An Interactive Spatial Decision Support System Enabling Co-Located Collaboration using Tangible User Interfaces for the Multiple Capacitated Facility Location Problem

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ABSTRACT

The Multiple Capacitated Facility Location Problem (MCFLP) is a well-known and studied in the international literature optimization problem. The geographical information data of the enterprises' locations are usually either ignored by the modeler or entered manually in these systems. In this paper, a spatial Decision Support System (DSS) is designed and implemented enabling co-located collaboration using tangible user interfaces through a tabletop. The location of the enterprises and the demand nodes can be added with the use of interactive Google Maps. The DSS extracts the geographical information of the selected locations, find the distances between them and executes a dynamic approximation algorithm for this problem. The interactive spatial DSS has been implemented using Java, TUIO protocol and Google Maps. The tabletop offers a user-friendly interface that can be manipulated with human fingers and fiducials.

Keywords: Decision Support System, Capacitated Facility Location Problem, Tangible User Interface, Geographical Information System, Location Allocation Problem.

1. INTRODUCTION

The facility location (or location-allocation) problem is a well-known operations research problem. The problem consists of a number of enterprises that attempt to find the best location in a specific area in order to install their new facilities while on the same time a number of already established similar facilities exist with known locations (Drezner et al., 2002; Aboolian et al., 2007). New enterprises seek the best location from a set of candidate locations in order to maximize their share and revenue in the specific market. The new enterprises cooperate with each other in order to avoid any overlapping between the market segments they will serve. The facility location problem has many practical applications in different fields, such as supply chain management, air-traffic control, web-server placement, capital investment etc. (Drezner & Hamacher, 2001; Marianov & Serra, 2002; Revelle et al., 2008; Melo et al., 2009).

The international research community offered many variants and extensions of the problem over the years; in this paper, we consider a particular type of the problem, called the Multiple Capacitated Facility Location Problem (MCFLP). In this version of the problem, the market requires a specific quantity/level of a product/service in a determined time period. A set of existing enterprises operate in a specific market producing/offering certain products/services. A set of new cooperating enterprises aim to enter the market and seek the best location from the available candidate locations. The goal of the new enterprises is to obtain the largest possible share of the specific, saturated by the present supply, market by avoiding on the same time any overlapping between the market segments that they will serve. The enterprises should be economically viable in order to enter the market. As such, the production of a new enterprise should be higher than a specified sales threshold level (Shonwiller & Harris, 1996). Existing enterprises should also ensure to be economically viable; if they fail to reach their production thresholds after the entering of the new enterprises, they will be taken off the map (Serra et al., 1999).

Only few software packages exist for the solution of facility location problems (Bender et al., 2002; FLP Spreadsheet Solver, 2014; Sitation, 2014). The geographical information of the enterprises' locations is usually either ignored or entered manually in these systems. Geographical Information Systems (GIS) can assist decision makers to analyze spatial information. GIS technologies have attracted significant attention from researchers. There are a few papers that proposed integration of GIS technologies on DSS for location problems (Lopes et al., 2008; Santos et al., 2011). Google Maps API provides access to read data associated with roads and supplies travel times for each road based on the speed limits.

This paper is an extension of the work of Papathanasiou et al. (2014) and Ploskas et al. (2014), in which we presented a web-based DSS that can assist policy makers find the best locations for their enterprises and discussed implementation issues for integrating GIS technologies on a spatial DSS, respectively. Two algorithms have been developed in the DSS of our previous work (Papathanasiou et al., 2014): (i) an algorithm that finds the exact solution of the problem so long as this exists, and (ii) a dynamic approximation algorithm that can calculate an approximation solution in an acceptable time interval. These algorithms have been proposed by Papathanasiou and Manos (2007). The innovation of this paper is that we develop an interactive spatial DSS with tangible user interfaces through a tabletop that supports decision-making and integrates geographical information data in the DSS for the MCFLP. The coordinates of the locations are not entered manually in imaginary vague market, but they are added with the use of an interactive map through fiducials in a real market (fiducials are markers used to recognize an object on a tabletop). Then, the DSS

extracts the coordinates of these locations and builds a market surface, which is simulated by a network with existing facilities nodes, demand nodes and candidate nodes. The spatial DSS was implemented using Java, TUIO protocol and Google Maps.

The structure of the paper is as follows. Section 2 presents some key features about the tangible user interfaces, a brief review of the use of tangible user interfaces on decision-making process, the principles of the constructed tabletop and the reason to choose such an interface. Section 3 briefly presents the mathematical form of the problem and the algorithm used to solve it, while in Section 4 the analysis and implementations steps of the spatial DSS are presented. Section 5 presents the proposed interactive system through a representative example. Finally, the conclusions of this paper are outlined in Section 6.

2. TANGIBLE USER INTERFACES

An interactive tabletop computer is a computing device that offers a large, horizontal digital display and enables one or more users to input commands to the device by interacting directly with the display surface (Scott et al., 2010). Fitzmaurice et al. (1995) were initially referred to the term graspable interfaces in 1995. The term tangible was later introduced by Ishii & Ulmer (1997) in 1997. The key idea of the tangible interfaces is the replacement of the traditional input devices (e.g. mouse, keyboard) with more natural and interactive devices, called fiducials. Two types of fiducials exist, active and passive ones. Passive fiducials are images that can be recognized through a camera. An example of a passive fiducial is shown in Figure 1.

Figure 1: Example of Passive Fiducial

The tabletop has been designed and constructed from scratch. The key design features of this tabletop are (for a more detailed description, see Athanasiadis, 2014):

- From the available technical solutions to construct a tabletop, Diffused Surface Illumination (DSI) was selected, because it recognizes objects and fiducials and there are no illumination hotspots due to the even illumination throughout the surface.
- Height of the tabletop: 85 cm.
- Display size: 42 inches (106.68 cm).
- A sort throw Benq MS612ST projector was used with a throw ratio of 0.90-1.08.
- An endlighten acrylic with leds on each side of it.
- Two cameras in a row, supporting 120 fps for 320x240 resolution and 60fps for 640x480 resolution each, with a lens focusing distance of 2.8 mm.
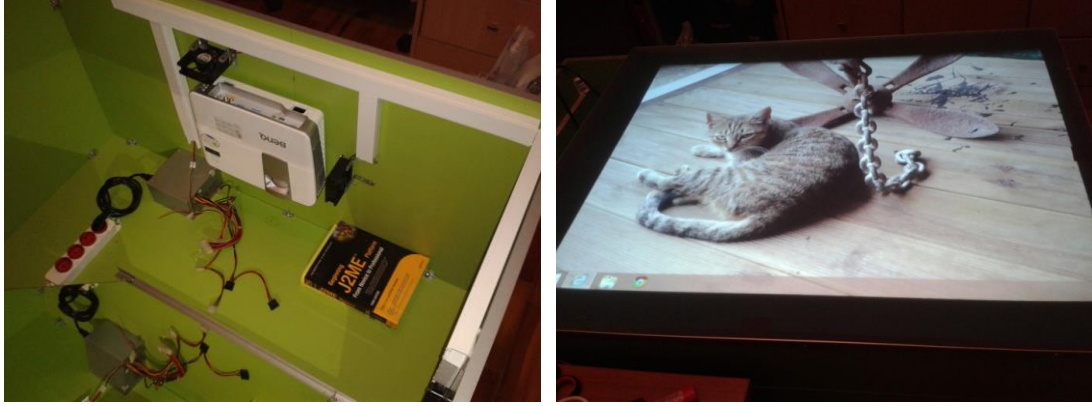
(a) Inside View of the Tabletop During the Construction   (b) Overview of the Tabletop

Figure 2: The Designed Tabletop

Tabletops have been widely used in decision-making process. Kientz et al. (2006) proposed a DSS to support collaborative decision-making for home-based therapy teams. Scotta et al. (2006) presented a multi-user tangible interface system that aims at introducing an instrument to improve the response phase of the decision-making process. Hofstra et al. (2008) used multi-user tangible interfaces for decision-making in disaster management. Scott et al. (2010) have used tabletop interfaces to support collaborative decision-making in maritime operations. Arciniegas et al. (2013) have used an interactive mapping device as the interface between spatial information and participants in order to support decision-makers in land use allocation problem in a peat-meadow polder in the Netherlands. Kunz et al. (2013) have utilized a tabletop to support expert team members co-located around maps for emergency response management. Wahab & Zaman (2013) have used a tabletop display for military decision making processes.

Tabletops are increasingly accepted as an alternative solution to typical software packages with Graphical User Interfaces (Ullmer & Ishii, 2000) because of their advantage of spatially multiplex direct interactions with computational models (Ishii et al., 2004). Ratti et al. (2004) used a tabletop display for the design of GIS user interfaces and outlined that tabletops are well-suited for these type of applications and can improve collaboration between a group of people present at a certain physical location. The goal of co-located groupware GIS is to provide a high-level of interactivity and to allow users to collaborate easily and efficiently; this can be achieved by using tabletop displays (Viard et al., 2011). Taking into consideration the aforementioned advantages of tabletops in GIS and co-located teams of decision-makers, we decided to use a tabletop display for the MCFLP.

3. MODEL SPECIFICATION AND ALGORITHMS

The mathematical form of the problem described in Section 1 can be formulated as follows (Papathanasiou et al., 2014):

$$\max \sum_i \sum_p DP_{ip} X_i \qquad (1)$$

or

$$\max \sum_i \sum_p aDP_{ip} Q_{ip} X_i \qquad (2)$$

s.t.

$$DP_{ip\min} \leq DP_{ip} \leq DP_{ip\max} \qquad (3)$$

$$\sum_i X_i = P \tag{4}$$

$$Y_{ij} - X_i \leq 0 \tag{5}$$

$$X_i = 0,1 \tag{6}$$

$$Y_{ij} = 0,1 \tag{7}$$

$$UP_{ij} = 0,1 \tag{8}$$

$$UM_{mj} = 0,1 \tag{9}$$

$$\sum_p DP_{ip} = \sum_p \sum_i \sum_j H_{ij}^p Y_{ij} UP_{ij} \tag{10}$$

where:

$|P|$: the cardinality number of new enterprises

$p_n \in P = \{p_1, p_2, ..., p_k\}, n = 1, 2, ..., k$

$|M|$: the cardinality number of existing enterprises

$m_f \in M = \{m_1, m_2, ..., m_k\}, f = 1, 2, ..., h$

$|I|$: the cardinality number of candidate nodes of new enterprises

$i_s \in I = \{i_1, i_2, ..., i_q\}, s = 1, 2, ..., q$

$|J|$: the cardinality number of demand nodes

$j_r \in J = \{j_1, j_2, ..., j_b\}, r = 1, 2, ..., b$

T: the time within which the market demands a specific quantity of the product in question

DP_{ip}: the production capacity in time T of the new enterprise p established in node i

DP_{ipmax}: the maximum production capacity in time T of the new enterprise p established in node i

DP_{ipmin}: the minimum acceptable production capacity in time T of the new enterprise p established in node i

DM_m: the production capacity in time T of the existing enterprise m

DM_{mmax}: the maximum production capacity in time T of the existing enterprise m

DM_{mmin}: the minimum acceptable production capacity in time T of the existing enterprise m

H_j: demand in demand node j

HP_{ij}^p: the fraction of demand in node j, which is serviced by node i where the new enterprise p has been located

HM_{mj}: the fraction of demand in node j where the existing enterprise m has been located

S_{pi}: the range of new enterprise p in node i and in time T (distance units)

S_m: the range of existing enterprise m in time T (distance units)

Q_{ip}: the production cost of new enterprise p in node i.

Q_m: the production cost of existing enterprise m.

a: the profit percentage.

The total number of network's nodes is $|I|+|J|+|M|$. Objective functions (1) and (2) refers to the maximization of the product that was produced, in the event that the cooperating enterprises choose the aggressive and the conservative tactic, respectively.

Constraint (3) refers to the range of prices which the quantity of production can obtain for each p_n within the given time T, while constraint (4) requires that precise $|P|$ enterprises are established. Constraint (5) allows the service only from nodes where units have been established and constraints (6) – (9) require that the these variables are integers to the values of zero and one. Finally, constraint (10) shows that each new enterprise's entire production is consumed; otherwise surplus stock of unsold products will be created.

The multiple capacitated facility location problem is NP-hard and the algorithms that have

been proposed to find the optimal solution use the Lagrangean relaxation method as the core technique or transportation simplex method. Hence, the execution time of an exact algorithm is prohibited for inclusion in an interactive spatial DSS. For the solution of the above model, a dynamic approximation algorithm that can calculate an approximation solution in an acceptable time interval is used, proposed by Papathanasiou & Manos (2007).

4. DESIGN AND IMPLEMENTATION

4.1. Integrating Geographical Data on the DSS

The locations of the candidate nodes are usually entered manually. Many DSS for the facility location problem simulate the market segment as a graph and the distances between the nodes are not always corresponding to the real situation. The DSS that we presented in Papathanasiou et al. (2014) used the same rationale (Fig. 3). The main aim of this paper is to present an interactive spatial DSS using tangible user interfaces that uses Google Maps to integrate GIS technologies on the MCFLP.
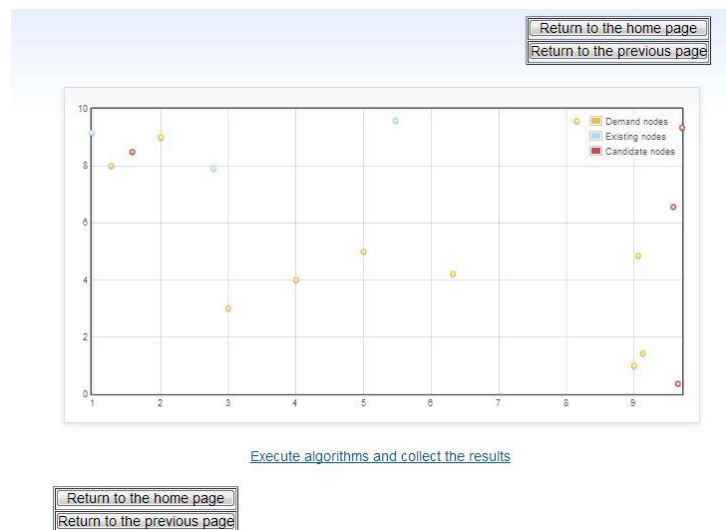

Figure 3: Market Representation for the MCFLP

Figure 4 displays the architecture of the proposed DSS. Initially, the decision maker selects the locations of the candidate nodes, the existing enterprises and the demand nodes via an interactive Google Map using fiducials on the tabletop. There are three types of fiducials, one for each type node (demand node, existing enterprise and new enterpise), as shown in Figure 5.
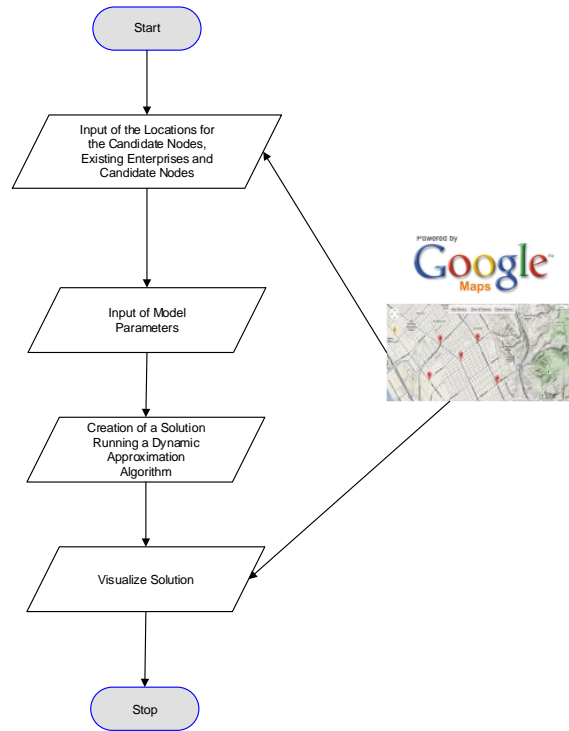
Figure 4: Architecture of the Interactive Spatial DSS

(a) View of the Demand Node (b) View of the Existing Enterprise (c) View of the New Enterprise

(d) Fiducial of the Demand Node (e) Fiducial of the Existing Enterprise (f) Fiducial of the New Enterprise
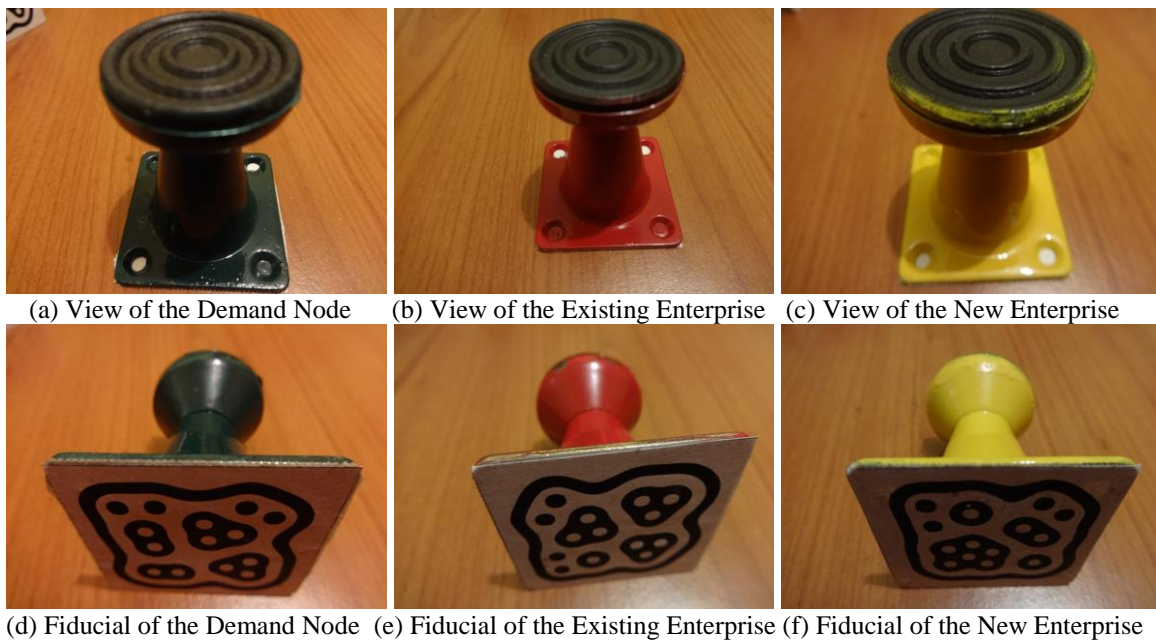
Figure 5: Types of Fiducials

The locations are added interactively in a Google Map, as shown in Figure 6. Then, the other parameters of the model are entered through user-friendly interactive forms or a Microsoft Excel file. In the next step, a dynamic approximation algorithm is executed and a solution is constructed. If a solution is found, then it is visually displayed through the use of a Google Map instance.
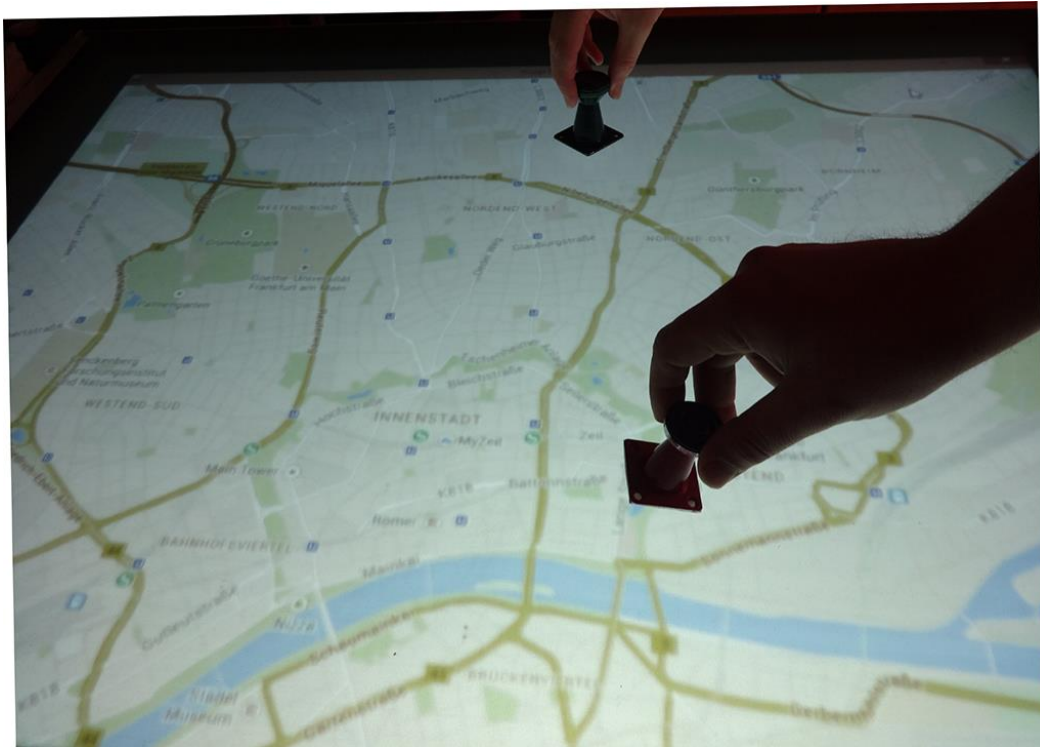
Figure 6: Adding Locations of the Nodes via an Interactive Map

4.2. Implementation Issues

The spatial DSS has been implemented using Java, TUIO and Google Maps. More specifically, the open source TUIO protocol (Kaltenbrunner et al., 2005) has been utilized in order to recognize a set of objects with fiducials and draw gestures onto the table surface with the finger tips. TUIO protocol is encoded using Open Sound Control format and the transport method is made through UDP packets to the default TUIO port number 3333.

Community Core Vision (CCV), previously known as tbeta, is an open source software that takes as input a video stream and outputs several tracking data, such as coordinates of the objects or events like finger down (Community Core Vision, 2014). CCV was selected compared to reacTIVision and Touchlib, because CCV has more filter options. The recognition of the camera from CCV requires the installation of the device driver named CL-EYE Platform Driver. Moreover, open source Unfolding library (2014) for Java was used to create interactive Google Maps and geovisualizations. The library supports various functions to get automatically the distance in km between two points in the earth.

5. PRESENTATION OF THE SPATIAL DSS

In this Section, the spatial DSS is presented through a small representative example. Initially, the locations of the demand nodes should be defined to the map. Let us assume that we have ten demand nodes. The decision maker has to pan and zoom to the desired locations and mark the locations by placing the fiducial that represents a demand node to the specified location, as shown in Figure 7.
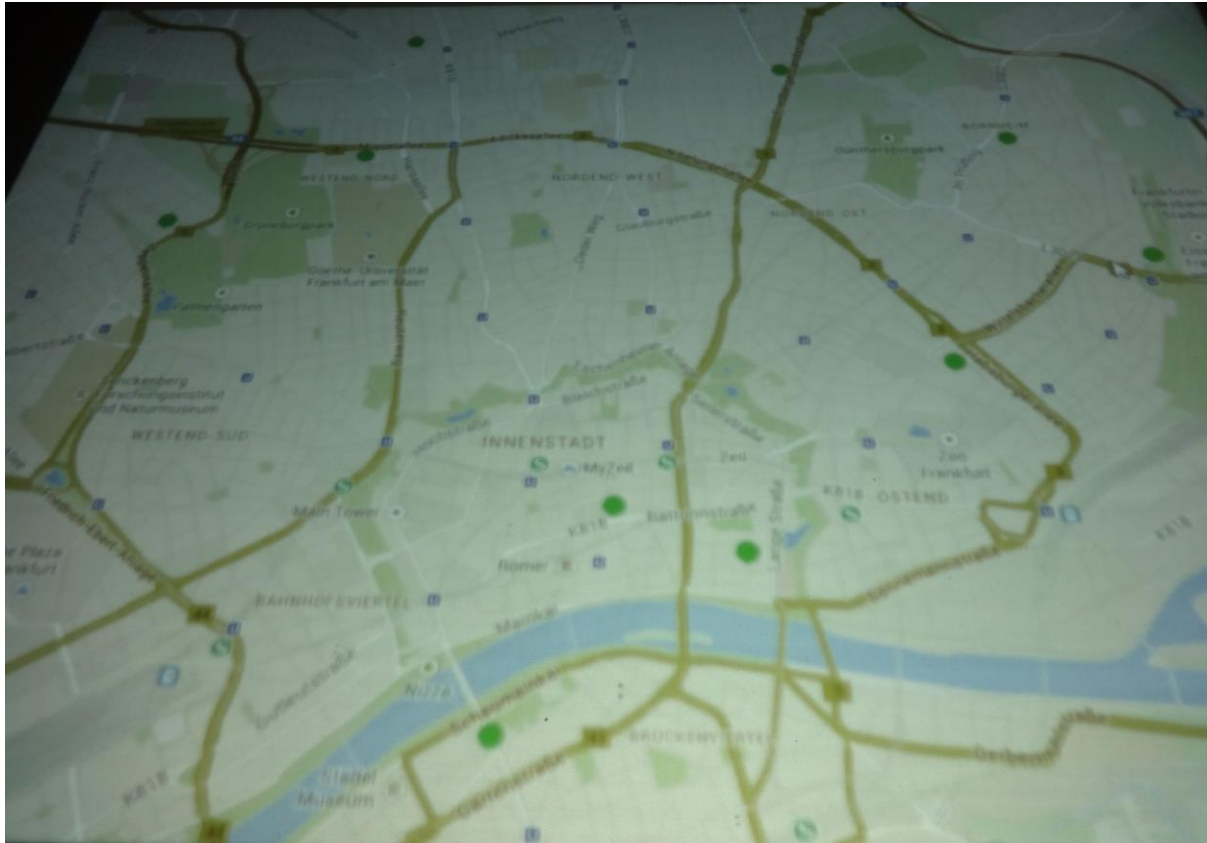
Figure 7: Adding Locations of the Demand Nodes

The decision maker should also add markers to the locations of the existing enterprises and candidate nodes by placing the fiducial that represents either an existing enterprise or a new enterprise to the specified location. Let us assume that we have three existing enterprises and four candidate nodes. The final representation of the market is shown in Figure 8.
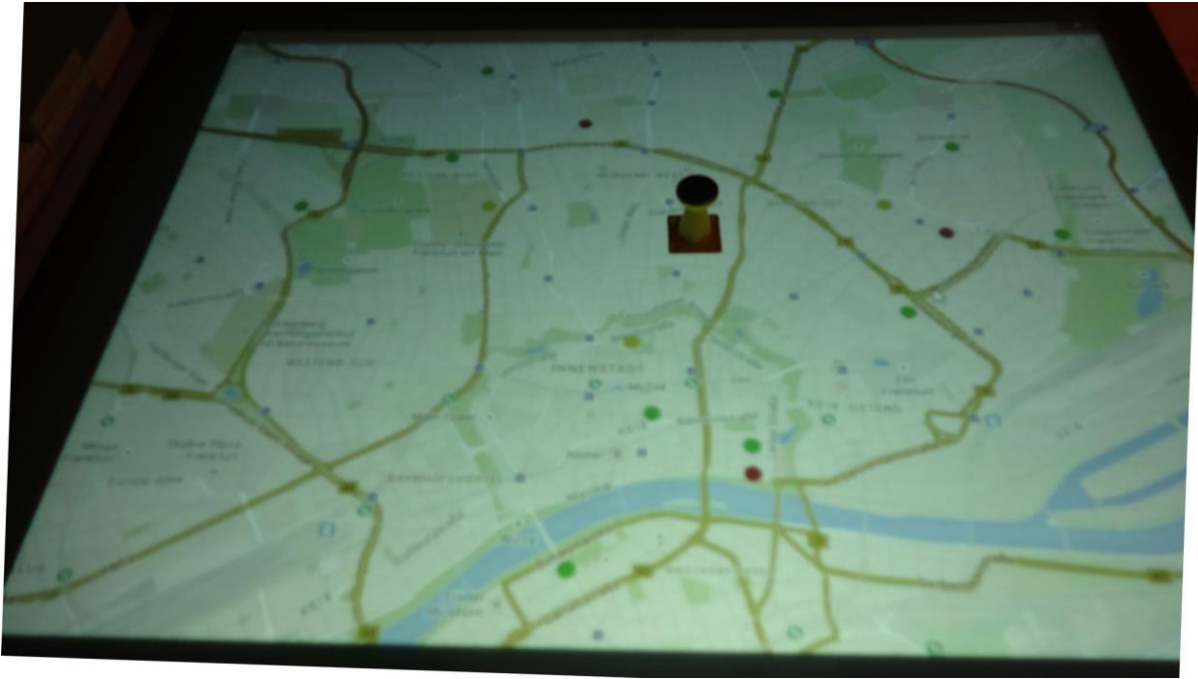
Figure 8: Final Representation of the Market

Then the decision maker should enter the other parameters of the model through user-friendly interactive forms or a Microsoft Excel file. The most common case is to download a Microsoft Excel template from the DSS and fill the appropriate data, as proposed in Papathanasiou et al. (2014). Then, a dynamic approximation algorithm is executed and the solution, if it exists, is presented via a Google Map, as shown in Figure 9. The results are also analytically presented in a pdf file. In the specific example, new enterprise 1 (NE1) serves five demand nodes (DN1 – DN5), while new enterprise 2 (NE2) serves three demand nodes (DN6 – DN8). Existing enterprise 2 (EE2) serves two demand nodes (DN9 – DN10), while the other two existing enterprises (EE1 and EE3) are not economically viable.
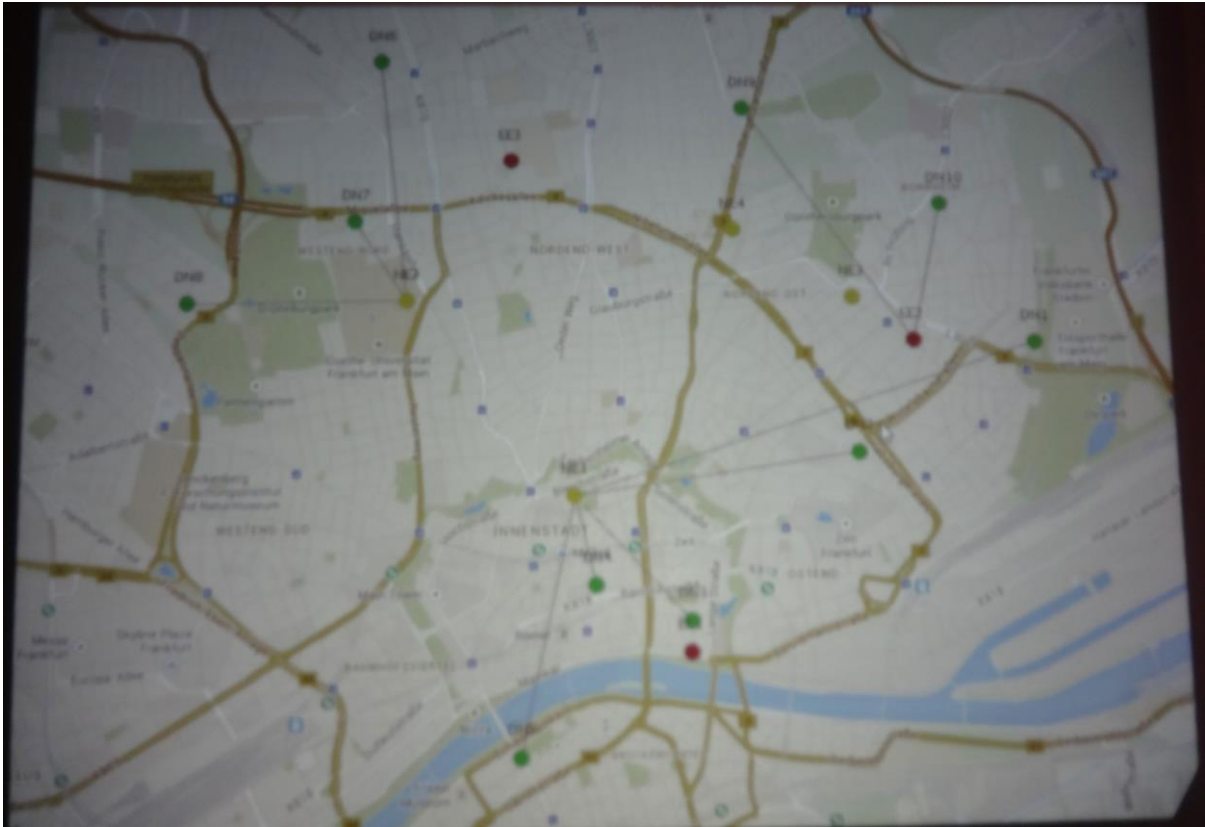
Figure 9: Representation of the Solution in a Map

6. CONCLUSIONS

The MCFLP is a well-known operations research problem with many practical applications. GIS technologies have not yet been integrated extensively on DSS for this problem. In this paper, we present an interactive spatial DSS enabling co-located collaboration with tangible user interfaces through a tabletop that supports decision-making and integrates geographical information data in the DSS for the MCFLP. The decision maker can easily add the locations of the nodes through an interactive Google Map. Then, the DSS can export the geographical coordinates and the time distances from the specified locations and execute a dynamic approximation algorithm for its solution. Finally, the solution of the problem is presented both on an interactive Google Map and on a pdf file.

The proposed spatial DSS has important managerial implications. First, decision makers can formulate their case studies and get a thorough analysis on if their enterprises should enter a market or not. The locations of the nodes are easily added through an interactive Google Map and the upload of other model's parameters is a straight-forward procedure. Some limitations also exist on the proposed DSS. First, some input data referring to the existing enterprises and the demand nodes may not be available to the decision makers. A second potential limitation of the proposed DSS is that although it allows multiple decision makers to co-operate with the tabletop, it does not deal with the collaboration.

In future work, we plan to deal with the collaboration of multiple researchers to the tabletop and enhance the DSS with other options that will give decision makers the

opportunity to get some alternative scenarios to investigate in order to obtain the largest possible share and revenue from a specific market.

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