The concept of web-based spatial decision support system for accessibility analysis

Jan Burdziej[1]

[1]Department of Cartography, Remote Sensing and GIS, Nicolaus Copernicus University, Torun, Poland, jan.burdziej@umk.pl

Abstract

This paper describes the concept of spatial decision support system (SDSS), which combines network analysis and spatial analysis of accessibility with a web-based map service. There are two main objectives of this research: (1) to assess spatial variation of accessibility to certain services within the city area based on network analysis and (2) to share this knowledge with potential users (citizens and local decision makers) in the form of a web-based SDSS. Such system can help people take better decisions regarding location and accessibility (by answering such questions as "Which part of the city has good access to primary schools and parks?"). These questions involve multi-criteria spatial analysis. This article focuses mainly on concepts and theory behind the web-based SDSS, as it is achieved with the help of open source solutions. An open source web-based spatial decision support system is proposed. It is based on GeoServer, which is used as a main data provider. Data is exposed as a WMS service. The web user interface is built using ExtJS and GeoExt frameworks with OpenLayers as a main map client. Finally, dynamic Styled Layer Descriptor (SLD), generated with PHP script is incorporated for creating interactive and user-oriented maps.

1. Introduction

1.1 Accessibility versus location and distribution

Spatial characteristic of a given phenomenon, e.g. shops in a city area, can be described at several different levels of complexity. At the first and the lowest level, location of one single shop can be described by its geographic coordinates and spatial relation to other facilities, e.g. residential areas. At the next level, location of all shops can be mapped and their spatial distribution can be analyzed in a wider context of the whole city. However, it is accessibility of shops that is important to citizens, rather than their geographical location or even spatial distribution. It is because in real life simple "as the crow flies" distance is hardly ever used. In other words, places that are closer in terms of a straight-line distance, may be relatively further apart when it comes to traveling between them (see Figure 1). Since we move along transportation networks, such as streets or sidewalks, it is distance or even travel time along these routes that is important to citizens rather then a straight-line length. Therefore, accessibility analysis of all shops in the city area may reveal hidden spatial patterns, which cannot be observed by assessing only spatial distribution. Thus, accessibility analysis (with a network analysis behind it) can be regarded as a third and more complex level of spatial analysis. It can be used for creating spatial models, which are closer to the reality than simple spatial distribution models, especially in socio-economical studies.

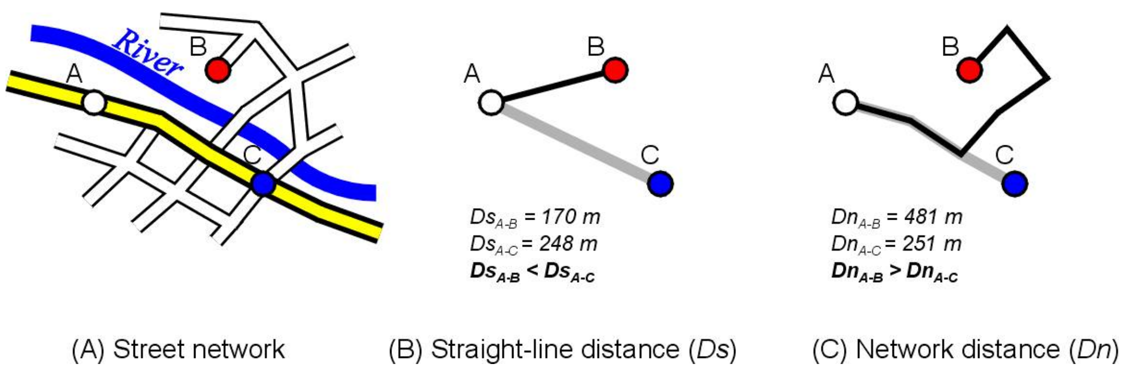

Figure 1. Straight-line distance versus network distance

Accessibility can be defined as a travel cost to a location of interest (Burdziej, 2009) and can be expressed in different units (e.g. distance, time, money). It is one of the key spatial components that affect people's activity. It is also argued that accessibility to certain facilities has a significant influence on level of life. Accessibility was considered to be a spatial "poverty line", an indicator of well-being and development opportunities of rural areas (Pozzi & Robinson, 2008). Nelson (2008), the author of a global map of accessibility, stated that "accessibility – whether it is to markets, schools, hospitals or water – is a precondition for the satisfaction of almost any economic need." Furthermore, he argued that accessibility is "relevant at all levels, from local development to global trade" (Nelson, 2008).

There is a growing awareness that accessibility is one of the main indicators of economic development. If the level of accessibility is low, it constitutes a hindering factor for economical growth. Cleaver (in: Barwell, 1996) in the context of studies on rural development in Africa stated that "improved accessibility will reduce the economic costs of moving goods from local markets and ease the barriers to social facilities. This will contribute to economic growth and enhanced social well-being."

Similar conclusions may be applied to urban environments. Although general accessibility within the city is higher than in rural areas due to dense street network and relatively shorter distances, there are also regions and districts with lower and higher level of accessibility to certain facilities (Comber et al., 2008). It is argued that good and equal access to services, e.g. health care (Felder & Brinkmann, 2002; Rosero-Bixby, 2004), parks and recreational areas (Erkip, 1997; Perkins et al., 2004; Oh & Jeong, 2007; Comber et al., 2008) and other facilities (Olvera et al. 2003; Burns & Inglis, 2007) is essential in providing certain quality of life. The equity of spatial access is also required for a sustainable development of a city.

The accessibility of a given location depends on many spatial and non-spatial factors, such as:

- road network (density, road type, traffic congestion, traffic lights, turning restrictions),
- actual weather conditions (wind, ice, snow),
- mean of transport and its characteristics (e.g. vehicle type: a car or a plane, type of transportation: private or public, vehicle speed, fuel consumption, load capacity),
- speed limits (indicated by road signs or safe driving policies),
- law regulations (ownership, access restrictions).

Depending on context, these factors may have different influence and importance. For example, accessibility for a sail boat will depend heavily on weather conditions, mainly wind speed and direction. For a car navigation these factors do not have a significant influence.

Spatial attractiveness of a given location may be defined by its accessibility, which is often regarded as the ease with which certain facilities may be reached from this location (Hansen, 1959; Zhu & Liu 2004; Zhu et al. (2005, 2006) in the accessibility analysis for housing development in Singapore used the following list of criteria: access to public transport, shopping centers, health-care services, banks, schools, community centers, post offices and parks. The list may include many other facilities, such as cinemas, theaters, sport centers etc. However, each citizen has its own priorities and needs. Parents with little children may look for a good access to kindergartens or schools, while older people may search for areas with good access to parks and health-care services. From the municipal authorities' point of view, it is important not only to assess general accessibility to different services, but also to assess its adequacy with respect to certain target groups.

This indicates that accessibility is a complex subject and many different criteria shall be examined in order to assess the accessibility with a reasonable accuracy. Therefore, there is a great need for an automated spatial decision support system that can help in this process.

GIS and decision support systems have been widely criticized for being closed, centralized systems, created by experts and for experts, unavailable for general public (Dragićević, 2004; Boroushaki & Malczewski, 2010). In a modern information society these tools and respective data shall be widely available to support all interested parties.

1.2 Objective

This paper describes the concept of a spatial decision support system (SDSS), which combines network analysis and spatial analysis of accessibility with a free and open source web-based map service. There are two main objectives of this project: (1) to assess spatial variation of accessibility to certain services within the city area based on network analysis and (2) to share this knowledge with potential users (citizens and local decision makers) in the form of a web-based SDSS.

Such system can help people take better decisions regarding location by answering such questions as “Which part of the city has good access to primary schools and parks?” Such questions involve multi-criteria spatial analysis of accessibility. This article focuses mainly on concepts and theory behind the web-based SDSS, as it is created with the help of open source tools.

An open source web-based spatial decision support system is proposed. It is based on GeoServer, which is used as a main data provider. The data is exposed as a WMS service. The web user interface is built using ExtJS and GeoExt frameworks with OpenLayers as a main map client. Finally, dynamic Styled Layer Descriptor (SLD), generated with PHP script is incorporated for creating interactive and user-oriented maps (Figure 2).

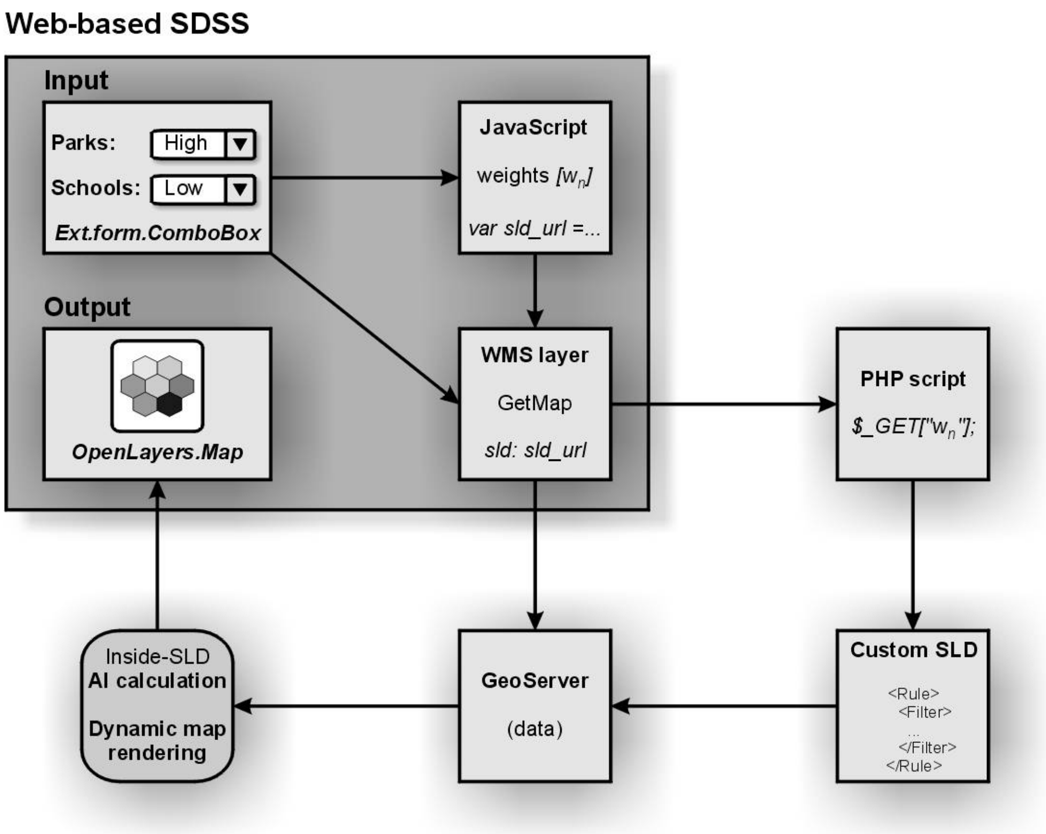

Figure 2. Architecture of the proposed web-based SDSS

1.3 Study area

The proposed SDSS will be applied to the city of Torun in central Poland. The city has roughly 200,000 inhabitants and an area of approximately 115 square kilometers. The Vistula river, which passes from East to West, divides the city into two parts. There is only one bridge over the river available for cars and pedestrians, which connects the two parts. The Old Town and the city center are located in the northern part. Additionally, most of shopping centers, offices, schools, kindergartens, cultural facilities and sport centers are located in the northern part. Currently, mainly due to higher land availability and lower prices, population of the southern part is rising. This process may lead to significant disproportions in accessibility to certain facilities within the town area. However, several major road constructions (including new bridge) are planned in the near future to address transportation problems. The accessibility analysis of a current situation, as well as the analysis for different development scenarios, may help local authorities take better decisions, resulting in a more equalized accessibility and more sustainable development of the town.

2. Methodology

The main aim of the proposed web-based SDSS is to find the most suitable locations for a given set of user-specified criteria, using accessibility measures. To achieve this aim, the system performs multi-criteria accessibility assessment of the whole city area. Based on this analysis, the most suitable locations are selected. Additionally, the least accessible areas can be easily identified and the accessibility in a given location can be determined.

The accessibility is calculated in a regular grid of hexagons. Hexagonal grid has been chosen as a sampling pattern due to several advantages over rectangular grids. It provides more equally distributed polygon centroids, higher spatial resolution with the same number of sampling polygons (de Sousa et al., 2006), simplier and less ambiguous nearest neighbor analysis and greater clarity in visualization (Birch et al., 2007).

Each hexagon in the analysis has a 100 m side length and an area of about 2.6 hectares. The whole study area is covered with 4,693 hexagons. Accessibility is calculated using network analysis, with the centroid of each hexagon as the origin and facility location as destination points for all routing analyzes.

The location is regarded as the most suitable, when its "average accessibility" is the highest. In order to quantify the measure of accessibility, Accessibility Index (AI) is proposed. It is calculated as a weighted average of accessibility to different types of facilities. Depending on user's choice, accessibility can be measured using distance (meters) and time (minutes) units. Users can specify descriptive priority for each category, which are translated into weights and used in AI calculations.

The final output of the proposed SDSS is a thematic map, which shows the AI values with a gradient color ramp. This map directly indicates areas with the highest, average or the lowest accessibility values. Additionally, users will be able to click on a map and retrieve AI value for a given location. Moreover, raw accessibility values, such as time or distance to the nearest shop, theater or school, can be retrieved.

2.1 Network analysis

The main aim of a network analysis in this project is to supply the web-based SDSS with raw accessibility data. In practice, network analysis is used to find the shortest and the fastest routes between many pairs of points. Each pair consists of a source point (a centroid of each hexagon) and destination point (represented by different points of interest, i.e. locations of facilities, such as hospitals and schools). This approach enables application of network analysis, which is basically a point-to-point approach, to a spatial (areal) research.

Routing analysis requires routing data, usually street network. It uses well-known algorithms that are implemented in various proprietary and open source GIS tools (ESRI, 2010; GRASS-Wiki, 2010; Neis & Zipf, 2007; Okabe et al., 2006). They provide algorithms for finding least-cost paths (i.e. fastest or shortest routes), solving Traveling Salesman Problem (TSP) or delineating service areas.

In this project, the network analysis is undertaken using ArcGIS Network Analyst (ESRI, 2010). Specifically, the origin-destination analysis tool is used, as it provides fast algorithm for calculating routes between a large number of pairs of origin and destination points. The final result is a table (called Origin-Destination Cost Matrix) with distance and travel time calculated for all pairs of points. In the case of this project there will be approximately 4,700 hexagon centroids as source points and over 400 points of interest (POI) as destination points. This will result in more than 18,800,000 routes to be calculated.

2.2 Accessibility analysis

The results acquired during the network analysis have to be filtered to obtain final accessibility values for each hexagon:

- shortest time to each facility category,
- shortest distance to each facility category.

In this way each hexagon will be assigned an accessibility value for each category (e.g. parks or schools) in two types of units: time (minutes) and distance (meters). At this stage of the analysis, spatial variation of accessibility in the city can be mapped and regions with low and high accessibility to certain services can be identified. Moreover, accessibility measured using different units can be compared. Correlation between time and distance accessibility values can be calculated and evaluated.

A sample attribute table with accessibility values for one hexagon is shown below:

Table 1. Sample attributes for one hexagon

CAT_ID	CAT_NAME	MIN_TIME [minutes]	MIN_DIST [meters]
A	Parks	13	11500
B	Schools	15	10850
C	Hospitals	8	5950
D	Shops	20	21300

2.3 Multi-criteria analysis

Values calculated in a previous step (accessibility analysis) can be used to assess accessibility individually for each facility category. Furthermore, average accessibility can be calculated for each hexagon. However, from the user's points of view the “average” approach is not very useful, as each citizen has its own priorities and different understanding of the term “suitable location”. Therefore, it is important to allow users to choose, which categories should be taken into account when evaluating a level of accessibility. In real-life scenario, when people are considering new location (e.g for a house), accessibility to several different facilities is taken into account. Moreover, from the user's point of view, some facilities contribute to the general "suitability" more than others.

A simple statistical measure, such as weighted mean, can be applied for the purpose of averaging the accessibility.

$$\bar{x} = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i} \qquad [1]$$

The Accessibility Index (AI) is proposed. It is calculated as a weighted mean of accessibility to different types of facilities $[x_1, x_2, \ldots, x_n]$ with non-negative weights $[w_1, w_2, \ldots, w_n]$. Weights are calculated based on user-specified descriptive importance ranks, e.g.: "Very high", "High", "Medium", "Low", "Very Low" and "None". These priorities are translated into temporary weights (*tw*) (5, 4, 3, 2, 1, 0 respectively), which are then normalized into final weights (*w*) so that they sum up to 1.

$$w = \frac{tw_i}{\sum_{i=1}^{n} tw_i} \qquad [2]$$

$$\sum_{i=1}^{n} w_i = 1 \qquad [3]$$

The final AI formula can be simplified to:

$$AI = \sum_{i=1}^{n} w_i x_i \qquad [4]$$

The table below shows an example of how AI can be calculated for a given set of user-defined priorities.

Table 2. Sample category weighting and AI calculation

CAT_ID	CAT_NAME	PRIORITY	VALUE	WEIGHT	MIN_TIME	MIN_DIST
A	Parks	Medium	3	0.500	13.00	11500.00
B	Schools	None	0	0.000	15.00	10850.00
C	Hospitals	Low	2	0.333	8.00	5950.00
D	Shops	Very Low	1	0.167	20.00	21300.00
				Mean =	**14.00**	**12400.00**
				AI =	**~12.50**	**~11283.33**

In this way AI for all hexagon values can be calculated. Based on the final AI (expressed in time or distance units), hexagons should be rendered with a color ramp to create a thematic map of accessibility. An example of a classification schema for AI for two different units (minutes and distance) is shown in Table 3.

Table 3. Time and distance AI classification

CLASS	WEIGHTED MEAN TIME	WEIGHTED MEAN DISTANCE
1	0 – 5 min	0 – 5 km
2	5 – 10 min	5 – 10 km
3	10 – 15 min	10 – 15 km
4	15 – 20 min	15 – 20 km
5	20 – 25 min	20 – 25 km
6	25 – 30 min	25 – 30 km
7	above 30 min	above 30 km

3. Web-based spatial decision support system

The proposed web-SDSS will have a form of a publicly available geoportal, created with Ext JS, GeoExt and OpenLayers frameworks. This web environment has certain implications on how the methodology can be implemented and how the main objective can be achieved.

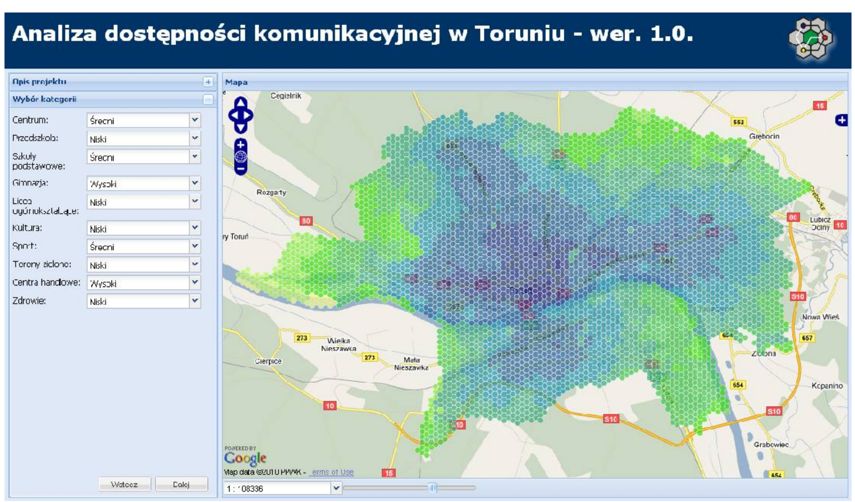

Figure 3. User interface of the proposed SDSS

3.1.1 JavaScript frameworks

The core structure and interface of the geoportal is built with Ext JS framework. Ext JS is a popular

JavaScript library used for building web applications (Sencha, 2010). It provides a wide range of customizable GUI controls, such as text fields, list boxes, comboboxes, radio buttons, checkboxes, tree controls, toolbars, tab panels, sliders, etc. Ext JS is available in dual-licensing model, with free and Open Source license available for works compatible with the GNU GPL license.

Mapping capabilities for the proposed web-SDSS are provided by OpenLayers, an open source JavaScript mapping library (OpenLayers, 2010). OpenLayers offers various classes and interfaces for creating advanced web-based geographic applications. It is well known for its compliance with GIS standards such as Web Mapping Service (WMS) and Web Feature Service (WFS) protocols or Styled Layer Descriptor (SLD). OpenLayers is a powerful mapping framework, which provides access to a wide range of geographic data formats.

GeoExt (GeoExt, 2010), another JavaScript framework, makes it easier to use Ext JS with OpenLayers. It provides ready-to-use geographic web controls, such as map panel, legend panel, layer tree or scale chooser. GeoExt embeds mapping functionality of OpenLayers wrapped in the Ext JS interfaces.

These three JavaScript libraries are employed to achieve the final goal: an interactive web-based SDSS for accessibility analysis.

3.1.2 Criteria weighting

At the first stage of accessibility analysis user has to set the importance level for each category. It can be defined using linguistic descriptions, such as “Very high”, “High”, “Medium”, “Low”, “Very Low” and “None”, available from the drop-down menu. *Ext.form.ComboBox* control is used for this purpose (Figure 3). Before proceeding, user has to specify priorities for all facilities categories. To exclude the given facility type from the accessibility analysis, “None” priority have to be selected from the list. At least one category needs to have an importance other than “None”, as division by zero (in AI calculation) is not allowed.

Code 1:

```
// Store variable
var store = new Ext.data.ArrayStore({
      fields: ['id', 'priority'],
      idIndex: 0
});

// Array variable with values
// and descriptive priorities
var priorities = [
      [0,'None'],
      [1,'Very Low'],
   [2,'Low'],
   [3,'Medium'],
   [4,'High'],
   [5,'Very High']
];
store.loadData(priorities);

// Combobox for category 1
var combo_1 = new Ext.form.ComboBox({
```

```
      store: store,
      displayField:'priority',
      valueField:'id',
      id:'w1',
      fieldLabel:'Category 1',
      ...
   emptyText:'Choose priority...',
});
```

In the next step, descriptive priorities are substituted by values (5, 4, 3, 2, 1, 0 respectively) defined in the *priorities* array. Final weight (normalized to 0-1 range) for each category will be calculated based on these values.

Code 2:

```
var w1 = Ext.getCmp('w1').getValue();
...
var wN = Ext.getCmp('wN').getValue();

var sum_w = w1 + ... + wN;

w1 = w1 / sum_w;
...
wN = wN / sum_w;
```

3.1.3 Visualization environment

The web environment creates two main problems with map rendering. The first one is the large number of objects that have to be rendered on the map in the same time (hexagon layer contains approximately 4,700 polygons). The second problem deals with creating custom thematic map dynamically, based on virtual attribute (AI) using a defined classification schema.

Another difficulty is that data is dispersed between client and server. On the server side, there is the hexagon layer, which contains geometry (polygons) with “raw” accessibility values: minimum time or distance. Priorities and weights for each category are defined and calculated on the client side. In order to render each polygon properly, Accessibility Index has to be calculated using data both from the client (priorities and weights) and from the server (“raw” accessibility values). This information has to be used for styling the map and displaying it on the client side.

There are several techniques to visualize polygon layer on a map in the web-GIS environment. It can be stored as a vector layer with hexagons and their attributes in one of the standard GIS formats, e.g. GML or GeoJSON. Using this technique, objects can be parsed individually, the AI can be calculated based on attributes retrieved with objects and each polygon can be rendered with a proper color according to the classification schema. OpenLayers and JavaScript framework can be used for this task. However, loading and rendering such a large number of objects will cause significant performance issues.

An alternative approach is to expose vector layer as a Web Map Service (WMS), which serves data as raster images, instead of vector graphic. The main advantage of this approach is that raster tiles are generated on the server. These tiles are sent to the client's browser as compressed *jpg* or *png* files, which results in a faster map rendering. However, WMS sends only map graphics without attributes. Therefore, it is not possible to directly calculate AI using WMS layer. This is where Styled Layer Descriptor (SLD) can be applied for advanced and dynamic map rendering.

3.1.4 Using SLD with WMS

A Styled Layer Descriptor is an XML-based mark-up language that allows user-defined symbolization of map layers (OGC, 2002; OGC, 2007; Zipf, 2005). Although SLD can be used for styling both vector and raster data, it is typically used for rendering layers provided by Web Map Service. SLD is an Open Geospatial Consortium (OGC) standard.

SLD allows advanced symbolization of points, lines and polygons. In this project polygons (hexagons) have to be symbolized using custom <*PolygonSymbolizer*> element:

Code 3:

```
<PolygonSymbolizer>
   <Fill>
      <CssParameter name="fill"><Literal>#FF0000</Literal></CssParameter>
   </Fill>
   <Stroke>
      <CssParameter name="stroke"><Literal>#FFFFFF</Literal></CssParameter>
      <CssParameter name="stroke-width"><Literal>0.1</Literal></CssParameter>
   </Stroke>
</PolygonSymbolizer>
```

3.1.5 SLD with filter encoding

A Styled Layer Descriptor can be used with filter encoding to identify a subset of data to by styled in a defined manner (OGC, 2005). Creating thematic map with the SLD definition requires filter encoding. The following non-spatial filter uses comparison operator <*PropertyIsLessThan*> to check if *AccessToSchools* is less then 10:

Code 4:

```
<Filter>
   <PropertyIsLessThan>
   <PropertyName>AccessToSchools</PropertyName>
   <Literal>10</Literal>
   </PropertyIsLessThan>
</Filter>
```

Each class can be defined in a different <*Rule*> with a proper <*Filter*> element. Using this syntax the hexagon layer may be classified and rendered based on its attributes, e.g. time to the nearest school or distance to the nearest park. However, the layer have to be styled using a virtual attribute, calculated "on-the-fly". Different approaches can be considered for creating dynamic and user-oriented maps with a combination of WMS and SLD (e.g. Zipf, 2005).

For this work filter encoding with *expressions* was chosen for dynamic map rendering. The final Accessibility Index (AI) can be calculated within the SLD body definition using a combination of

<Add>, *<Mul>*, *<PropertyName>* and *<Literal>* elements with logical operator *<And>*. It takes into account weights defined for each category and "raw" accessibility values to calculate AI dynamically for every single polygon in WMS layer.

Code 5:

```
<Rule>
   <Name>Category 1 - Weighted Average Distance: 0 - 5000 m</Name>
   <Filter>
      <And>
         <PropertyIsGreaterThanOrEqualTo>
            <Add>
               <Mul>
                  <PropertyName>AccessToSchools</PropertyName>
                  <Literal>WEIGHT_1</Literal>
               </Mul>
               <Mul>
                  <PropertyName>AccessToParks</PropertyName>
                  <Literal>WEIGHT_2</Literal>
               </Mul>
            </Add>
            <Literal>0</Literal>
         </PropertyIsGreaterThanOrEqualTo>
         <PropertyIsLessThan>
            <Add>
               <Mul>
                  <PropertyName>AccessToSchools</PropertyName>
                  <Literal>WEIGHT_1</Literal>
               </Mul>
               <Mul>
                  <PropertyName>AccessToParks</PropertyName>
                  <Literal>WEIGHT_2</Literal>
               </Mul>
            </Add>
            <Literal>5000</Literal>
         </PropertyIsLessThan>
      </And>
   </Filter>
</Rule>
```

WEIGHT_1 and *WEIGHT_2* literal values have to be substituted by weights calculated on the base of user-specified importance levels using Equation [2].

The total number of possible AI results for one hexagon can be calculated using the following equation:

$$\bar{V}_n^k = n^k \qquad [5]$$

where:

n – number of importance levels,

k – number of facility types.

In case of 6 importance levels (n) and 10 facility types (k) there are 60,466,176 different variations, thus the same number of different accessibility maps that can be generated. Assuming users can choose from two types of accessibility units (minutes or meters), the number of possible variations doubles. This is why AI cannot be calculated once and stored as attributes inside the base hexagon layer. For the same reason SLD definitions cannot be created for all possible variations. It has to be created "on-the-fly" individually for each user request.

3.1.6 SLD generated with PHP script

In this work WMS layer is provided by GeoServer. It is required that every vector layer stored in GeoServer has a style (defined using SLD) associated with it (GeoServer, 2010). This style, however, cannot be directly modified by the client, thus cannot be adapted to meet specific user preferences.

WMS specification allows sending custom style definition inside the WMS GetMap request (OGC, 2007):

Code 6:

```
http://yourfavoritesite.com/WMS?
   REQUEST=GetMap&
   BBOX=0.0,0.0,1.0,1.0&
   LAYERS=Rivers,Roads,Houses&
   STYLES=CenterLine,CenterLine,Outline&
   WIDTH=400&
   HEIGHT=400&
   FORMAT=image/png
```

This style definition may be easily created on the client side. JavaScript can be used to fetch user preferences (from *Ext.form.ComboBox*), calculate weights and construct the proper style definition. Alternatively, *STYLES* parameter can be substituted by *SLD_BODY* parameter, which accepts literal SLD definition (stored in a string variable). However, the size of this definition may become an important limitation.

Sample SLD definition shown in Code [5] describes one final class of accessibility. In this example only two categories of facilities (schools and parks) were used in AI calculations. Provided that 10 different POI categories and 7 classes for thematic mapping will be used, the SLD definition becomes very large.

OpenLayers uses HTTP requests for adding new WMS layers. It is a commonly reported issue that HTTP requests have limitations in terms of a maximum URL length allowed. Although this limit is not imposed by HTTP protocol itself, it is dependent on both server (GeoServer in this case) and client (web browser). HTTP-GET request is prone to instability and errors caused by long URLs (Microsoft, 2010; W3C, 1999), especially in such browsers as Internet Explorer (Microsoft, 2010). Alternatively HTTP-POST protocol can be used with large SLD definition, but browsers such as Opera or Mozilla may have problems with transparent WMS.POST layers (OpenLayers, 2010). For these reasons it is more convenient and safer to store SLD file externally (OGC, 2007):

Code 7:

```
http://yourfavoritesite.com/WMS?
   REQUEST=GetMap&
   BBOX=0.0,0.0,1.0,1.0&
```

```
SLD=http://myclientsite.com/mySLD.xml&
WIDTH=400&
HEIGHT=400&
FORMAT=PNG
```

However, as it was stated before, all possible SLD definitions cannot be created due to large number of possibilities. Therefore, the external SLD definition need to be generated dynamically. A simple PHP script can be efficiently used for this purpose. The script will dynamically create SLD definition using values passed via URL:

Code 8:

```
var sld_url  = "http://localhost/sld.php?w1=" + w1 + ... + "&wN=" + wN
```

JavaScript is responsible for reading user preferences and calculating weights on the client side. These values are used to generate URL string (*sld_url*), which is a reference to a PHP script. PHP script fetches weight values from the URL (using *$_GET["w1"]*) and inserts them into the SLD body. SLD body is created as a string variable and is returned by the PHP script to the WMS request. With this method HTTP-GET request limit can be bypassed and SLD can be generated dynamically using given weight values.

Code 9:

```
<?php
$sld='<StyledLayerDescriptor version="1.0.0"><NamedLayer><Name>access:hex</Name>';
$sld.='<UserStyle><Name>Results of Accessibility Analysis</Name><FeatureTypeStyle>';
// ************ Category 1 ************
$sld.='<Rule>';
$sld.='<Name>Category 1 - Weighted Average Distance: 0 - 5000 m</Name>';
$sld.='<Filter>';
$sld.='<And>';
$sld.='<PropertyIsGreaterThanOrEqualTo>';
$sld.='<Add>';
$sld.='<Mul>';
$sld.='<PropertyName>AccessToSchools</PropertyName>';
$sld.='<Literal>';
$sld.= $_GET["w1"];
$sld.= '</Literal>';
$sld.='</Mul>';
$sld.='<Mul>';
$sld.='<PropertyName>AccessToParks</PropertyName>';
$sld.='<Literal>';
$sld.= $_GET["w2"];
$sld.= '</Literal>';
$sld.='</Mul>';
$sld.='</Add>';
$sld.='<Literal>0</Literal>';
$sld.='</PropertyIsGreaterThanOrEqualTo>';
$sld.='<PropertyIsLessThan>';
$sld.='<Add>';
$sld.='<Mul>';
$sld.='<PropertyName>AccessToSchools</PropertyName>';
$sld.='<Literal>';
$sld.= $_GET["w1"];
$sld.= '</Literal>';
$sld.='</Mul>';
$sld.='<Mul>';
$sld.='<PropertyName>AccessToParks</PropertyName>';
$sld.='<Literal>';
```

```php
$sld.= $_GET["w2"];
$sld.= '</Literal>';
$sld.='</Mul>';
$sld.='</Add>';
$sld.='<Literal>5000</Literal>';
$sld.='</PropertyIsLessThan>';
$sld.='</And>';
$sld.='</Filter>';
$sld.='</Rule>';
// ************ END OF STYLE DEFINITION ************
$sld.= '</FeatureTypeStyle></UserStyle></NamedLayer></StyledLayerDescriptor>';
echo $sld;
?>
```

3.1.7 Creating dynamic layer with OpenLayers

Finally, a new WMS layer will be added to the map using the following syntax:

Code 10:

```javascript
var hex = new OpenLayers.Layer.WMS("Accessibility Analysis",
      "http://localhost:8080/geoserver/wms",
      {layers: 'access:hex', transparent: true, format: 'image/png', sld: sld_url},
      {isBaseLayer: false, unsupportedBrowsers: [], singleTile: false}
      );

map.addLayer(hex);
```

The layer will be rendered using SLD definition returned by the external PHP script. In this way, using a mash-up of JavaScript, PHP, WMS and SLD frameworks custom thematic maps can be dynamically generated and smoothly rendered in client's browser.

4. Conclusions

Accessibility has an important impact on people's everyday life. It influences the amount of daily travels and related costs, it also determines how easily certain facilities and services can be accessed. All these factors significantly contribute to the general “quality of life”. Therefore, it is important for people to assess accessibility while taking spatial decisions (such as relocation or spatial planning).

The proposed approach shows how a point-to-point network analysis can be used to find and describe spatial patters of accessibility within a given area. Moreover, this paper describes a simple and intuitive method for multi-criteria analysis of accessibility to certain services in a web environment. Once accomplished, the proposed web-based SDSS can be used by both citizens and decision makers to support their spatial decisions. Citizens may use the tool for finding areas that fulfill their current accessibility needs. City planers may easily identify districts with low accessibility to certain services, e.g. kindergartens. This information, compared with spatial distribution of families with little children, may help them finding the most suitable location for a new kindergarten.

Moreover, the approach proposed in this paper can be used to simulate future changes. For instance, network dataset can be updated with a planned road and accessibility can be assessed for this scenario. Comparing several different models can show how the accessibility will be affected in each case and the most optimal solution can be chosen.

A combination of open standards, such as WMS, WFS and SLD, with highly flexible and customizable open source map clients, such as OpenLayers, can efficiently support the idea of open GIS. Not only in terms of open source software, but also in terms of open access to GIS tools. These tools can help translating geographic data into useful information and knowledge. Furthermore, this knowledge can be shared and can be used for better decision making by all interested parties. In this way open source GIS can substantially support the idea of information society and sustainable spatial development.

The next step for this project is to build a detailed network dataset for the city of Torun (including turning and access restrictions, speed limits etc.) and calculate actual accessibility. These results will then supply a web-based SDSS (described in this paper) with core data. Once finished, the system will be published in the Internet.

Additionally, different methods of multi-criteria evaluation will be examined and more complex approach to Accessibility Index (AI) calculations will be studied. Finally, implementation of additional services to the web-based SDSS will be considered.

References

Barwell, I 1996, *Transport and the Village. Findings from African Village-Level Travel and Transport Surveys And Related Studies,* World Bank Discussion Paper No. 344. Africa Region Series, viewed 5 June 2009, <http://www4.worldbank.org/afr/ssatp/Resources/WorldBank-DiscussionPapers/WBDP344.pdf>.

Birch, CPD, Oom, SP & Beecham, JA 2007, 'Rectangular and hexagonal grids used for observation, experiment and simulation in ecology', *Ecological Modelling*, vol. 206, no. 3, pp. 347–359.

Boroushaki, S, Malczewski, J 2010, 'Measuring consensus for collaborative decision-making: A GIS-based approach', *Computers, Environment and Urban Systems*, vol. 34 (2010), pp. 322–332.

Burdziej, J 2009, 'Multi-criteria spatial analysis of land accessibility for seismic operations', *Annals of Geomatics*, vol. VII, no. 2(32), pp. 23-32.

Burns, CM & Inglis, AD 2007, 'Measuring food access in Melbourne: access to healthy and fast foods by car, bus and foot in an urban municipality in Melbourne', *Health & place*, vol. 13, no. 4, pp. 877–885.

Comber, A, Brunsdon, C & Green 2008, 'Using a GIS-based network analysis to determine urban greenspace accessibility for different ethnic and religious groups', *Landscape and Urban Planning*, vol. 86, no. 1, pp. 103–114.

de Sousa, L, Nery, F, Sousa, R & Matos, J 2006, 'Assessing the accuracy of hexagonal versus square tilled grids in preserving DEM surface flow directions', proceedings of the *7th International Symposium on Spatial Accuracy Assessment in Natural Resources and Environmental Sciences*, edited by Caetano, M & Painho, M.

Dragićević, S 2004, 'The potential of Web-based GIS', *Journal of Geographical Systems*, vol. 6, pp. 79–81.

Erkip, (Beler) F 1997, 'The distribution of urban public services: the case of parks and recreational services in Ankara', *Cities,* vol. 14, issue 6, pp. 353-361.

ESRI 2010, ArcGIS Network Analyst | Overview, viewed 23 June 2010, <http://www.esri.com/software/arcgis/extensions/networkanalyst/index.html>.

Felder, S & Brinkmann, H 2002, 'Spatial allocation of emergency medical services: minimising the death rate or providing equal access', *Regional Science and Urban Economics*, vol. 32, no. 1 (2002), pp. 27–45.

GeoExt 2010, JavaScript Toolkit for Rich Web Mapping Applications — GeoExt v0.7, viewed 21 June 2010, <http://www.geoext.org/>.

GeoServer 2010, Introduction to SLD — GeoServer 2.0-SNAPSHOT User Manual, visited 29 June 2010, <http://docs.geoserver.org/stable/en/user/styling/sld-introduction.html>.

GRASS-Wiki 2010, Vector network analysis – GRASS-Wiki, viewed 23 June 2010, <http://grass.osgeo.org/wiki/Vector_network_analysis>.

Hansen, W 1959, 'How accessibility shapes land use', *Journal of the American Institute of Planners*, vol. 25 (1), pp. 73–76.

Malczewski, J 1999, *GIS and Multicriteria Decision Analysis*, Wiley and Sons, New York.

Microsoft 2010, Maximum URL length is 2,083 characters in Internet Explorer, viewed 20 June 2010, <http://support.microsoft.com/kb/208427>.

Neis, P & Zipf, A 2007, 'A Web Accessibility Analysis Service based on the OpenLS Route Service', proceedings of the *International Conference on Geographic Information Science (AGILE),* Aalborg, Denmark.

Nelson, A 2008, 'Travel time to major cities: A global map of Accessibility', *Global Environment Monitoring Unit – Joint Research Centre of the European Commission*, Ispra, Italy, viewed 4 July 2010, <http://bioval.jrc.ec.europa.eu/products/gam/index.htm>.

Perkins, HA, Heynen, N & Wilson, J 2004, 'Inequitable access to urban reforestation: the impact of urban political economy on housing tenure and urban forests'. *Cities*, vol. 21, no. 4, pp. 291–299.

Pozzi, F & Robinson, T 2008, 'Accessibility Mapping in the Horn of Africa', *IGAD Livestock Policy Initiative Working Paper No. 11 – 08*, FAO, Rome, viewed 20 June 2009, <http://www.igad-lpi.org/publication/docs/IGADLPI_WP11_08.pdf>.

OGC 2002, *Styled Layer Descriptor Implementation Specification*, Open Geospatial Consortium.

OGC 2005, *OpenGIS® Filter Encoding Implementation Specification*, Open Geospatial Consortium.

OGC 2007, *Styled Layer Descriptor profile of the Web Map Service Implementation Specification*, Open Geospatial Consortium.

Oh, K & Jeong, S 2007, 'Assessing the spatial distribution of urban parks using GIS', *Landscape and urban planning*, vol. 82, pp. 25–32.

Okabe, A, Okunuki, K, Shiode, S 2006, 'SANET: a toolbox for spatial analysis on a network', *Geographical Analysis*, vol. 38, pp. 57–66.

Olvera, LD, Plat, D & Pochet, P 2003, 'Transportation conditions and access to services in a context of urban sprawl and deregulation. The case of Dar es Salaam', *Transport policy*, vol. 10, no. 4, pp. 287–298.

OpenLayers 2010, OpenLayers: Home, viewed 20 June 2010, <http://www.openlayers.org/>.

Rosero-Bixby, L 2004, 'Spatial access to health care in Costa Rica and its equity: a GIS-based study', *Social Science & Medicine*, vol. 58, no. 7, pp. 1271–1284.

Sencha 2010, Ext JS – Client-side JavaScript Framework, viewed 21 June 2010, <http://www.sencha.com/products/js/>.

W3C 1999, World Wide Web Consortium, HTTP/1.1:Protocol Parameters, The Internet Society, Internet RFC 2616, Fielding et al., viewed 29 June 2010, <http://www.w3.org/Protocols/rfc2616/rfc2616-sec3.html#sec3.2.1>.

Zhu, X & Liu, S 2004, 'Analysis of the Impact of the MRT system on accessibility in Singapore using an integrated GIS tool', *Journal of Transport Geography*, vol. 12, pp. 89-101.

Zhu, X, Liu, S & Yeow, MC 2005, 'A GIS-based multi-criteria analysis approach to accessibility analysis for housing development in Singapore', proceedings of *SSC 2005 Spatial Intelligence, Innovation and Praxis: The national biennial Conference of the Spatial Sciences Institute*, September 2005, Melbourne.

Zhu, X, Liu, S & Yeow, MC 2006, 'Accessibility analysis for housing development in Singapore with GIS and multi-criteria analysis methods', *Applied GIS*, vol. 2 (2), pp. 13.1–13.12.

Zipf, A 2005, 'Using Styled Layer Descriptor (SLD) for the dynamic generation of user-and context-adaptive mobile maps–a technical framework', Web and Wireless Geographical Information Systems, pp. 183–193.