Integrating Location Models with GIS in a Sitting Support System

Malick M. Ndiaye[1], Ismaila Abubakar[2] and Shaikh Arifusalam[1]
[1] Systems Engineering Department,
[2] City and Regional Planning,
King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia
Correspondence address: mndiaye@kfupm.edu.sa

Abstract
Reasonable and useful information can be analysed and presented through a Geographical Information System (GIS) for any desirable spatial application. This paper considers the problem of opening new facilities in the presence of competing firms. We build a Spatial Decision Support System (SDSS) that link together selected information from the database of a GIS with a mathematical decision model which is based on the Maximum Capture model (MaxCap) that support the process of selecting the optimal locations for the facilities. The problem of opening petrol stations is considered as a case study to illustrate the design of the DSS and how quantitative and qualitative decisions factors can be taken into consideration to illustrate customer's behaviour while patronizing a given outlet.

Key Words: GIS, Decision Support Systems, Location Analysis; Maximum Capture Models.

1- Introduction

The importance of Locational Analysis does not need to be reiterated as a considerable amount of scientific research has been dedicated to the subject [1, 2]. Various mathematical models, solution methods and applications have been developed to the satisfaction of decisions makers in locating public or business facilities. Indeed one of the most critical decisions in the process of starting a new business is to find an efficient location that will best support the objectives of the proposed business. It's not unusual that a business failure is due to its "bad" location. Thrall et al. [3] mentioned a good location as one of the most important competitive advantages that a company can possess. The strategic importance of site location operations has been given careful thought and different approaches and models have been developed over time to assist decision makers in minimizing potential mistakes.

The emergence of GIS and its development have revolutionized the urban and facilities planner's mode of working and their art of decision making. The field of GIS is currently expanding at a tremendous rate due to its innumerable benefits, and its applicability is found in many fields including urban planning, environmental management, transportation, engineering, and medicine among numerous others [13, 14,]. It offers new research perspectives to various academic fields and has evolved beyond the initial stages of data management and mapping, and has advanced into spheres such as modeling and analysis thus facilitating spatial decision making [4]. Furthermore, GIS is nowadays being implemented not only as a standalone system but integrated into other systems. The system supports different types of analysis and provides agencies, organizations and institutions in the urban area with a more powerful decision support tool to make more informed decisions regarding facilities location. Municipalities and cities are now actively using GIS for location and management of most public utilities, facilities and services: water supply, sewage collection and treatment, electricity and telecommunication networks, land use planning, police and fire dispatching and routing, etc.

Many research projects have explored the potential of using GIS to take input from user, store spatial data, and perform an analysis and display the outcome in a map. For example, GIS has been used to quickly and reliably process spatially referenced data as a decision support tool in facility location. Cheng et al [5], present GIS utility for finding a solution to selecting a location for a shopping mall where queries are set to find the optimal location using four location problems, viz: minimum distance; maximum demands coverage; maximum incomes coverage; and optimal centre. Gemitzi et al [6] also used GIS to deal with a problem of siting areas for construction of stabilization ponds for domestic wastewater treatment using suitability variables, such as topography, land use, type of geological formation, distance to major rivers or lakes, distance to existing cities and villages, existence of environmentally protected areas, mean minimum monthly temperatures and required wastewater effluent characteristics. For each variable mentioned, a grid file was created and use in grid analysis. The result is a composite map, which highlights the areas that satisfy all the suitability criteria. Integration of GIS application with other models has also been on the increase. For example, a research by Wang [7] integrates GIS with simulation model and developed a prototype system of traffic impact analysis. In the research, GIS is used to prepare data and execute the models and present the modelling results in a geographic context. Another project by Altmann et al [8], integrates a mathematical model with GIS to assess the potential of locating an 'Energy Tower' for production of electricity in Australian continent. The project analysed some important parameters that affect the power production of the Energy Tower into the model, which enables the ranking and selection of promising sites. Our work here is a contribution in that same line, integrating location decision methods with a GIS.

In the next section we present a literature review in the field of location and the maximum capture model (MaxCap) in particular; we also introduce a modified version of it that take into consideration the service levels at the different outlets. In section 3 we describe the integration phase in which we highlight the way we linked the GIS to a mathematic solver (Cplex). We present in section 4 a case study to illustrate how one can navigate through the different pages of the SDSS to use it as a decision tool. Finally some new perspectives are presented in the concluding section.

2- The Maximum Capture Models

In the context of private sector facilities location, studies that take into consideration competition between operators have been mainly developed to help evaluate market shares after all competitors have entered the market. The first model on that respect was introduced by Hotelling [9] which assumes that consumers will (always) patronize the nearest open facility. Since then various models using this assumption have been developed. One such case was a multi-facility version in which a new operator seeks to open simultaneously *p* new facilities among a given set of potential sites. In 1986, Revelle [10] presented the Maximum Capture Model (MaxCap) in which a new competing firm *A* seeks to locate *p* new stores in a spatial market where others *q* existing firms are already operating; it is assumed that all existing facilities belong to the same firm say *B*. The new firm *A* is looking to maximize its market share.

Our proposed model when compared to traditional Maxcap models has few differences. If a facility satisfies to be the closest to a given demand area, only a prorated demand equal to its attractiveness will patronize it, the rest or residual demand, will choose to use the competing firm *B*. And In case competing firms located at equal distances to a customer, the later will chose to shop at the one that offers the highest service level and not necessarily the oldest one as previously considered. So we introduce a Maximum Capture model that takes into account the service level at each outlet (MaxCap SL).

The model can be described as follows. Let the market be represented by a connected and undirected network G= *(V, E)* with node set *V* and arc set *E*. The objective is to open *p* new facilities out of a subset of potential sites *J* in *V,* in order to maximize the market capture for the entering firm. This is done by reallocating clients to their nearest open facility given the service level available at each site.

The MaxCap SL model is presented as follows.

$$Max \sum_{i\in I}\sum_{j\in J} a_i \alpha_j \rho_{ij} x_{ij} + \sum_{i\in I} a_i (1-\alpha_{b_i})\left(1-\sum_{j\in J}\rho_{ij}x_{ij}\right) \quad (1)$$

subject to

$$\sum_{j\in J} x_{ij} = 1, \qquad \forall i \in I \quad (2)$$

$$x_{ij} \le y_j, \qquad \forall i \in I, \forall j \in J,$$

$$\sum_{j\in J} y_j = p, \quad (3)$$

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

Where

I, I = Set of existing demands all assumed to be located at the vertices of the graph.

J, J = Set of potential locations for the new petrol stations.

p = Number of outlets to be effectively open by firm *A*.

Q = Number of outlets existing of firm *B*.

a_i = Demand at node *i*.

b_i = Set of actual locations of q firm B's outlet in j.

$$\rho_{ij} = \begin{cases} 1 & \text{if } \mathrm{d}_{ij} < \mathrm{d}_{ib_i} \\ 0 & Otherwise \end{cases}$$

$$x_{ij} = \begin{cases} 1 & \text{if demand node i is assigned to node j} \\ 0 & Otherwise \end{cases}$$

$$y_j = \begin{cases} 1 & \text{if a new outlet is opened at node j} \\ 0 & Otherwise \end{cases}$$

The objective function (1) has two components. The first is the total demand attracted by the new firm *A* from the customers that directly have patronized its outlets ($\rho_{ij}x_{ij}$=1). The second term is the residual demand attracted from its competitor firm *B*. That is for any demand node that is not allocated to the new firm *A* ($\sum_{j\in J}\rho_{ij}x_{ij} = 0$), a residual demand of $a_i(1-\alpha_{b_i})$ from firm *B* will be allocated to *A*. The constraint set (2) force each demand node to be allocated to only one open site at a time, but allocation can only be made if an outlet is opened at node j (3). The constraint (4) fixes the number of new outlets to be exactly p.

3- Model Integration into DSS

The proposed decision support system is built using complete integration of all the components in a way that once the parameters are given, the end user does not formally see or interfere with the process of finding the optimal solutions. Basically, the end user has initially to enter a series of new information related to the pre-selected sites, the level of initial investment on each site and the number of outlets to be opened. The GIS database is then updated to include the new data. After that a series of files are generated from the GIS database to be pre-processed using an executable C++ program which in return will generate all the files required by the mathematical solver (Cplex). The solver then calls the MaxCap SL model to optimally determine the new locations. An output file that contains the location of the selected sites is created and sent to the GIS to display them.

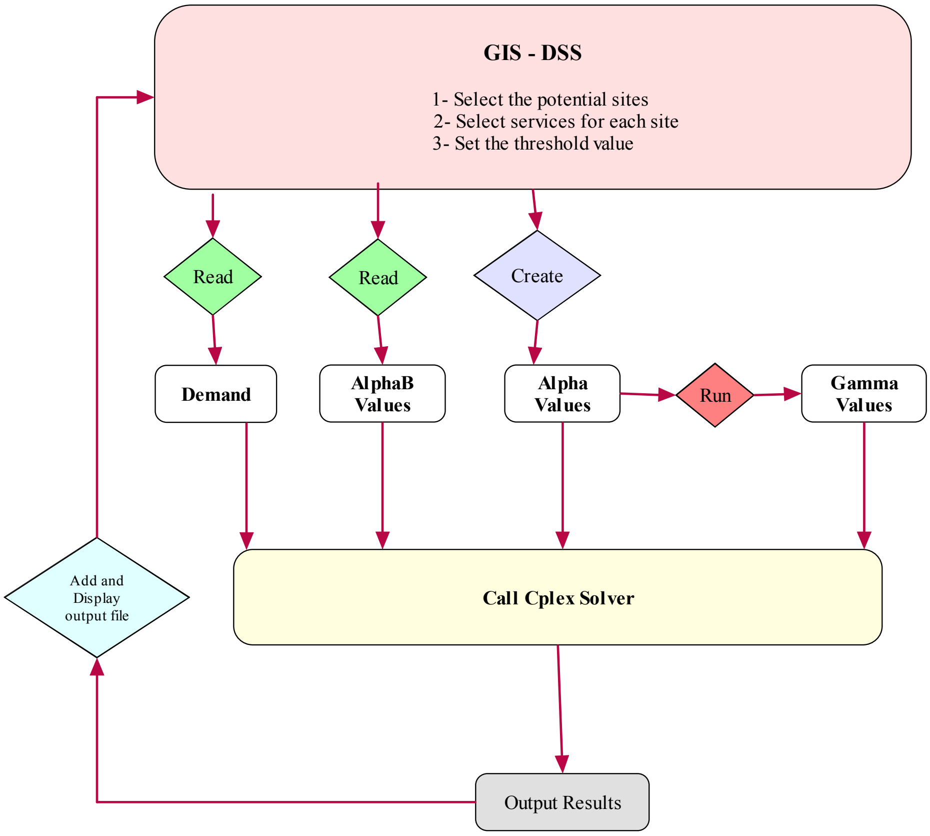

Fig.1: Full DSS integration chart

More details about the integration phase are provided in the following case study which is used to illustrate the different steps the end user has to go through to utilize the SDSS.

4 - Case Study

In the Saudi Arabia, the use of GIS technology is growing rapidly and is being widely used in the management of land uses, infrastructure, and public facilities by governmental agencies, municipalities and diverse companies [10, 11]. The main objective in this section is to illustrate the linking together of the developed mathematical model (MaxCap SL) with GIS and a mathematical solver to build a decision support system for siting petrol station in Dana residential district in Dhahran, Saudi Arabia.

In the case of the location of retailing facilities like petrol filling stations, a large number of criteria should be taken into consideration before exercising any effective decision-making. The criteria include among others, the road network accessibility, the fuel storage capacity, the onsite services offered, the presence of competition and the presence of driving factors. All these factors have clear impact on the number of potential users. Other characteristics considered for this particular market are as follows.

- All firms are marketing exactly the same product delivered to them by the same supplier, that is in our case, the Saudi national oil company (Saudi ARAMCO).
- There is (almost) no price competition between firms.

One reason for choosing a residential area is to minimize the impact of the added demand due to irregular local traffic.

4.1 Input Data

The considered study region has been clustered into 56 different demand areas that form a network of nodes and arcs. The demand associated to each demand area corresponds to the numbers of house blocks in that area. All existing petrol stations in the district, 4 in total, are assumed to belong to the same firm *B* and are located at demand areas {7,27,46,56}. All their features (capacities, road access, presence of a nearby supermarket, onsite service) were evaluated to estimate their corresponding service level α_j. We assume then a competing firm *A* is looking to open *p* new outlets out of the 56 potential sites.

Table 1: Demand for the Network

Node #	Demand	Node #	Demand	Node #	Demand	Node #	Demand	Node #	Demand	Node #	Demand
1	30	**11**	36	**21**	36	**31**	10	**41**	40	**51**	17
2	34	**12**	22	**22**	32	**32**	8	**42**	34	**52**	19
3	36	**13**	30	**23**	41	**33**	40	**43**	36	**53**	12
4	28	**14**	34	**24**	26	**34**	42	**44**	41	**54**	9
5	40	**15**	14	**25**	24	**35**	40	**45**	23	**55**	9

6	28	**16**	54	**26**	45	**36**	32	**46**	23	**56**	11
7	13	**17**	30	**27**	50	**37**	49	**47**	38		
8	32	**18**	50	**28**	18	**38**	45	**48**	28		
9	36	**19**	48	**29**	12	**39**	6	**49**	42		
10	33	**20**	28	**30**	17	**40**	55	**50**	35		

4.2 Implementation and solution procedure

In this section, the different procedures used to run the SDSS program is provided. The first part explains the development of the GIS database and files used in the SDSS. In the second part, all the steps for running the SDSS in its integrated version are provided in details.

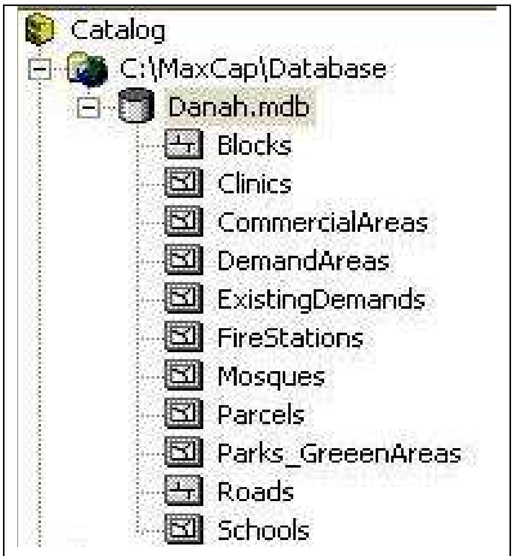

Fig 2: Data files in the developed GIS

A. Geodatabase Development: The first part was to develop the GIS geodatabase, and design user-interface windows and buttons. This involves the following steps:

1. The first step was to convert the AutoCAD files of Danah area into a format suitable for GIS (that is shapefile format). The converted parcels were initially in polyline which were converted to polygons using ET tools.
2. The features were then separated into parcels, schools, clinics, mosques, commercial areas and open/sports grounds and converted into shapefiles for use as separate layers

3. The parcels layer shows all the parcels available in Danah. Each parcel is denoted as one demand area. (The constraint is that one could not specify whether the parcel is vacant or used for some other purpose).
4. The area was also digitized into number of demand areas depending upon service level, accessibility. This was done on a different layer named demand area.
5. the road network in the area was also extracted and roads were categorized into highways, major roads and streets
6. Lastly, a personal geodatabase is created using the shapefiles in fig. 2
7. Three buttons are also created (fig. 3): 'START' for starting the program; 'THRESHOLD' for setting the threshold value; and 'SOLVE' for providing a solution to the SDSS
8. Three frames are also created for choosing a proposed site to locate a business, types of facilities on the site and the threshold distance which is the maximum extra distance a customer is ready to travel to patronize the next best competitor.

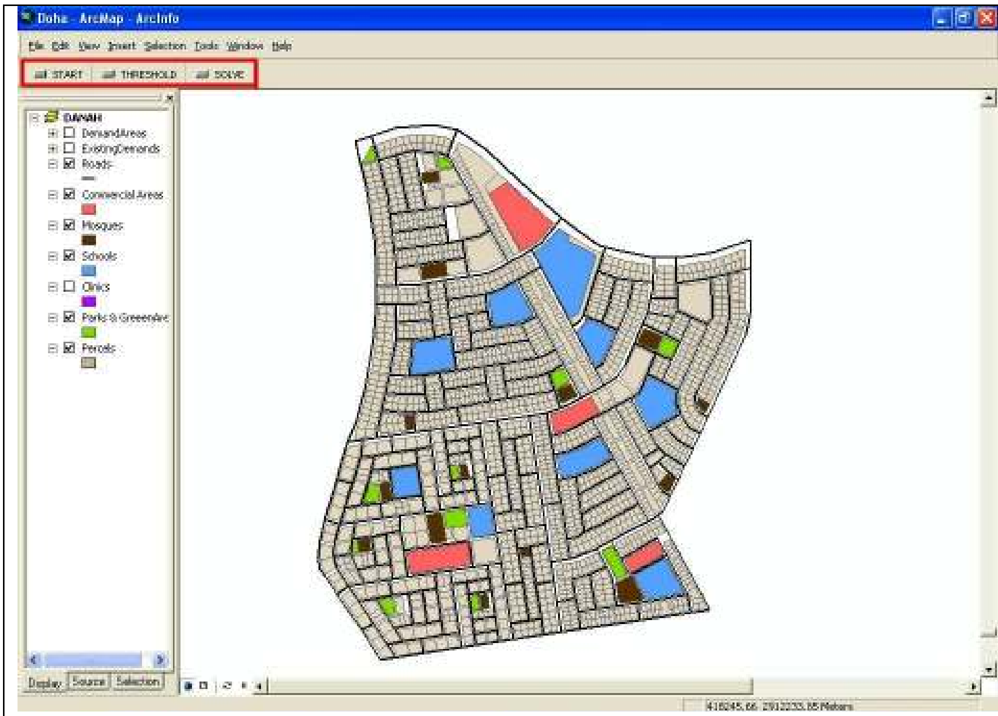

Fig. 3: 'Start', 'Threshold' and 'Solve' buttons

B. Running the Program: The program is run through the following steps:

1. At the beginning of the program, user clicks START button to launch the program. He will be greeted with the following message in a pop-up window shown in fig. 4

"Please Select The Sites You Would Like To Locate Your Petrol Filling Station"

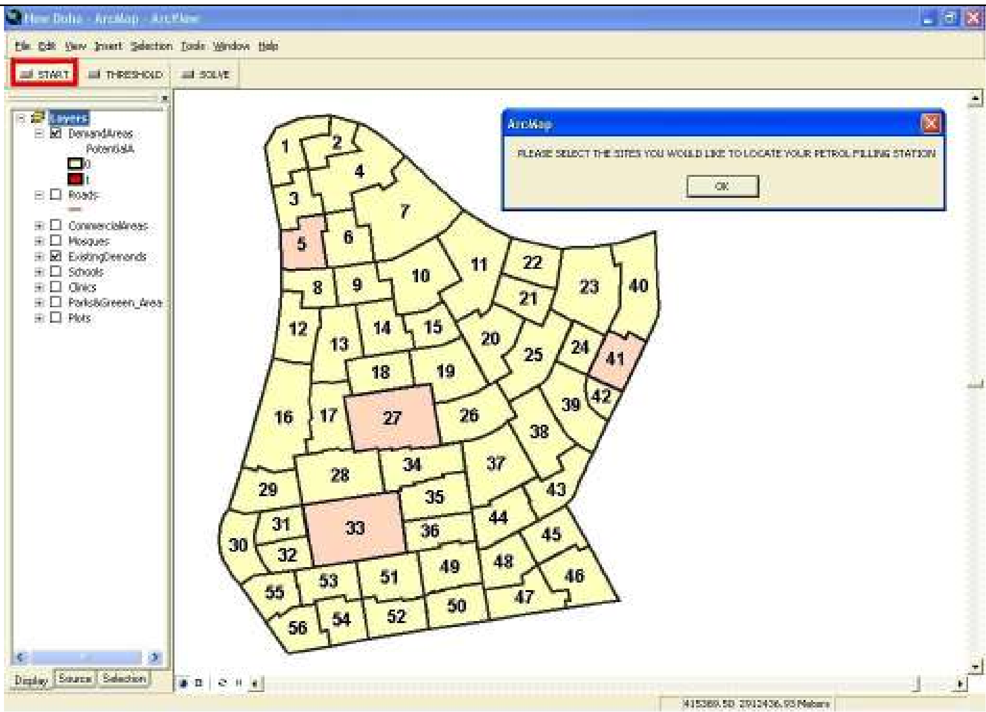

Fig 4: Starting the SDSS Program

The user then clicks OK and continues to the next stage

2. Then a frame is displayed to prompt the user to choose from combo boxes the potential locations, as many as he wants to select. In the presented example, the user chooses five sites **5, 15, 25, 35** and **45** (fig. 5). The total sites are presently 56, but can vary depending on the database and study area. User can also decides to deselect a site if he changes his mind by clicking it again or clicking the CLEAR button as shown in fig 5.

3. For each chosen site, the user indicates the type of facilities he wants to locate on that potential sites the options are as follows:

- Accessibility to the site: roads
- Capacity of the potential station: number of pumps, tanks, service men
- Driving factors: supermarket, malls ,
- Onsite services: car wash, car service, tire works etc
- Others: restaurant, ATM
- Presence of competing petrol stations

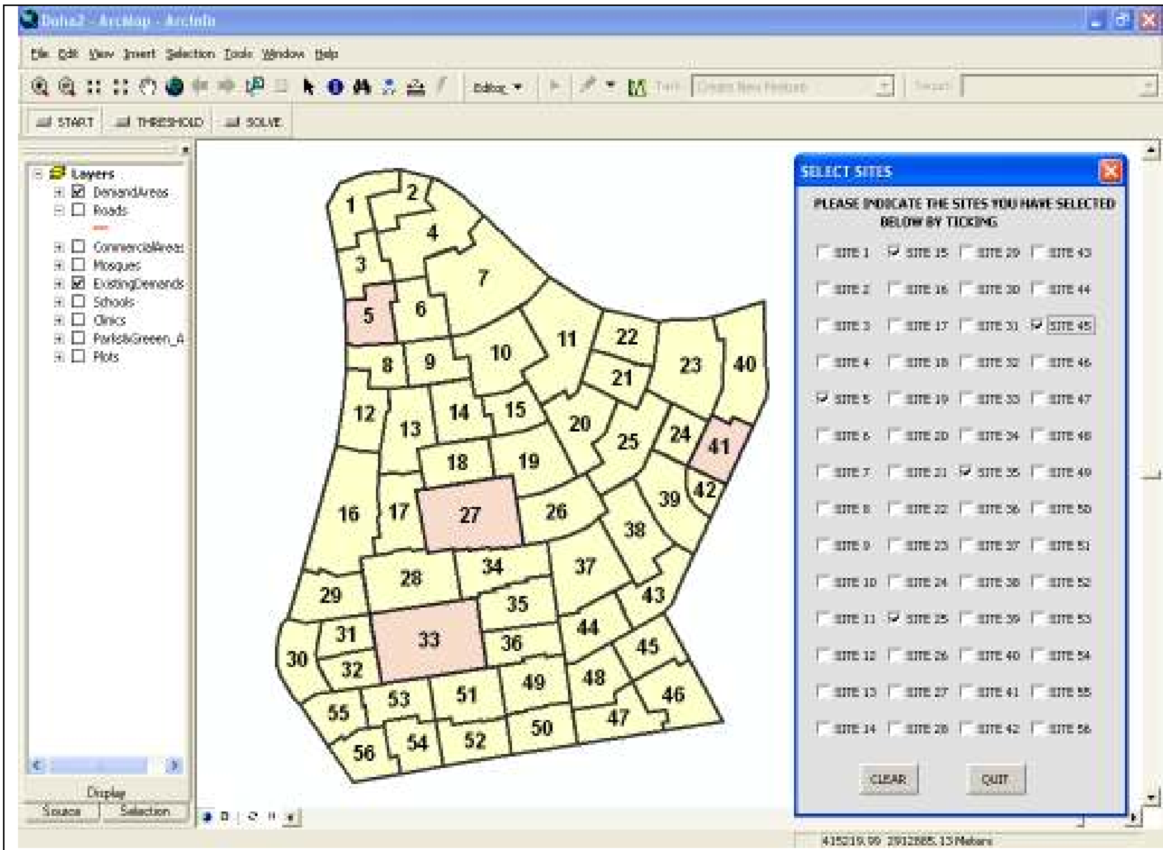

Fig. 5. Selecting the potential sites

After choosing the facilities, user clicks SEND and a value called Alpha value is calculated by the system and stored in a text file against the chosen site. The QUIT button is used when the user has finished selecting facilities. See the fig. 6

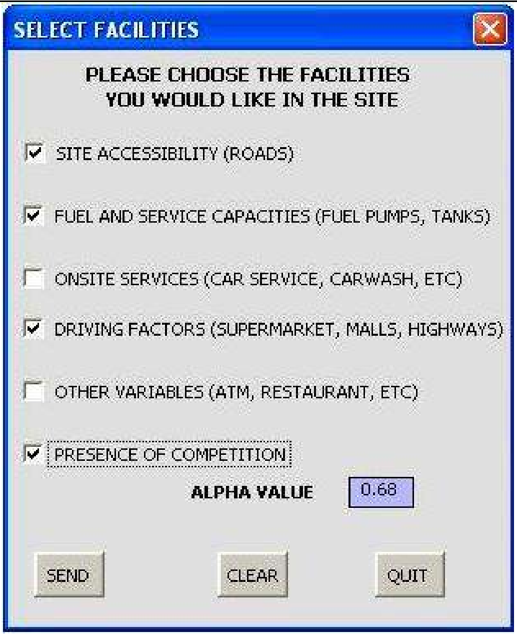

Fig.6: Selecting the services that will be offered on each selected site

4. After the user has finished selecting the potential sites and the proposed facilities, then he is asked "HOW MANY SITES DO YOU WANT TO OPEN OUT OF THE SELECTED ONES". He enters a value and clicks "OK". In this case, the user is interested in opening two petrol stations in Danah as shown in fig. 7. He can change his mind and write another value by retyping another value. After selecting that the chosen value is stored in a text file as input into the CPLEX program.

Fig 7: Choosing the number of petrol station to open

5. The last step is when user clicks SOLVE button**,** the following actions takes place:

a. Text files are created, as input into the CPLEX program containing:
b. The list of the 56 potential nodes
c. The number of demands in each of the 56 potential nodes
d. The list of the 4 existing nodes
e. The number of demands in each of the 4 existing nodes

The CPLEX program is run which takes all the text files as input and solves the program. The program generates the result as an Excel file that is used by the GIS for displaying the selected sites as in the case study in fig. 9 which shows the optimal locations of siting the two proposed petrol stations in red color

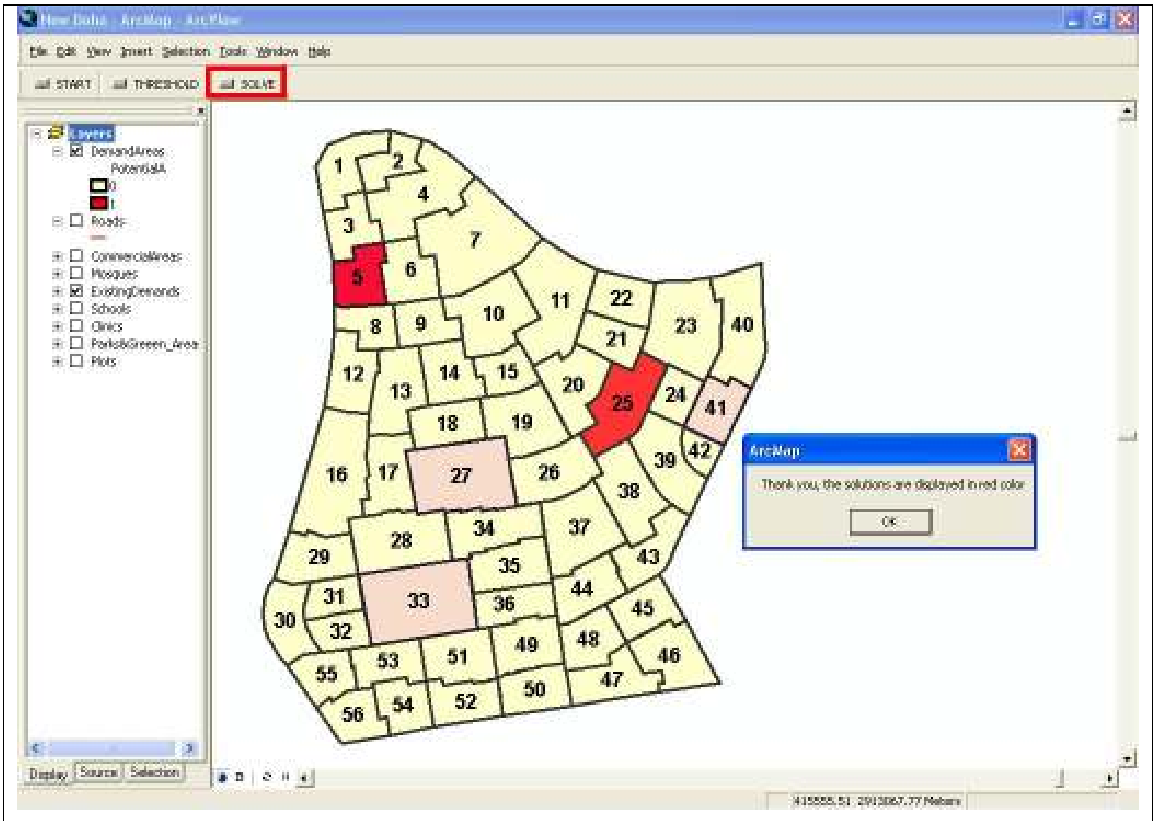

Fig. 9. Selected sites are displayed

4.3 Results and Discussion

The work as carried out provides a good framework for integrating decision analysis tools with a geographical information system. From the GIS database one can easily extract quantitative data as well as qualitative data (given that they are available). A GIS provides also the possibility to perform some pre-analysis and in case of facility location one can survey the area to select the potential sites. A GIS also allows to define at will aggregated areas of studies and as need be, extract all the data related to them.

This SDSS can be modified and incorporated as it is in a real GIS; It can assist at a city level for instance to contribute in making rational planning decisions. In many countries there are strict governmental regulations to be followed for opening new petrol stations. Such regulations deal with safety concerns (which usually try to ovoid very populated areas) as well as the allowance of a minimum distances between open outlets to guarantee a minimum demand to each open outlet. Such regulations can easily be integrated in an extended version of this work to allow full decision support in locating such facilities.

One can also easily extend this work to other type of public facilities, like clinics, parks and schools, for which governmental regulations apply in a similar way as for the location of pump stations. This will make such facilities more accessible to the public and hence they would be more utilized.

6- Conclusion

We have examine in this paper a spatial decision support systems which allows the end user to select the best locations for opening new outlets in the context of a competitive market. It provides the opportunity to test different scenarios in a short time by assessing for instance different levels of services or different sets of potential locations.

This work opens the possibility to consider other applications in location science and GIS applications. Solutions methods also be developed to include the already reach analysis tools offered by a basic GIS software. It allows tailoring solutions to match more specifically users' needs. We intend to address these issues in our future research.

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Dr Malick M. Ndiaye (PhD) is an Assistant Professor in the department of Systems Engineering, King Fahd University of Petroleum and Minerals, Saudi Arabia. He holds a PhD from the university or Bourgogne in France and Master's degree from the University Paris 1 la Sorbonne (France). His research areas cover Operations Research, Optimization, Location Theory and its applications to GIS, and Convex Analysis. Several of his research interests have received Research grants funded by the "Capital Region of Brussels", location of semi obnoxious facilities and The University of Birmingham, UK among others. He taught courses in the areas of Linear and Nonlinear optimization, Operations Research, Facilities Location and Layout Design. Dr M. Ndiaye is a member of the Euro Working Group on Location Analysis. He can be contacted at mndiaye@kfupm.edu.sa

Ismaila Abubakar is a strategic planner with King Fahd University of Petroleum and Minerals (KFUPM), Saudi Arabia. He has a Bachelor of Urban and Regional Planning, MSc. Computing from The Robert Gordon University, United Kingdom and a Master of City and Regional Planning from KFUPM. He was a lecturer in the department of Urban and Regional Planning, Ahmadu Bello University Zaria, Nigeria. His research interests are in planning support systems, urban growth management and environmental planning and sustainability. He can be contacted at ismail@kfupm.edu.sa

Mr. Shaikh Arifusalam is Lecturer in the department of Systems Engineering. He obtained his M.S. from the Systems Engineering Department, KFUPM, Dhahran, KSA in Industrial Engineering. His major area of research includes operations research, scheduling and simulation. He has been a member in many of the university projects. He taught introductory course for technology, taught different labs in the areas of methods engineering, human factors engineering and stochastic systems simulation. He can be contacted at arif@kfupm.edu.sa