Application of Multi-Criteria Decision Making to create a map of suitability areas of city Lviv for selection of the location a residence

*A. Babushka, A. Romanovskiyi (Lviv Polytechnic National University)

SUMMARY

The territory of the city of Lviv was divided into zones with the help of Multi-Criteria Decision Making and the Analytic Hierarchy Process to build a map of the suitability of housing. Criteria that have a direct impact on the quality of daily life were taken into account. These criteria were given relative importance. Based on these criteria, geoprocessing operations and the necessary calculations to obtain a suitability map was performed. The zoning of the city of Lviv was determined to assess the suitability of the place of residence.
Introduction

In recent years, Ukraine take a place active building cities with housing estates. The biggest cities of Ukraine are experiencing the widest development. Lviv is no exception, within which new buildings are put into operation every month. These processes create new problems and challenges that need to be addressed quickly. It is no secret that in most, the territory of Ukrainian administrative units has not relevant master plans and urban development projects. This leads to the fact that a lot of construction is illegal, either in violation of state-building norms or without taking into account long-term development plans. In December 2019, the Lviv City Council published information on illegal constructions on the territory of Lviv, their number reached 10 objects. In addition to official data, there are many more objects with violations of various kinds. This situation indicates that local governments need to create relevant plans for long-term development, to develop detailed plans of areas for design.

Multi-Criteria Decision Analysis, or MCDA, is a valuable tool that we can apply to many complex decisions. This approach is very useful in the field of GIS for site selection. For assessment living quality districts of city Liverpool, Great Britain (Mulliner et al) was compound MCDA. In cooperation with the local government were defined points of influence on life quality. As a result was got benefits, based on assessment points and value for potential investors and buyers. By applying this method of analysis it is possible to solve a problem of residential real estate. In (Da Wei, Yijie Ding) was made a map of suitability for residence selection in city Guangzhou, China, based on constraints and factors map. Constraints map was made to exclude zones, where the building is not possible, factors map was made to the points which influence the suitability of the area.

Proceeding of Multi-Criteria Decision Analysis can be done in special software for GIS and spatial analysis tasks. Map of best districts city Kuopio, Finland for choosing residence to introduce in (Albacete, et al). Applying analysis tools of software ArcGIS were created two maps for young families and alone people based on the accessibility of infrastructure, educational, medicine, and cultural objects. Creating map of suitability could be selected as some factors which have a specific influence on the study area. It depends on the location and problems of the study area. For the city Mattara, India has created a map of suitability based on the density of population (Madurika, Hemakumara). This research was made in ArcGIS software by applying some extensions such as Spatial Analyst and Model Builder and was proven advantage of using these tools for implementing of MCDA.

Methodology

This study mainly uses tools and methods of analysis, namely - the method MCDA. This is the general name of the method, which is based on the use of numerous data transformation operations, building hierarchical relationships between input data and assigning them importance factors, scaling different data formats into a single system. The first stage of the work was the selection of criteria that may affect the quality of housing in certain areas. The consistent part of MCDA is the Analytic Hierarchy Process (AHP), which is a powerful tool that has been used in numerous applications in the field of GIS (Saaty, 1977). It organizes the basic rationality by breaking down a problem into its smaller constituent parts and then calls for only simple pairwise comparison judgments, to develop priorities in each hierarchy.

The task of this observation is to define the grade of the area city Lviv for residence selection. For completing research of the areas of the city in the field of real estate management, were selected some criteria which have a direct influence on the suitability for living or constructing new apartments. That criteria can be divided into the groups:

- Educational objects (school, kindergarten);
- Infrastructure objects (supermarket, public transport stops);
- Cultural objects (cinema, theatre);
- Leisure objects (parks and green zones);
- Other (noise level, building density).
The assessment point of the factors from all groups excluding Other is the distance between the object and map unit, see Figure 3. For assessing noise level Figure 2 was used a map created by applying the Weighted Overlay tool combining the influence of the noise from roads (20%), airport and routes of aircraft (40%), railway (25%), tramline (15%). The resulting map was introduced in relative units. The map of building density represents units per square kilometer.

Figure 1. Schema of Analytic Hierarchy Process with criteria which included in MCDA to define suitability areas.

Figure 2. Map of noise level was applied as input data, measured in relative units

Figure 3. Map of distance to school was applied as input data, measured in meters

As a lot of data were used in different measuring units, therefore is not possible to get the result in one measuring system. Wherefore the most important point in MCDA is the standardization of the data. That operation can be done through the recalculation of units every criterion in one selected system (Yankiv-Vitkovska et al, 2020). There are two cases: for direct linear correlation with criteria (1), for inverse correlation with criteria (2).

\[ X_i = \frac{(x_i - \text{min}_i)}{(\text{max}_i - \text{min}_i)} \] (1)

\[ X_i = \frac{\text{max}_i - x_i}{(\text{max}_i - \text{min}_i)} \] (2)

Figure 4. Direct (left) and inverse (right) dependence of suitability on the criterion.

The next step of implementing MCDA is rescaling selected criterion according to standardization methods. Table 1 is presented the distances from objects of every criteria to every unit on the map. The distances and relative units of Density and Noise were reclassified according to the data in Table 1.
Table 1. Conformity of every criterion to the scale 1-7, (*data introduce in relative units).

<table>
<thead>
<tr>
<th>Scale</th>
<th>School, m</th>
<th>Kindergarten, m</th>
<th>Retail, m</th>
<th>Bus stops, m</th>
<th>Park, m</th>
<th>Culture, m</th>
<th>Density*</th>
<th>Noise*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 0-200</td>
<td>0-200</td>
<td>0-100</td>
<td>0-100</td>
<td>0-500</td>
<td>0-500</td>
<td>0-368</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2 200-400</td>
<td>200-400</td>
<td>100-200</td>
<td>100-200</td>
<td>500-1000</td>
<td>500-1000</td>
<td>368-1105</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3 400-600</td>
<td>400-600</td>
<td>200-300</td>
<td>200-300</td>
<td>1000-1500</td>
<td>1000-1500</td>
<td>1105-1942</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4 600-1000</td>
<td>600-1000</td>
<td>300-400</td>
<td>300-400</td>
<td>1500-2000</td>
<td>1500-2000</td>
<td>1942-2913</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>5 1000-1800</td>
<td>1000-1800</td>
<td>400-800</td>
<td>400-800</td>
<td>2000-3500</td>
<td>2000-3500</td>
<td>2913-4152</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>6 1800-3000</td>
<td>1800-3000</td>
<td>800-1600</td>
<td>800-1600</td>
<td>3500-5500</td>
<td>3500-5500</td>
<td>4152-5860</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>7 3000-8000</td>
<td>3000-8000</td>
<td>1600-5000</td>
<td>1600-5000</td>
<td>5500-10000</td>
<td>5500-10000</td>
<td>5860-8540</td>
<td>No Data</td>
<td></td>
</tr>
</tbody>
</table>

For getting the value of every selected criterion, were made a pairwise comparison matrix Table 2. The goal of this comparing is the weight of every input criterion between each other.

Table 2. Pairwise comparison matrix

<table>
<thead>
<tr>
<th>School</th>
<th>Kindergarten</th>
<th>Supermarket</th>
<th>Bus stops</th>
<th>Parks</th>
<th>Culture</th>
<th>Noise</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>School</td>
<td>1.00</td>
<td>4.00</td>
<td>4.00</td>
<td>2.00</td>
<td>2.00</td>
<td>4.00</td>
<td>4.00</td>
</tr>
<tr>
<td>Kindergarten</td>
<td>1.00</td>
<td>1.00</td>
<td>4.00</td>
<td>4.00</td>
<td>2.00</td>
<td>4.00</td>
<td>4.00</td>
</tr>
<tr>
<td>Supermarket</td>
<td>0.25</td>
<td>0.25</td>
<td>1.00</td>
<td>0.25</td>
<td>0.25</td>
<td>2.00</td>
<td>2.00</td>
</tr>
<tr>
<td>Bus stops</td>
<td>0.25</td>
<td>0.25</td>
<td>1.00</td>
<td>0.25</td>
<td>0.25</td>
<td>2.00</td>
<td>2.00</td>
</tr>
<tr>
<td>Parks</td>
<td>0.50</td>
<td>0.50</td>
<td>4.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>Culture</td>
<td>0.50</td>
<td>0.50</td>
<td>4.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>Noise</td>
<td>0.25</td>
<td>0.25</td>
<td>0.50</td>
<td>0.50</td>
<td>2.00</td>
<td>2.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Density</td>
<td>0.25</td>
<td>0.25</td>
<td>0.50</td>
<td>0.50</td>
<td>2.00</td>
<td>2.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

A standardized matrix was completed applying the result of pairwise comparison. As output data got a weight of each criterion for creating the map of suitability.

Table 3. A Standardized matrix

<table>
<thead>
<tr>
<th>School</th>
<th>Kindergarten</th>
<th>Supermarket</th>
<th>Bus stops</th>
<th>Parks</th>
<th>Culture</th>
<th>Noise</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>School</td>
<td>0.25</td>
<td>0.25</td>
<td>0.21</td>
<td>0.21</td>
<td>0.19</td>
<td>0.19</td>
<td>0.27</td>
</tr>
<tr>
<td>Kindergarten</td>
<td>0.25</td>
<td>0.25</td>
<td>0.21</td>
<td>0.19</td>
<td>0.19</td>
<td>0.19</td>
<td>0.27</td>
</tr>
<tr>
<td>Supermarket</td>
<td>0.06</td>
<td>0.06</td>
<td>0.05</td>
<td>0.05</td>
<td>0.02</td>
<td>0.02</td>
<td>0.13</td>
</tr>
<tr>
<td>Bus stops</td>
<td>0.06</td>
<td>0.06</td>
<td>0.05</td>
<td>0.05</td>
<td>0.02</td>
<td>0.02</td>
<td>0.13</td>
</tr>
<tr>
<td>Parks</td>
<td>0.13</td>
<td>0.13</td>
<td>0.21</td>
<td>0.21</td>
<td>0.10</td>
<td>0.10</td>
<td>0.03</td>
</tr>
<tr>
<td>Culture</td>
<td>0.13</td>
<td>0.13</td>
<td>0.21</td>
<td>0.21</td>
<td>0.10</td>
<td>0.10</td>
<td>0.03</td>
</tr>
<tr>
<td>Noise</td>
<td>0.06</td>
<td>0.06</td>
<td>0.03</td>
<td>0.03</td>
<td>0.19</td>
<td>0.19</td>
<td>0.07</td>
</tr>
<tr>
<td>Density</td>
<td>0.06</td>
<td>0.06</td>
<td>0.03</td>
<td>0.03</td>
<td>0.19</td>
<td>0.19</td>
<td>0.07</td>
</tr>
</tbody>
</table>

After all mathematical operations with criteria were done the process of creating a map of suitability area of city Lviv Figure 5 for assessing their quality for residence selection. For this procedure were chosen software package ArcGis. By applying the tool of Weighted overlay were calculated 6 zones which define the relative difference of suitability.

Table 4. Weights

<table>
<thead>
<tr>
<th></th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>School</td>
<td>22.9%</td>
</tr>
<tr>
<td>Kindergarten</td>
<td>22.9%</td>
</tr>
<tr>
<td>Supermarket</td>
<td>6.8%</td>
</tr>
<tr>
<td>Bus stops</td>
<td>6.8%</td>
</tr>
<tr>
<td>Parks</td>
<td>11.6%</td>
</tr>
<tr>
<td>Culture</td>
<td>11.6%</td>
</tr>
<tr>
<td>Noise</td>
<td>8.6%</td>
</tr>
<tr>
<td>Density</td>
<td>8.7%</td>
</tr>
</tbody>
</table>
Conclusions

Multi-Criteria Decision Making an Analytic Hierarchy Process was successfully implemented for GIS analysis. According to a created map of suitability, the areas of Lviv were divided into zones with different assessment points for residence selection. Every zone within the borders of the city has an equal area, which made the calculation correct. By analysis of the map results, it is possible to locate every selected object in the city and define to which zone they are related, and check their accessibility. Therefore this kind of analysis is affordable for many tasks where needed high-quality GIS analysis, especially for urban planning.

References


