한국지리정보학회지 6권 3호 : 21~32(2003)

# 3D Visualization Approaches for Evaluating Location Solution Performances

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# 시설물 접근성 분석을 위한 GIS의 3차원 시각화 기법 적용

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## ABSTRACT

This paper discusses the design of location optimization visualization and feasibility of 3 dimensional visualization techniques. In generic GIS visualization of location analysis, 2 dimensional visualization techniques have been used to map location elements and model solution, such as displaying demand and supply points, drawing connecting lines (e. g. spider line) of optimal locations to their demands, and representing density of location variations. Nevertheless, current GIS and location analysis literatures have little attentions in 3D visualization applications for location optimization problems. Previous research has been neglected 3D visualization of solution performances and its evaluation of solution quality. Consequently, this paper demonstrates potential benefits of 3D visualization techniques and its appropriate GIS applications for location optimization analysis. The visualization effectiveness of 3D approaches is examined in terms of spatial accessibility, and solution performance of optimal location models is evaluated. Finally, this paper proposes extensive 3D visualization perspectives for location analysis and GIS research as a further research agenda.

***KEYWORDS: Visualization, Location Optimization Performance, 3-Dimensional Approach, GIS***

## 요 약

지역 분석 연구에서 접근성 분석은 오랜 연구 주제였으며, GIS에서 지리정보의 시각적 표현 및 지도화는 많은 장점과 이점을 제공하고 있다. 본 연구의 목적은 특정 지역의 접근성 결과를 해석하는데 있어, GIS의 3차원 시각화(visualization) 표현 기법들의 유용함을 사례지역의 분석을 통해서 보여 주고자 하는 것이다. 본 연구는, 기존 연구(Kim, 2002)의 후속 연구로써 영국 리즈시를 실

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2003년 6월 26일 접수 Received on June 26, 2003 / 2003년 9월 9일 심사완료 Accepted on September 9, 2003

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험대상으로, 영국의 그리드 메쉬(British Nation Grid system) 위치 정보[1]를 바탕으로 한 1991 년도 인구센서스를 이용하였다. 본 연구에서는 시설물에 이용 주민들간의 접근성을 분석하고 결과를 해석하는데 3차원 시각화 기법이 어떻게 이용될 수 있으며, 어떠한 장점들이 시설물 입지와 관련된 공간의사결정에 기여할 수 있는지를 고찰하였다. 본 연구의 결론은, 분석 지역마다 상이하게 나타나는 분석 결과의 효과적인 시각적 표현 방법은 GIS를 이용한 공간의사결정 및 대안 제시에 있어 중요할 뿐만 아니라, 향후 국내 지리정보 연구에 많은 기여를 할 수 있음을 제시하고자 하는 것이다.

**주요어: 시각화, 최적 접근성, 3차원 접근, GIS**

## VISUALIZATION AND LOCATION OPTIMIZATION

Visualization is an important component of GIS location analysis to understand, analyse, and explain spatial data and location decision support. A GIS that implements good visualization tools allows decision-makers to be aware of spatial and location problems in more consistent ways, leaving less room for misunderstanding and misinterpretations (Buttenfield and Mackaness, 1991). Visualization is a means of interaction between computers and people based around a graph environment (Gahegan, 2000). A well-organised visual contact and display of geographical data help users understand spatial phenomena and support an effective spatial decision support tool (Dorling, 1993).

Appropriate visual interactive interface encourages the interaction of end users (analyst) and computer (location solution algorithm). Cartographic symbols and graphics demonstrates an effectiveness of optimal facility location visualization that represents optimal sites, best routes, and draw allocated spider-lines over 2D space (Armstrong, et al., 1992). An appropriate integration strategy also fortifies the use of visualization tools in location decision support system (Densham, 1996). 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 visualization mechanism should be developed. Though this implication has led a wide range of visualization applications in GIS, visualization issue is an area of sustained neglect in the field of location analysis and GIS. There are few examples that link visualization to the evaluation of location model's solution performance within GIS environments. Not much is known about appropriate visualization techniques presenting different solutions in a proper way.

Gahegan (2000) pointed out accurately about the quantification of spatial data for visualization, which the visualization utility should be available, as the feedback of the visualization problem. He argued that effective evaluation of spatial analysis results is complicated, because the results are ultimately analysed by humans (analysers, planners, decision-makers), whose judgements are subjective, and which will of course vary between individuals and circumstances. However, this problem should not be overlooked since it is necessary to provide an objective method of discerning the right functionality for the visualization. This argument can be questioned for the visualization of location optimization solutions e. g. how one algorithm works better than another for a location optimization problem in terms of solution quality. Traditionally, we would measure and evaluate the solution effectiveness by user perception or previous experiment experience. It might be simple to establish, if a visualization presents plain location solution results as straightforward. However, it is hard to visualise when large size of data is involved, and complex problem is generate by which the evaluation of solution results of multiple algorithms causes complex visualization results.

Under these circumstances, traditional 2D visualization approaches demonstrate some limitations in discerning the ′good and bad′situation in the task of evaluating the effectiveness of optimal location problem. Given two location algorithms are employed, 2D approach is not appropriate to visualise the extent of solution quality to which different optimization techniques can generate different optimal solution values for the same optimal location. For example, if a point or zone is located as the best optimal site with different best solution values by two optimization methods, the visual effectiveness is reduced to quantify the degree of the accessibility variation with contour line or thematic map. In addition, if the volumes of the accessibility difference are intended to visualise, multiple solution visualization is not be allowed to visualise both good and poorly serviced locations to be identified simultaneously.

This paper discusses visualization aspects in location analysis, especially evaluating location optimization performances through visualising optimal solutions using the techniques of a current GIS software system. Appropriate 3D visualization approaches are investigated with the visualizationof the quantities of multiple optimal solutions, by which the solution differences are easily detected and determined within current GIS environments. This paper presents 3D visualization examples that would supersede traditional 2D approaches for the location optimization visualization and proposes further directions of 3D visualization techniques for location optimization.

## ASSESSMENT, MODEL, AND SOLUTION ALGORITHMS

### 1. Assessment procedures

To identify and compare optimal solutions in GIS location analysis, there are several different conventional ways of assessing its performances: viz. plots of objective function values, maps of solution polygons, and tables of computing time against problem size. These approaches, however, do not exhibit the extent of the solution interpretation of different location optimization algorithms. A more desirable methodology to overcome these limitations of conventional methods would be as follows (Kim, 2002) :

Step 1. Produce a specimen spatial solution

Step 2. 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 optimization.

Step 3. Calculate the objective function surface for this grid.

Step 4. Produce a three dimensional surface.

Step 5. Repeat for a different number of centres
Step 6. Animate the maps

There are three refinements that can be made (Kim, 2002):

1. Inject noise into the data and animate the effects of the noise on the3Dimensional response surface. This paper employs the population weighted point data interpolated from polygon centroid in enumeration districts of Leeds areas, England UK (www. surpop. ac. uk)
2. Subtract the surfaces from a base set of results showing differential performances.
3. Profile the 'deprived' areas.

Note that the assessment and refinement procedures used are based on the grid calculation method of local operation techniques in ArcView GIS raster data analysis (Chang, 2002).

### 2. Location model

For the location optimization problem, this paper explores the p-median problem that aims to search for the best optimal facility location for their customers so that total travel costs (e.g. travel distance) from demands to the closest facility are minimised. The p-median problem can be formulated as the following nonlinear programme:

$$\text{Minimise} \;= \sum_{i=1}^{n}\sum_{j=1}^{p} w_i c_{ij} \lambda_{ij}$$

Subject to

$$\sum_{i=1}^{p} \lambda_{ij} = m, \text{ for } j = 1, \ , n$$

$$ij = 0 \text{ or } 1, \text{ for } i = 1, \ , n, \ j = 1, \ , m$$

Where, $i$ is the demand location and $j$ is the facility location: $w_i$ 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 which Euclidean distance function is used, as an infinite number of locations are possible for each $j$ facility since each $i$ is a point in a continuous space. $n$ is the number of demand (customers), and $p$ is the number of facilities to be located on a plane: $ij$ is allocation decision variable (1 if assigned, or 0 if not).

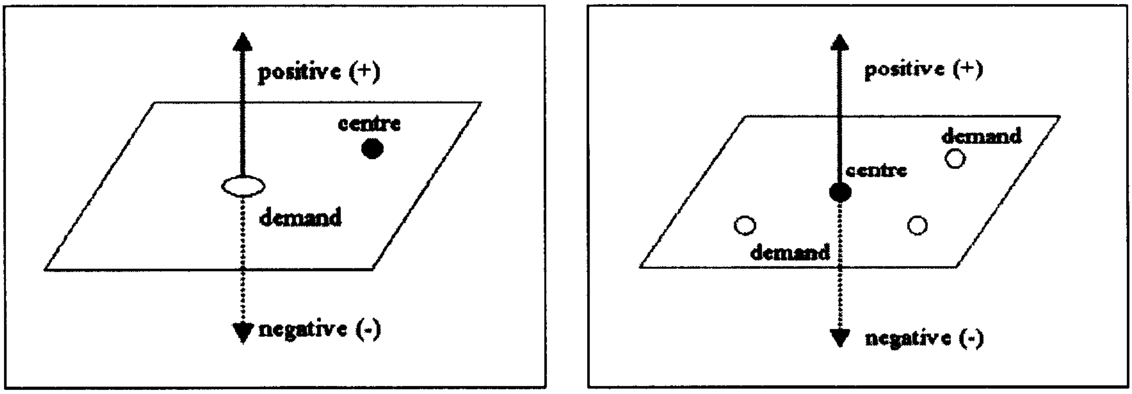
### 3. Solution algorithms

For solution techniques, alternative search heuristic and a spatial genetic algorithm are used, which calculate the objective function of the location model and generate optimal solutions. The former technique uses alternative local improvement procedure that was introduced by Cooper (Cooper, 1963, 1964, 1968). It has been known as a simple and an easy search functionality for solving large complex location-allocation problems (Yeh and Chow, 1996). Alongside the conventional heuristic, genetic algorithm (GA) techniques are more intelligent stochastic search technique than the random restart method. The algorithm improves upon random restart by mimicking evolutionary process through survival of the fitness strategy in biology. Genetic algorithmused in this paper employs an exploitative procedure of a canonical genetic algorithm proposed by Goldberg (1989) and is based on binary strings with crossover along with mutation as variation operator, and fitness-proportionate selection.

## 3D VISUALIZATION FOR LOCATION OPTIMIZATION

While 2D maps regard the optimal solution value only as a continuous Z value, 3D uses Z value as a multiple value that can be an elevation value or any other kind of measurement with respect to the application domain. To present this aspect, this paper uses ArcView GIS's '3D Analyst' extension. The 3D Analyst uses various 3D functions to represent multiple Z values, including an animation function that changes views by rotating the observer position around the target object. This provides a possible opportunity for building a virtual reality environment for location site evaluation.

FIGURE 1 shows a simple diagram of the 3D based comparison for the p-median problem. To compare the solutions of the two algorithms, both demand and supply should be geocoded and visualised. Each algorithm computes the p-median problem to obtain the best solution. Simultaneously, accessibility results from the demand points of the Surpop grid cells are determined, from which positive and negative relationships between demand and centre factors can be computed. For example, if both the Cooper algorithm and the genetic algorithm generate an optimal centre at the same location, yet determine different accessibility results, the demand can be positive in the GA and negative in the Cooper algorithm, or vice versa. In this case, with respect to supply, each optimal facility has different solutions. This can be emphasised by a positive and negative 3D visualization. With regard to location optimization, each location



(a) Visualization of demand part (b) Visualization of supply part

- Examples of centres and demand coordinates;
  Centre points: (430790,438899), (431805,435794), etc
  Demand points: (439700, 449700), (439900,449700), (439500,449500), (439700,449500), etc

- Index: if minimisation function is applied,
  0 (no difference): exact same location-allocation relationship
  \> 0 (positive): worse location-allocation relationship
  < 0 (negative): better location-allocation relationship

FIGURE 1. Diagram of 3-Dimensional visualization

object, such as the optimal centre and demand, can be represented by a single valued function, and an optimal solution value for the optimal centre can be, either 'accessibility' (i.e. Euclidean distance between demands and the nearest centre), or 'total travel distance' for each demand (multiplied the physical travel distance with weight, population at a demand point, or zone). To represent the p-median solutions as a multiple Z value in a 3D format, first, the ArcView extension generates a quasi 3D visualization using an isometric model, such as mesh line illustration. Mesh line representation is one of the most straightforward ways of rendering 3D data, providing a direct perspective viewing transformation. In the model, then, the Z value associated with an x and y location is projected onto an x, y, and z coordinate reference system. The z attribute also has a z axis comparable with the x and y location of spatial objects in a map. Each Z value can define a position on the z axis, which creates a surface with no volume visualised within a real 3D space.

FIGURE 2 shows the mesh line examples of the p-median optimal solutions from the centres and demands perspective. For this visualisation, a hypothetic optimal facility location problem is undertaken, which searches for 20 optimal facility locations among 1,388 demand points in Leeds City. To guarantee robust solution results, the Cooper′s heuristic repeats for 250 times, and different starting solutions are created at randomly at every iteration. To correspondent similar computational performance,

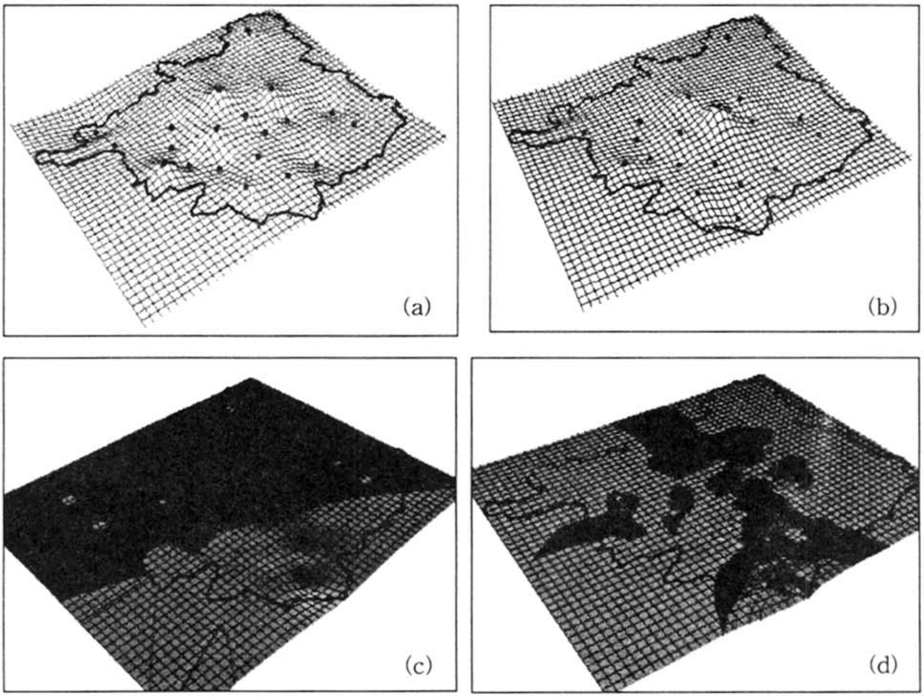
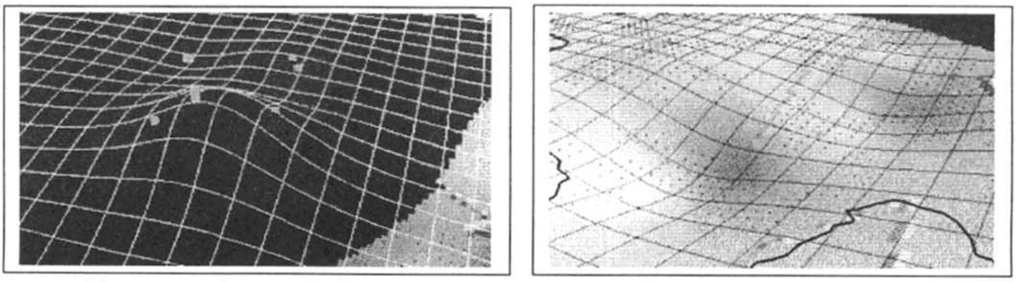


**FIGURE 2.** Mesh line visualization of optimal solution values of p-median problem

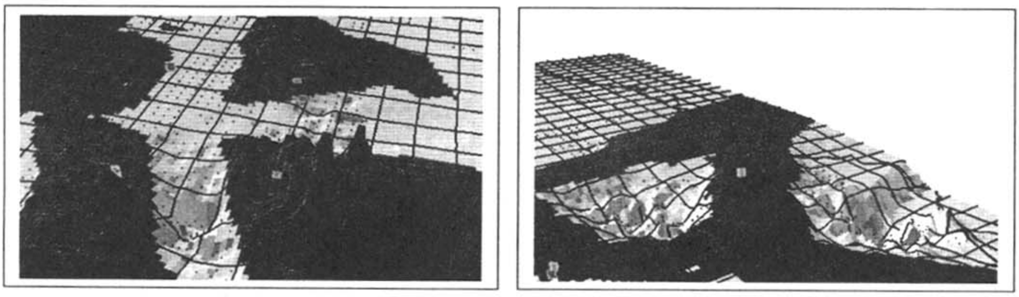
the GA implements the parameters setting; population size = 100, generation size = 100, crossover rate = 0.95, mutation rate = 0.01. Note that after the running, it is found that the GA is superior to the Cooper's heuristic in solution performance. This result also supports other previous literatures discussing the superiority of GA techniques for location-allocation problems (Houch et al, 1996; Gong et al, 1997; Krzanowski and Raper 2001). The optimal solution values are interpolated into a 2D surface raster data, and the positive and negative relationship for each aspect (supply and demand part) is calculated based on the process shown in FIGURE 1. 'Map Calculator' function of ArcView is used to produce a new grid data of the model solution results, and the mesh line script calculate the solution variation. Then, '3D plug-in function' in the 3D extension is used to illustrate the 2D data into an appropriate 3D form. In FIGURE 2, the two sub-figures (a) and (b) shows 3D mesh line views of total travel distance of the p-median supply part, and the two subfigures, (c) and (d), shows the positive and negative changes of the p-median solution between Cooper heuristic and GA technique. The wire representation exhibits a 3D visualization benefit for location analysis that is easy to detect where good and bad, or deprived service provision areas from optimal centres.

The 3D extension and its proprietary tools also simulate a human observer view that enables to search the areas shown mostly accessible from multiple solution techniques together. For example, the mesh lines appear closer together at steep points, where large changes in solution results have occurred; flat areas are obvious due to the regularity of the mesh.



(a) Positive part of supply aspect

(b) Negative part of supply aspect



(c) Positive part of demand aspect

(d) Negative part of demand aspect

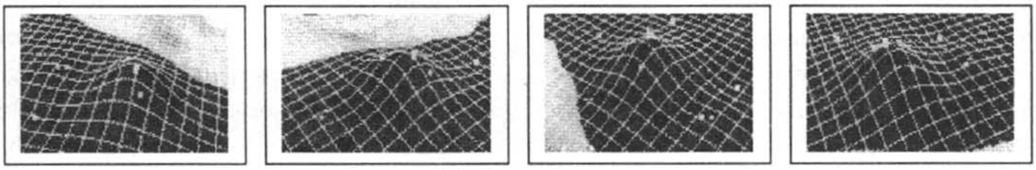
**FIGURE 3.** 3D isometric visualization of optimal solution value difference

FIGURE 3 shows an optimal site of supply and demand part zoomed-in, which illustrates how to vary the total travel distances over 3D format and the perspective transformation enabling to deliver simple depth cues where mesh lines become denser. By this rendering, the mesh line model comes to appear three-dimensional, and assists in detecting variations in the optimization techniques′ location solutions.

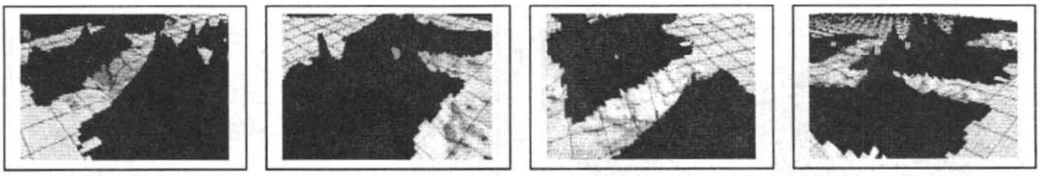
FIGURE 4 shows the view examples that add support the view and validation of 3D optimal solutions in real time perspective. 2D features(i. e. solution values, centres, and demands on a grid ArcView theme) can be seen in 3D by draping and extruding. They can be navigated and moved around in real-time to gain new insights of location optimization visualization.

3D representation also makes it possible to identify accessibility variation in demands to the nearest centre and makes it easy to detect optimization solution changes around the best optimal centres.

FIGURE 5 shows graduated colouring views of the accessibility 3D in demand aspect. This accessibility is calculated based on physical distance(Euclidean distance) between the

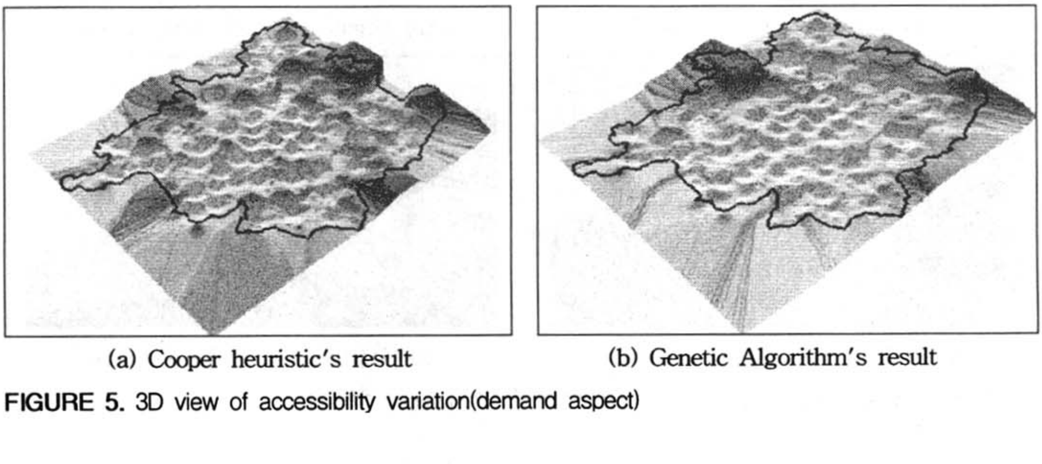


(a) Supply part



(b) Demand part

**FIGURE 4.** Animated maps with different view directions

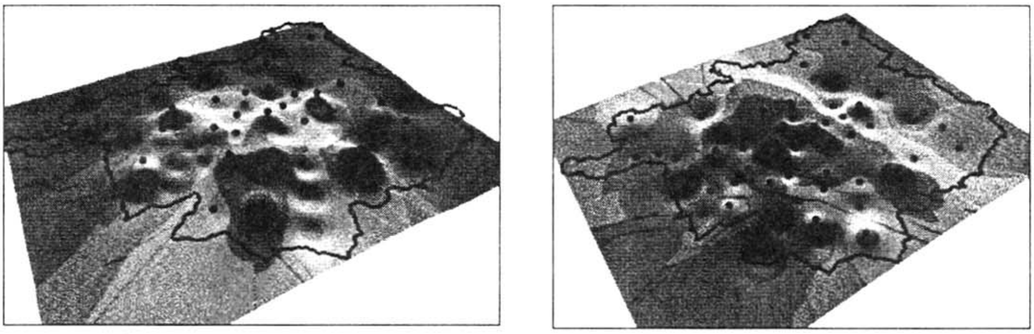


(a) Cooper heuristic's result (b) Genetic Algorithm's result

**FIGURE 5.** 3D view of accessibility variation(demand aspect)

nearest demands to their optimal centre for 20 optimal centre location problem. In this paper, every demand point on the Surpop grid data is allocated to thenearest optimal centre, and the physical distance is calculated and mapped on the 3D view. On the map, the deprived accessibility is viewed on coloured shading hills or peaks, and it exhibits that places are under insufficient service provision circumstance from the optimal centres. The map comparison also makes easy to detect the location and the distribution of affluent or deprived areas over the 3D view.

As supply aspect of 3D view, FIGURE 6 illustrates the supply view of the optimal centre locations and the changes of the total travel distance solutions in the p-median problem. The coloured shading indicates the accessibility



(a) Cooper heuristic' result (b) Genetic Algorithm's result

**FIGURE 6.** 3D views of total travel distances(supply aspect)

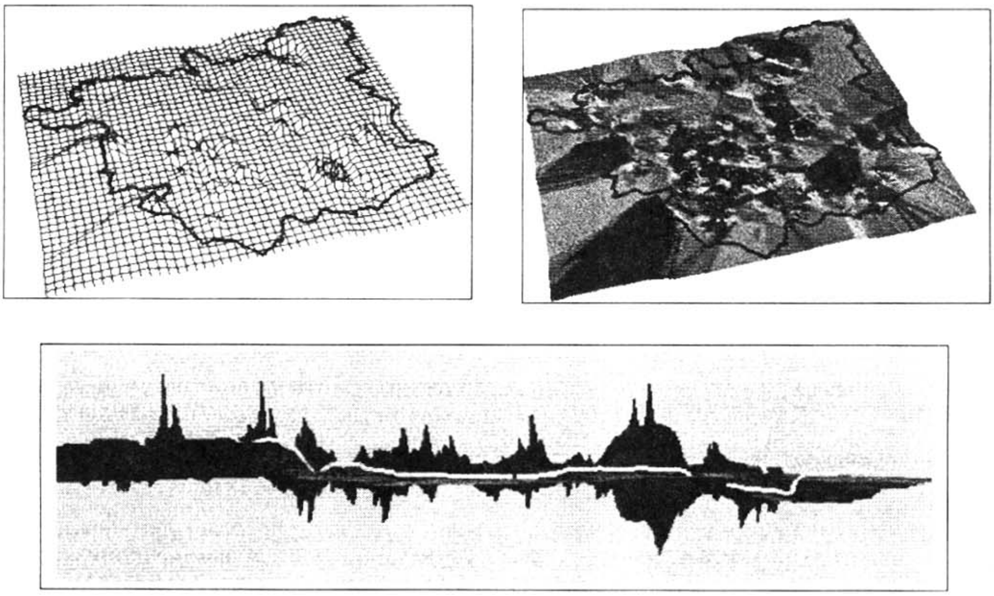


**FIGURE 7.** 3D view of total travel distance solution

of service provision of each optimal centre, such that darker red coloured area covers more demand numbers with higher total travel distance costs than blue-coloured areas. This implies service equality of optimal centres to their customers, which can assess the levels of service provision of optimal centres, whether a service fairly performs to meet a location objective (i. e. p-median), or poorly serves their demands (customers to public services).

Optimization solution differences that the two algorithms generate are also visualised clearly in the 3D view approach. FIGURE 7 displays the solution differences with the meshline approach and graduated colouring views. On this map, it is easy to detect the area where one algorithm obtains a better accessibility than another algorithm, from which solution variation can also be easily estimated. In addition, both better- and poorly-serviced areas can be effectively mapped on the 3D views, which can assist analysts understand the solution landscape. The maps in FIGURE 7 are comparable with the maps in FIGURE 2 as other example of mesh line visualization. Note that when a difference shows a positive relationship, such as a hill and a peak, the area is considered poorer quality for the GA and better quality for the Cooper alternative heuristic, or vice versa. (See the index description of FIGURE 1).

## CONCLUSION

2D visualization has been usually employed to represent location elements of location optimization models, such as positions of optimal centres and demands, location-allocation connections, changes and variations of accessibility solutions. However, conventional 2D approaches have been encountered visual limitations to illustrate the location elements of multiple location solutions. In this case, a 3D environment can offer several benefits of visual representation and evaluation of location solution. 3D colour shading views and extensive 3D perspective view can improve the evaluation of location solutions. This approach indicates both the degree of service provision and the extent of moderate travel condition between demands and their service centres. It makes easy to identify location equality circumstance of facility catchment areas. When the solution is mapped on a proper 3D view, it is easily to detect of deprived service areas, and the assessment of the service provision state is also easily analysed. This is equivalent to the mapping benefit of geographical objects. A successful visualization of geographical events enables analysts or planners to explore spatial patterns and relationship between location elements.

In illustrating complex spatial solution results, GIS applications have represented spatial information in various dimensional visualization formats, from a basic 2D to an advanced 3D transformation. This paper explored 3D visualization approaches to visualise the various solution performances of location optimization problems. It further discussed the usefulness of the 3D approach in detecting areas where good (or poor) levels of service are located, and where accessibility to the optimal centres varies over space. Visualization techniques within GIS can effectively illustrate accessibility solution values around the best location areas, and can show how these values compare with the values of local optimal locations. These benefits provide not only insight into understanding location optimization problems within a problem space (i. e., the whole Leeds area), but also support the practice of detecting solution variation at a specific targeted area.

Adequate visualization approach is an important part of location problem solving process, because as the visualization is a final stage, a successful visualization output enables analysts or planners to evaluate location model′solution results, whether they can meet a location planning objective, and assist to decide alternative options. A well-designed GIS visualization framework not only enables integration and manipulation of location elements, but also enables even non-experts to evaluate location optimization results.

At the decision-making level, the detection of accessibility variation at specific targeted areas, and a visual examination of solutions would be useful in exploring alternative optimal facility locations. At the practical level, it is also important for location planning decision-makers to be aware of solution alternatives. Cartographic symbols and mapping can reinforce the building of location decision support systems within GIS, thus linking GIS with location analysis and optimization problem solving. An important task for the next generation of research will be to develop appropriate frameworks and tools to integrate GIS environments and location optimization.

This study proposes several avenues of further research. Firstly, visualization plays a crucial role in gaining new insights into, and understanding of, the structure of location optimization problems. To increase the strength of visualization, GIS visual techniques should expand to various location analysis situations and include wide application problems. Case studies would be recommended as further research work to identify the visualisation effectiveness, which would present the usefulness of visualisation approach in facility location analysis. Secondly, as the development of visualization techniques enables decision-makers to recognise meaningful alternatives strategies, location optimization visualization techniques should be explored as a GIS analysis tool. Nevertheless, the visualization aspects of supply and demand sides are undertaken differently for them, GIS visualization techniques can expand their application capabilities towards various practical areas. Finally, further research should propose more activated and robust user interfaces for GIS environments in order to build an integrated supporting system for location decision making.

## 주)

1) The British National Grid는 영국 (잉글랜드, 웨일즈, 스코틀랜드)의 모든 지리정보에 대한 위치좌표를 설정하는 기준이다. 영국의 최서부에 위치한 시실리섬(Scilly Isles)을 기준점(0,0)으로 하여 GIS 내에서 1m 격자 간격으로 동쪽(eastings)과 북쪽(northings) 방향을 기준으로 좌표점이 부여된다. 예를 들어 (271384, 096572)라는 건물의 좌표는 시실리 섬으로 부터 동쪽으로 271km 384m, 북쪽으로 96km 572m 지점에 위치한 것으로 계산된다. 북아일랜드(Northern Ireland)의 경우는 아일랜드공화국의 the Irish National Grid 방식을 따른다. 자세한 정보는http://www.gps.gov.uk/natgrid/introduction.asp를 참조.

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