수 있는지를 살펴보고자 하였다. 이러한 연구 목적을 위해서 본 연구에서는, 분석 기법의 상이한 결과에 따라 발생하는 각 지역간의 접근성 차이를 동시에 효과적으로 표현하기 위해서 어떠한 시각화 기법들이 고려되어야 하는지를 살펴보고자 하였다. 이를 위하여 첫번째로, 최적 분석 모형으로써 수송비용 최적화 문제를 목표로 하는 p-median 입지 계획문제를 설정하여, 분석 알고리즘으로써, 전통적으로 우수한 분석 알고리즘으로 알려진 Cooper 알고리즘과 새로운 공간 최적화 기법중의 하나인 유전자 알고리즘을 적용하였다. 두번째로, 이들 두 기법들이 제공하는 분석 결과 (접근성의 상이)들을 대상으로 어떠한 지역에서 얼마나 상이한 접근성이 차이를 보여 주는지를 접근성의 가감을 통해서 살펴 보았다. 예를 들어 특정 지역의 동일한 최적 입지시설에 대해 Cooper 알고리즘을 적용하였을 경우, 유전자 알고리즘의 분석 결과보다 접근성이 불리한 결과가 나올 경우, 혹은 어떠한 지역에서 상이한 접근성의 정도를 지도화할 경우, 그 변화성을 2 차원과 3 차원 visualisation 기법들을 통해서 얼마나 시각적으로 효과적으로 표현할 수 있는가를 파악하고자 하였다. 마지막으로, 본 연구는, 효과적인 시각적 표현은 공간 입지 의사결정에 주요한 부분이 될 수 있으며, 이를 위해 최소한의 기본적인 연구결과으로써, 어떠한 방향에서 GIS 상의 공간 최적화 기법 평가를 위한 visualisation 기법들이 이용될

수 있는 지를 간단한 예들을 통해서 살펴 보았다. 이와 더불어 본 연구의 발전을 위한 여러 후속 연구들이 제시될 수 있다. 첫째로, 다양한 입지문제의 적용이 필요하다. 실제 한국사회에서 요구되는 다양한 공간입지 문제를 위한 효과적인 대안으로써, GIS 내의 적합한 시각화 기법들을 이용한 다양한 최적화 문제 적용은 본 연구의 범위 확대에 필수적이다. 둘째로, 본 연구에서 제시된 시각화 기법의 향상된 기법 연구가 필요하다. 기본적인 2 차원과 3 차원 기법들과 더불어 GIS 이용자들의 다양한 요구에 부응할 수 있는 고차원적인 시각화 기법들이 개발되어야 한다. 셋째로, 시각화 기법과 공간 입지분석 기법간의 통합화 연구도 GIS 연구에 필수적이다. 그러므로 본 연구의 발전을 위해서 이러한 후속 연구들이 계속 되어야 한다.

주요어: 지리정보시스템, 모델 성능 비교, 입지최적화, 시각화 기법

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