INTERNATIONAL JOURNAL OF
NUMERICAL ANALYSIS AND MODELING
Volume 9, Number 2, Pages 217–231

AN INTERACTIVE GEOSPATIAL ANALYSIS PLATFORM FOR FACILITY LOCATION DECISION-MAKING

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Abstract. The Facility Location Problem is an important research topic in spatial analysis. This paper focuses on the Static and Mobile Facility Location (SMFL) Problem, which aims to identify those static and mobile facility locations that serve a target area most efficiently and equally. This paper formalizes the SMFL problem as a bi-objective model and then solves the model by using a novel heuristic algorithm, named Static and Mobile Facility Location Searching (SMFLS). The algorithm consists of two steps: static facility location searching and mobile facility location searching. In order to solve the model for large datasets efficiently, a clustering-based heuristic method is proposed for the static facility location searching while the mobile facility location searching is implemented using a greedy heuristic method. Experiments on synthetic datasets demonstrate the efficiency of the SMFLS algorithm. In addition, with the aim of conducting facility location decision-making conveniently and efficiently, in this paper, an interactive geospatial analysis platform, named Geospatial Analysis Platform using Interactive Maps (GAPIM) is proposed by combining the bi-objective models and the SMFLS algorithm with an interactive map. Experiments on Alberta public health service data are conducted, with the results demonstrating the efficiency and practicality of the platform.

Key words. GIS, Interactive map, Static and mobile facility location problem, Heuristic algorithm

1. Introduction

The 'facility location problem' is an important research topic in spatial analysis. The aim of this problem is to 'determine a set of locations for supply facilities so as to minimize the total supply and assignment costs' [28]. Given the importance of effective facility location, a large number of facility location models [28, 24] and optimizing algorithms [4, 18, 8, 7] have been developed.

The purpose of the Static and Mobile Facility Location (SMFL) problem is to identify the best locations for static and mobile facilities in order to serve a given target area efficiently and equitably. The static facility is located for improving the *efficiency* of facility locations, such as minimizing the average travelling distance between static facilities and clients. The mobile facility is located for improving the *equity* of facility locations, such as minimizing the maximum travelling distance necessary for clients to receive service either from the static facility or the mobile facility. In reality, many services have to be delivered by using a combination of both static and mobile facilities. For example, for emergency medical services, hospitals should be located to achieve full coverage of the people in a target region while ensuring the minimum average travelling distance. This usually results in hospitals being located near to, or within, dense communities. However, patients in sparse and remote areas may live far away from a hospital since the total number of the hospitals is limited. In order to offer fast response service for patients in an entire region, ambulances must be located in a way that shortens the maximum travelling distance for patients to access medical services. Compared with the facility location problems dealing with single facility type [28, 24, 4, 18, 8], the static

Received by the editors January 1, 2011 and, in revised form, February 20, 2011.
2010 *Mathematics Subject Classification.* 90B50,90C90,90C59.

and mobile facility location problem is more complicated in that it requires two different searching strategies for static facilities and mobile facilities while taking into account the inter-relations between these two types of facilities. However, none of existing methods can be applied to the SMFL problem directly.

During the past 30 years, Geographical Information Systems (GIS) have evolved to include advanced location model development and have been applied to more complicated / advanced application scenarios [9, 26]. The central element of a GIS is the use of a location referencing system so that data about a specific location can be analyzed in relation to other locations. By integrating a wide range of facility location models and optimizing algorithms, GIS is an ideal and sometimes indispensable tool for making facility location decisions [13, 37, 32, 3, 5, 23, 15]. However, two problems limit current geospatial information systems for making facility location decisions. First, for users who lack expertise in GIS, it is inconvenient, if not impossible, to use the existing GIS-based facility location analysis tools. For example, a public health planner would like to investigate locations for new screening centers (i.e., static facilities) and screening vehicles (i.e., mobile facilities) into a screening program. He/She may have a few sites in mind and can point out approximate locations on a map. However, without any GIS training, he/she cannot upload the coordinate information of those sites into a GIS system and use the spatial analysis tools provided by the GIS. Second, it is computationally inefficient for users to use existing GIS-based facility location analysis tools. The computational demand of these tools requires considerable computational resources, and hence there are limited applications within light computational environments (e.g., web environment). In addition, with web-based interactive maps (e. g., *Google Maps* and *Microsoft Bing Maps*) becoming more and more popular, people are tending to access and manipulate increasing amounts of geospatial information on the web. However, seldom current GIS systems support bringing numerous geospatial information on the web into location analysis automatically.

The purpose of this paper is to develop a geospatial analysis platform for solving the static and mobile facility location problem conveniently and efficiently by combining a facility location model and an optimizing algorithm with an interactive map.

The contributions of our work can be summarized as follows:

First, this paper formalizes the SMFL problem as a bi-objective facility location model and then solves the model by using a novel heuristic algorithm named Static and Mobile Facility Location Searching (SMFLS). The algorithm splits the location decision into two steps: static facility location searching and mobile facility location searching. In order to solve the model for large datasets efficiently, a clustering-based heuristic method is proposed for the static facility location searching while the mobile facility location searching is implemented using a greedy heuristic method.

Second, the Geospatial Analysis Platform using Interactive Maps (GAPIM) is developed for solving facility location problems conveniently and efficiently by combining the bi-objective facility location model and the SMFLS algorithm with an interactive map. The platform creates a user-friendly web environment for customers to search useful geographic information, to input and visualize geographic information, and to specify spatial analysing parameters and constraints. The platform requires less execution time for searching for optimal facility locations because the searching is only triggered on the regions selected by users on the interactive map instead of the whole area. In addition, the platform is designed to be extensible such that new location models, algorithms and operational procedures can easily be integrated into the system.

Finally, we evaluate the platform using a real application, optimizing the facility locations for the emergency medical service in the province of Alberta, Canada. Experiments show that the platform is practical and efficient for locating hospitals (i.e., static facilities) and ambulances (mobile facilities) in the province.

The paper is organized as follows. Section 2 summarizes related work on interactive map systems, static and mobile facility location models, and solution approaches to the models. In Section 3 we introduce the facility location optimization function for solving the static and mobile facility location problem, which include a bi-objective model and a cluster-based heuristic algorithm. We also evaluate the function on synthetic datasets and discuss the rationale for integrating it into the GAPIM. In Section 4, the general structure of the GAPIM is proposed as well as the interface and the functionality of the GAPIM for solving the static and mobile facility location problem. Experimental studies on real datasets are presented in Section 5. Finally, Section 6 concludes the paper with a discussion of future research directions.

2. Related work

2.1. Interactive map systems. An interactive map system is a software system designed to interactively manipulate maps [2]. Given the usefulness of interactive map systems, they have been used as part of location modeling research. Lu [25] proposes a Web-based GIS system for collaborative mobile planning. Combined with an interactive map and spatial analysis functions, the system aims to offer a new, efficient means for mobile planning. It also aims to enable various departments and the public to participate in activities of urban mobile planning, such as geo-referenced information collection. Peng and Huang [30] present a Web-based transit information system that integrates GIS technologies with web serving, network analysis and database management. By integrating an interactive map interface, the Web-based transit information system enables users to interact with information on transit routes, schedules, and trip itinerary planning. However, to our knowledge, no existing system uses interactive maps for facility location decision-making.

2.2. Static and mobile facility location models and solution approaches. Facility location decision-making is a critical element in strategic planning for a wide range of private and public firms [29]. The static and mobile facility location problem is a specific type of the hierarchical facility location problem [33]. In the problem, the services would be delivered to clients through the cooperation of static and mobile facilities. Several models have been developed for locating static and mobile facilities.

Sanchez [34] proposes a model to find locations of static and mobile facilities within the industry context. In the model, both static facilities and mobile facilities are located to maximize profits with the constraint that both static facilities and mobile facilities can only serve a given number of clients (called capacity). The static facility cannot be revoked or relocated while the mobile facility can be revoked or relocated in a period for thriving in face of continuous and unpredictable change of clients demands. The model is useful when only static facilities are no longer the best or the unique solution to satisfy clients demands in a target area. Since the model is developed for maximizing profits, the equity of facility locations is not discussed.

Two types of approaches are used to solve facility location models: exact solution approach [7] and heuristic approach [10]. Since the facility location problem is NP-hard [12], attempting a solution consumes a large amount of computational resources. The exact solution approach, such as branch and bound [34], can produce the best solution but cannot handle models with large amounts of constraints and variables since this consumes an unacceptable amount of computational resources. In order to solve a model with large amounts of constraints and variables, a heuristic approach is developed. This can produce acceptable solutions using fewer computational resources but it will not guarantee finding the best solution.

3. Facility location optimization function for the static and mobile facility location problem

A facility location optimization function includes a facility location model to formalize the problem and an algorithm to solve the model. In this section, we start with formalizing the static and mobile facility location problem as a bi-objective facility location model in subsection 3.1. The Static Mobile Facility Location Searching (SMFLS) algorithm developed to solve the model is introduced in subsection 3.2. In subsection 3.3, the SMFLS algorithm is tested using synthetic datasets.

3.1. Bi-objective static and mobile facility location model. Given a set of population centers and a set of candidate sites for facilities, the *Static and Mobile Facility Location* (SMFL) problem is to identify optimal locations for a predefined number of static and mobile facilities that maximize the efficiency and equity of facility locations. Unlike the research related with the static and mobile facilities before, we locate static mobile facilities by using two separate strategies. The static facility is located with the aim of improving the efficiency of facility locations by minimizing the average travelling distance between static facilities and population centers. Mobile facility is located with the aim of improving the equity of facility locations by minimizing the maximum travelling distance for people in population centers to get service either from the static facility or the mobile facility. In the following, we first introduce how to define the efficiency and equity of facility locations. Then, an objective model is given for location optimization.

Definition 1 (**Efficiency**) Given a set of population centers D and a set of static facilities S, the efficiency of facility locations is measured by the population weighted average travelling distance from population centers to their assigned static facilities, as shown in equation (1).

$$\frac{\sum_{d_j \in D} dist(d_j, s_i) * d_j.w}{\sum_{d_j \in D} d_j.w} \tag{1}$$

Where $s_i \in S$, $d_j \in D$ and clients in population center d_j is assigned to get the service from static facility s_i; $d_j.w$ is a positive number representing the number of clients in population center d_j.

Definition 2 (**Equity**) Given a set of population centers D, a set of static facilities S and a set of mobile facilities M, the equity of facility locations is measured by the maximum travelling distance for people in population centers to receive service either from a static facility or a mobile facility, as shown in equation (2).

$$Max\{dist(d_j, s_i||m_k), d_j \in D\} \tag{2}$$

Where $s_i \in S$, $m_k \in M$ and $dist(d_j, s_i||m_k)$ is the travelling distance from a population center d_j to its assigned static facility s_i or to the closest mobile facility m_k, whichever is shorter.

In addition, we consider the static facility capacity constraint, i.e., each static facility can satisfy a limited number of clients. People in each population center can only be assigned to their closest unfulfilled facilities. However, the mobile facility capacity constraint is not considered in the paper. We assume that mobile facilities are always available for any client in population centers.

Definition 3 (**A bi-objective static and mobile facility location model**) Given a set of candidate sites for static facilities and mobile facilities, the predefined number of static facilities and mobile facilities, the locations of static facilities are first chosen by satisfying:

$$Objective(1) : Max\ \ efficiency = Min\{\frac{\sum_{d_j \in D} dist(d_j, s_i) * d_j.w}{\sum_{d_j \in D} d_j.w}\} \tag{3}$$

Then the locations of mobile facilities are chosen by satisfying:

$$Objective(2) : Max\ \ equity = Min\{Max\{dist(d_j, s_i||m_k), d_j \in D\}\} \tag{4}$$

3.2. SMFLS: Static and Mobile Facility Location Searching algorithm. In this subsection, we propose a heuristic algorithm called Static and Mobile Facility Location Searching (SMFLS) to solve the model above. The algorithm splits the location decision into two steps: *static facility location searching* and *mobile facility location searching.*

3.2.1. Static facility location searching. Static facility location searching is a clustering-based heuristic method derived from the Interchange algorithm [35]. Clustering is the process of grouping a set of objects into classes so that the objects within a cluster have high similarity to one another, but are dissimilar to the objects in other clusters [16]. The clustering process is used to reduce the searching space for each facility. Compared with the clustering based approach [22], the clustering-based heuristic method in this paper limits the selected facility locations among the candidate sites. The procedure involves three steps:

Step 1: *initialize.* The locations of static facilities are selected randomly among the candidate sites.

Step 2: *allocate capacity and construct clusters.* Each population center is assigned to its closest unfulfilled static facility and each unused candidate site is assigned to its closest static facility. After the assignment, each static facility together with the population centers and the candidate sites assigned to it is considered as a cluster. Population centers are assigned in a descending order of a priority value. The priority value proposed by Ghoseiri and Ghannadpour [14] is calculated for each population center as the absolute difference in the distances to its first and second closest static facilities. Because the objects in a cluster are closer to each other than the objects from other clusters, for every static facility in a cluster, there is a high probability that its optimal location is in the cluster. In this case, for each cluster, the optimal location of a facility is the candidate location within that cluster that minimizes the average travelling distance from population centers in the cluster to the static facility. So, the optimal location of a facility in each cluster is searched out by trying every candidate sites in the cluster. Through separating the whole area into different clusters, the searching space for every static facility is reduced from the candidate sites in the whole area to the ones in its cluster.

Step 3: *relocate one facility.* Among all the clusters, the cluster with the smallest corresponding average population weighted travelling distance is searched out. The static facility in that cluster is tried to change from its original site to the optimal location in the cluster. The change is accepted only if the corresponding average travelling distance of the cluster is smaller than the average travelling distance of the original static facility configuration. Because each cluster is defined as the locations of a static facility and its assigned population centers and candidate sites, after one static facilitys location being changed, the distribution of clusters as well as the optimal location in them is also changed. Thus, only one static facility is changed to the optimal location in its cluster in each iteration.

Step 2 and step 3 are iterated until no change happened in step 3.

3.2.2. Mobile facility location searching. The location of mobile facilities depends on the location of population centers and static facilities. To reduce the execution time, we use a greedy heuristic method in this step [21].

Based on the distribution of population centers and static facilities, one mobile facility is located at a time, always the candidate site that reduces the value of equation (2) at most being selected. The method stops when the predefined number of mobile facilities has been sited.

3.3. Computational experiments on the SMFLS algorithm. The SMFLS algorithm proposed in this paper aims to find acceptable solutions of the bi-objective model efficiently so that it can be used within a web-based context. In the SMFLS algorithm, the clustering-based heuristic method and the greedy heuristic method are used for the static facility location searching and the mobile facility location searching, respectively. Since the greedy heuristic method [21] has been widely used to solve NP problems, its accuracy and efficiency have been evaluated well. The following experiments will focus on the evaluation of the efficiency and accuracy of the clustering-based method by comparing the performance of the clustering-based method with that of the Interchange algorithm (one of the most popular heuristic algorithms) under different numbers of candidate sites.

Synthetic datasets for population centers were created in a 300*300 area. All experiments run on three kinds of datasets, in which 80% of the population centers consist of 4, 6, 8 dense clusters, respectively, and the remaining 20% are uniformly distributed in the area. All values in the following experiments are the average of the results from running the algorithm three times on each of three kinds of datasets. All the population centers are treated as the candidate sites for static and mobile facilities. The number of clients in each population center is set to 30. The number of the static facilities is set to five. To make sure static facilities are adequate to meet the overall demands, the capacity constraint of each static facility is set to 600,000. The Euclidean distance between two locations is used to represent the travelling distance between them. In the following experiments, *Average travelling distance* is the value of equation (1) representing the efficiency of facility locations. The experiments are performed on a Core 2 Quad 2.40GHz PC with 3GB memory, running on Windows XP platform. The comparison results are shown in Figure 1.

The left graph in Figure 1 shows the execution time of the clustering-based heuristic method increases from 7.9 seconds to 157,756.5 seconds (43.8 hours) when the number of candidate sites increases from 1,000 to 100,000. However, when the number of candidate sites increases from 1,000 to 20,000, the execution time of the Interchange algorithm dramatically increases from 46.0 seconds to 188,121.5 seconds (52.3 hours), In Figure 1, we do not have the results for the Interchange algorithm when the number of candidate sites is over 20,000. The reason is that the Interchange algorithm cannot be finished under the available computing resource.

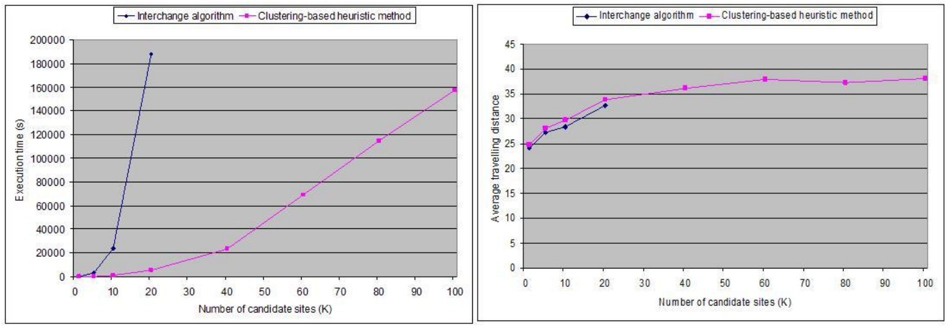

FIGURE 1. Comparison between the clustering-based heuristic method and the Interchange algorithm. Left:Execution time; Right:Average travelling distance.

Thus, we can conclude that the clustering-based heuristic method is much more efficient than the Interchange algorithm for the static facility searching.

The right graph in Figure 1 shows the average travelling distance of the clustering-based heuristic method increases from 24.7 to 38.1 when the number of candidate sites increases from 1,000 to 100,000. For the Interchange algorithm, its average travelling distance increases from 24.1 to 32.6 when the number of candidate sites increases from 1,000 to 20,000. The relative difference of the average travelling distance can be calculated as:

$$\frac{avg(cluster) - avg(Interchange)}{avg(Interchange)} \tag{5}$$

where $avg(cluster)$ is the average travelling distance of the clustering-based heuristic method and $avg(Interchange)$ is the average travelling distance of the Interchange algorithm. The relative difference is 2.5%, 2.9%, 4.2%, 4.0%, when the number of candidate sites is set to 1,000, 5,000, 10,000, and 20,000 respectively. Thus, we can conclude that the Interchange algorithm produces better results than the clustering-based heuristic method. However, the results produced by the clustering-based heuristic method are acceptable since the relative difference of the average travelling distance between the clustering-based heuristic method and the Interchange algorithm is small.

In summary, compared with the Interchange algorithm, the clustering-based heuristic method can dramatically reduce the execution time and has an acceptable accuracy. The clustering-based heuristic method is more useful being applied on real time applications or being applied on large datasets while the Interchange algorithm needs too much computational resource to produce results. In addition, as shown in the experiments, even though the SMFLS algorithm can dramatically reduce the execution time, this time is still unacceptably high for web applications when the number of candidate sites is large. For example, the SMFLS algorithm would take 190 seconds to solve a problem with 5,000 candidate sites. According to [19], 10 seconds is about the limit for keeping a web-user's attention focused on the service. Since the number of candidate sites is the major determinant of execution time, a good method for selecting candidate sites for facilities may reduce the execution time. In this sense, to add the bi-objective model and the SMFLS algorithm into a web platform, it is necessary to include an interactive map system with the platform. The interactive map system can reduce the execution time for searching optimal facility locations because the SMFLS algorithm only searches the candidate sites within the regions drawn by users on the interactive map.

4. GAPIM: a Geospatial Analysis Platform with Interactive Maps for Facility Location Decisions

In this section, the GAPIM is proposed to provide users an interactive and convenient way to make facility location decisions. In subsection 4.1, the general architecture of the platform is introduced and the implementation of each component is discussed. In subsection 4.2, the functionality and the query interface of the platform specifically for solving the static and mobile facility location problem is proposed.

4.1. Architecture of the GAPIM. The GAPIM is a web-based Java application. Since Java can be compiled into platform-independent byte codes, the platform has good flexibility and can be used on different types of operation systems. As shown in Figure 2, the platform consists of five components: *Web Client*, *Web Server*, *Application Server*, *Bing Maps Web Server* and *Bing Maps Application Server*, the latter two of which are implemented by calling the *Bing Maps* Application Programming Interface (API) [6].

The GAPIM uses the three-tier client-server architecture. The three-tier architecture is composed of the Client tier (web client), Server tier (web sever and Bing Maps web server), and Application tier (application server and Bing Maps application server). The web client is the web browser, which encapsulates the interactive map. This is responsible for showing the user interface (as HTML and JavaScript pages), gathering users requests and communicating with the web server and the Bing Maps web server. The web server is built on Apache Tomcat [36]. The functionality of the web server is implemented by using the Java Server Page (JSP) [20] language. The web server and the Bing Maps web server act as middleware to handle user requests and to transfer these requests to the application server. The application server and the Bing Maps application server are used to process user requests. Facility location optimization functions are embedded into the application server in order to handle the facility location queries. In the current version, the function to solve the static and mobile facility location problem is implemented. The database is implemented by MySQL 5.1 [27], a popular open source database software.

User requests from a web client are transferred to the web server in two ways. Requests created by operations on the interactive map in the web client are first sent to the Bing Maps web server. The Bing Maps web server then transfers users' requests to the Bing Maps application server, receives the geographical information from this application server and sends the geographical information back to the web client or to the interactive map. Other requests in the web client are sent to the web server directly. The web server handles the requests and read the related data from the database. Based on users requests, the web server either sends the data to facility location optimization methods or directly returns the data as results. The web server returns results to the web clients though two ways. The results including geographical information are written as [1]KML files and send to the interactive map in the web client. The other results are written as HTML pages and send to the web client.

[1]KML is a tag-based structure with nested elements and attributes and is based on the XML standard. It is used for expressing geographic annotation and visualization on existing or future Web-based, two-dimensional maps and three-dimensional Earth browsers (OGC, 2008).

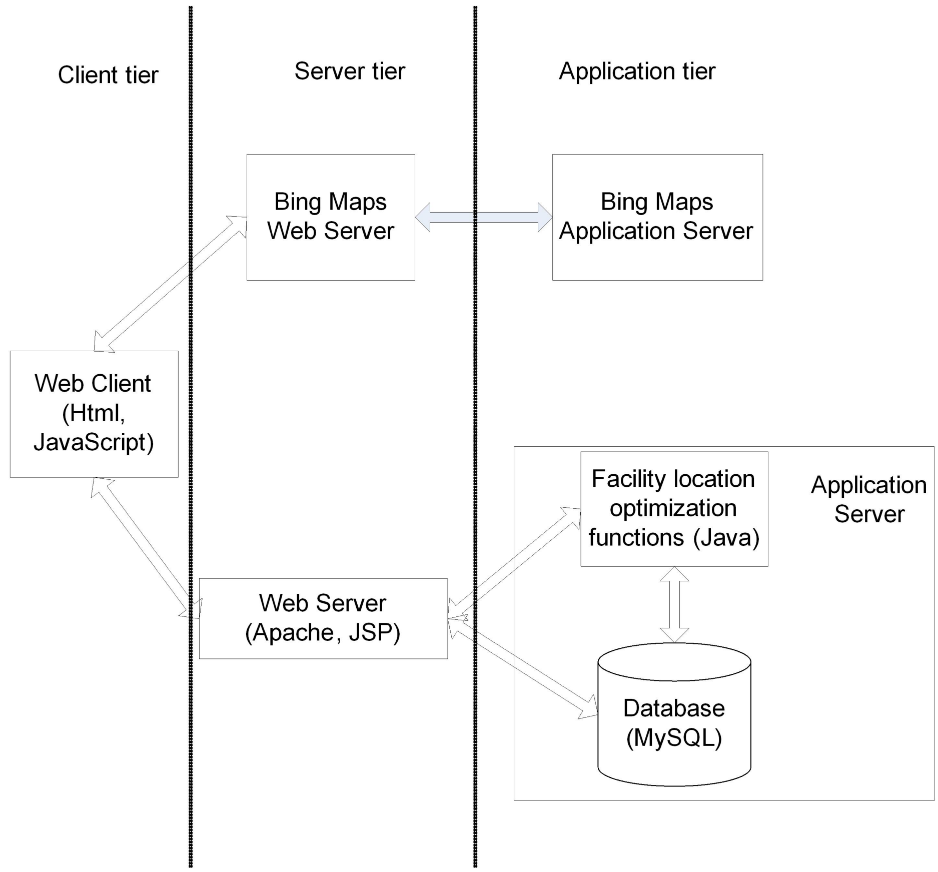

Figure 2. Architecture of the GAPIM

4.2. Functionality and querying interface for the static and mobile facility location problem. In this subsection, functionalities and query interfaces in the web client for solving the static and mobile facility location problem are introduced in detail. As shown in Figure 3, the query interface includes the following four main parts: *map control bar*, *interactive map*, *text input area* and *existing facility searching bar*.

A unique feature of the user interface (as shown in Figure 3) is that it is a web-based system with an interactive map interface, which provides users a map interface to select candidate sites for facilities directly on the map. Users also need to enter the number of static facilities and mobile facilities and the capacity of each static facility in the Text input area. The platform supports three types of selection methods on the interactive map: *Polygon Selection*, *Circle Selection* and *Point Selection*.

Polygon Selection chooses all the population centers within the polygon as candidate sites for facilities. As shown in the top left in Figure 4, users are required to right click the interactive map twice. The two points right clicked are seen as the diagonal vertexes of the searching rectangle. The locations of population centers within the searching rectangle are categorized as candidate sites used in the SMFLS algorithm.

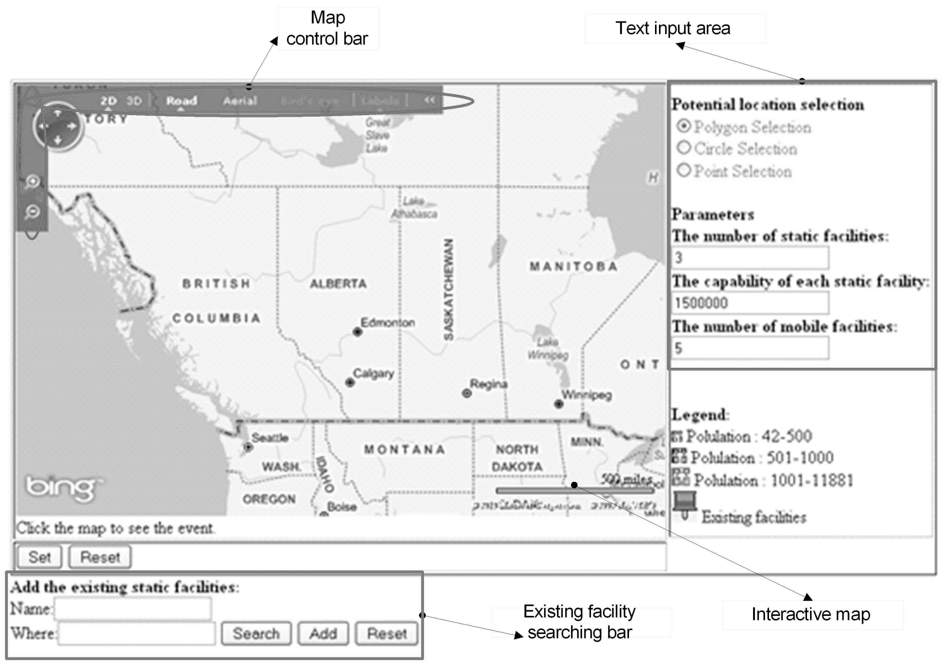

FIGURE 3. Querying interface

Circle Selection is another useful search approach for choosing population centers within an area as candidate sites. Using this approach, one can consider questions such as Which locations are best for building facilities within 5 miles of the marked location? Users are asked to right click on the interactive map to decide the centre of a circle. Then a dialog box is prompted to receive the radius of the circle. Finally, the circle and the population centers within it, are marked on the map, as shown in in the top right in Figure 4. Polygon Selection and Circle Selection provide a way that reduces the searching space of the SMFLS algorithm from all the population centers to the population centers that occur within the boundary that users draw.

Point Selection allows users to supplement candidate sites for facilities by adding several discrete locations. By zooming in to a suitable scale on the map, some qualified sites might be found and can be added into candidate sites by using point selection. For example, in in the bottom left in Figure 4, buildings and roads are represented on the map distinctly. The location right clicked by users is marked as an arrow and is added into the candidate sites. Point Selection allows users to upload coordinates of candidate sites intuitively. Based on the new candidate sites, which include some favorite locations users added, the results of the SMFLS would become more practical.

In some applications, the locations of existing facilities should be considered when new facilities are added. The GAPIM supports users to search the locations of existing facilities by using the existing facility searching bar (as shown in bottom right in Figure 4). Based on the context typed into the *Name* and *Where* dialog, the coordinate information of existing facilities can be found and pinned on the interactive map. The name, address and contact information of a facility are shown when moving the mouse over the top of the pin. The coordinates of existing facilities are transferred to the web server using the *add* button.

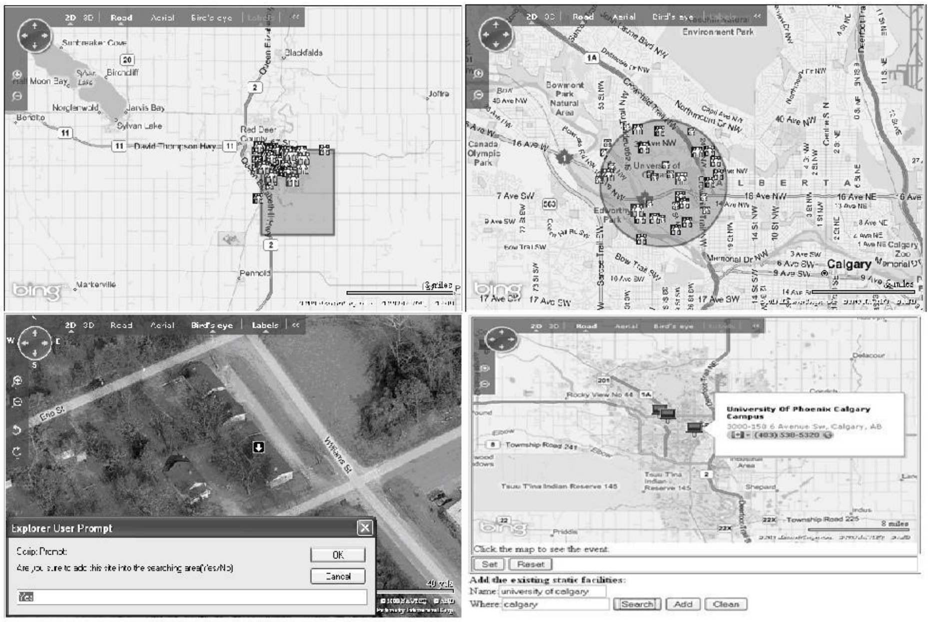

FIGURE 4. Types of operations in the web client.Top: Polygon selection(left);Circle selection(right); Bottom: Point selection(left);Existing facility searching(right)

Some map rendering functions, such as zooming and display styles setting are also provided in the Map control bar, which is inherited from the Bing Maps interface. The display styles in the interactive map are *2D*, *3D*, *Road*, *Aerial* and *Birds eye* (oblique-angle imagery). The zoom levels of the map display rang from 1 through 19 in the interactive map.

5. Experiments

In this section, we evaluate the GAPIM by applying it to a real application, building the emergency medical service system in Alberta, Canada. The problem is to add three hospitals and two ambulances into the existing emergency medical service system in Alberta. The locations of the new added hospitals and ambulances seek to minimize the average travelling distance (i.e., the value of equation (1)) and the maximum travelling distance (i.e., the value of equation (2)) for people to get the medical service. Thus, the static and mobile facility location model is chosen to solve the problem. The population center dataset is from 2006 Canadian census data at the Dissemination area (DA) level [11]. The location of DAs is estimated by Postal Code Conversion File (PCCF) [31]. 5180 DAs are used in the research, whose population values range from 42 to 11881. The total population in the province of Alberta is 3,262,075. In the following, the capability of each hospital is the number of residents could be assigned to that hospital but not the maximal number of patients could get medical service from there simultaneously. We use the Euclidean distance between two locations to represent the travelling distance between them [17].

Alberta Health Services (AHS) [1] is the province-wide organization responsible for providing hospital and other health care in the province. The AHS has two types of facilities, hospital and ambulance, to provide emergency medical service. In this case, we seek to locate new hospitals and ambulances in Alberta while considering the locations of the existing hospitals. Since the locations of ambulances could be changed easily, the locations of existing ambulances are not considered. The name list of the existing 20 hospitals in Alberta is extracted from Alberta Health Services. The capability of each hospital is set at 150,000 (the average capability of the existing hospitals). The location information of each existing hospital is searched by using the existing facility search bar.

Figure 5 shows the optimal locations of hospitals and ambulances chosen by the GAPIM, while the existing 20 hospitals are taken into consideration and all the population centers are added as candidate sites. Three hospitals are located on the eastern border of the province, northwest of the province and the centroid of the province (between Edmonton and Red deer). Two ambulances are located in the northwest of the province and in the south of the province (near Lethbridge). As expected, the newly located static and mobile sites are in the area where it is inconvenient to access services from existing facilities. The average travelling distance is 56.4 km, the maximum travelling distance is 584.0 km and the execution time is 180 seconds.

The right picture in Figure 6 shows the optimal locations of hospitals and ambulances chosen by the GAPIM, while the existing 20 hospitals are considered and only the locations of interest to users are added as candidate sites. The locations of interest are input by point selection (as shown in the left picture in Figure 6). The three hospitals are located in the three biggest cities: Edmonton, Red deer and Lethbridge. The two ambulances are located in the northwest of the province. Compared with Figure 5, the result that takes into account the locations of interest to users is more reasonable since the hospitals are not located in remote areas. The efficiency and equity of facility configuration in Figure 6 is better than that in Figure 5 since in the former, the average travelling distance is reduced to 34.0 km, from 56.4 km, and the maximum travelling distance is reduced to 532.0 km, from 584 km. The execution time is 2.3 seconds, down from 180 seconds.

In conclusion, the application in Alberta province proves the efficiency and usefulness of the GAPIM. First, the GAPIM allows users to add spatial constraints on the facility location searching methods. Specifically, the SMFLS algorithm only searches the candidate sites within the points and areas of interest that users have selected instead of searching all the candidate sites in the entire area. This reduces the size of candidate sites and that reduces the execution time to an acceptable level (i.e., 2.3 seconds in the right picture in Figure 6. Second, the GAPIM can produce better results by counting locations of interest that have been input by users. For example, the values of the average travelling distance and the maximal travelling distance in the right picture in Figure 6 are lower than those in Figure 5. Third, the GAPIM has the capability to take into account existing facilities while in the process of locating new ones.

6. Conclusion and future work

In this paper, a Geospatial Analysis Platform with Interactive Maps (GAPIM) is proposed for solving the static and mobile facility location problem conveniently and efficiently. First, we formalize the problem as a bi-objective model in terms of efficiency and equity. Second, a heuristic algorithm, named SMFLS is developed to solve the model. In order to solve the model for large datasets efficiently, the

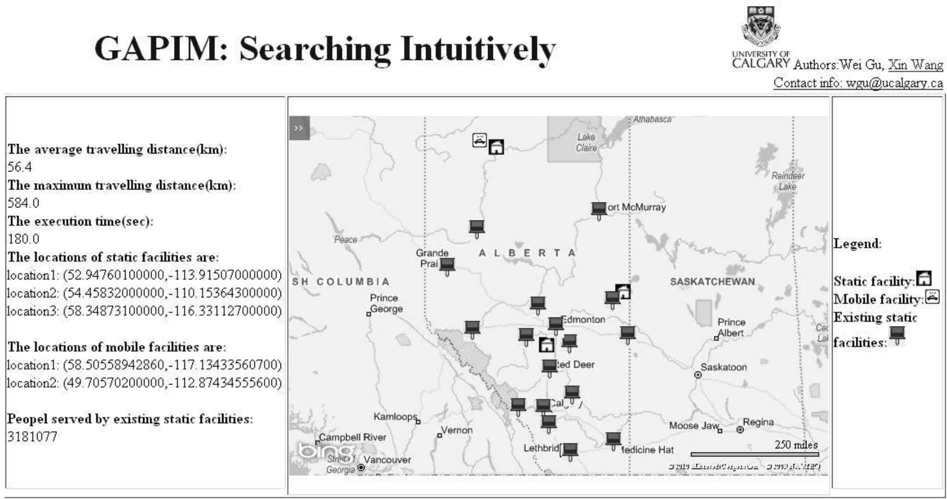

FIGURE 5. Locating three hospitals and two ambulances using the GAPIM while taking into consideration the existing emergency medical service system and adding all the population centers as candidate sites

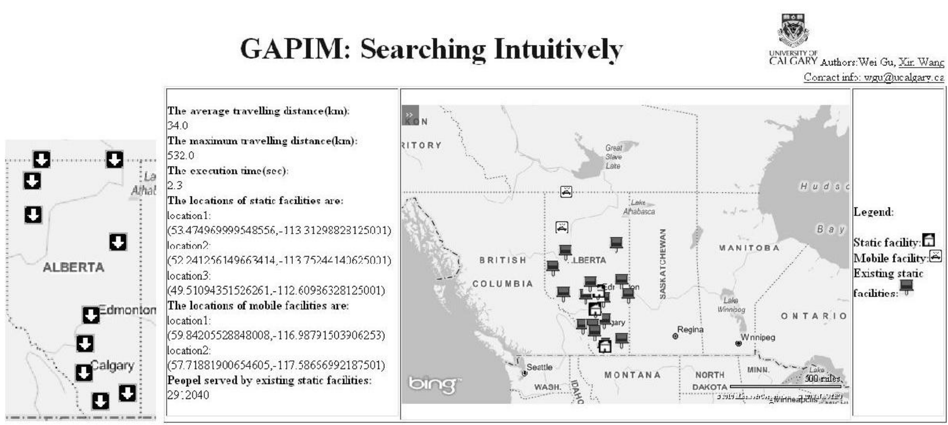

FIGURE 6. Locating three hospitals and two ambulances using the GAPIM while taking into consideration the existing emergency medical service system and only adding the points interested to users as candidate sites. Left:Point selection;Right:Searching result

SMFLS algorithm adopts a clustering-based heuristic method to do the static facility location searching and a greedy heuristic method to do the mobile facility location searching. The clustering-based heuristic method separates the candidate sites of static facilities into different clusters and then reduces the searching space for each static facility from the candidate sites in the whole area to the candidate sites in the cluster where the static facility occurs. Third, the GAPIM is developed by encapsulating the bi-objective model and the SMFLS algorithm as a facility location optimization function and calling the Bing Maps API as an interactive map for gathering geographical data and user queries. To our knowledge, the GAPIM is the first web-based platform to handle facility location problems by integrating facility location optimization functions with interactive maps. The platform provides users a simple interface for entering geographic information and constraints, which enhances public participation and collaboration in the facility location decision-making processes. In addition, the platform is designed to be extensible such that additional location models, algorithms and operational procedures can easily be integrated. The preliminary experiments have proved the efficiency and usefulness of the GAPIM. The experimental results show that the GAPIM reduces the execution time for determining the optimal locations of static and mobile facilities, and has the ability of taking into account existing facilities.

In the future, we would like to extend and apply the GAPIM to a specific application by adding more domain knowledge, such as capital cost and operating cost. In addition, we seek to introduce a pre-processing method and spatial data index in our algorithm to reduce the execution time further. Finally, travelling time and travelling distance would be used to replace the Euclidean distance.

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