Headquarters Papers
#UOET Proceedings 2023
https://www.milak.at/nike/uoet

doi: 10.5281/zenodo.11172301

Multi-Dimensional and Multi-Domain Battlespace Complexity Pre-Evaluation for Urban Areas of Operation

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The geography dictates the operational tactics and the sooner the geographical particularity of the area of operations is known, the better leaders can prepare for that. Beside mountainous regions, forests and open landscape, urban areas have the potential to be very complex: structures along all three spatial axes and filled with public, administrative or private content. Using open-source data, the degree of urban complexity can be pre-evaluated by tools of geospatial statistics to provide simple classification for military decision-makers on a map.

Key Words: data analysis, geographical information system, geospatial statistics, open-source data

1. Introduction

The world of available geographical data has increased constantly in quality and quantity over the last decades. One worldwide relevant provider for open spatial data is called OpenStreetMap[1] (OSM), which can be understood as a platform where participants enter and request spatial features. This global data set does not only allow creating maps of different scales in a high update frequency, e.g. OpenTopoMap[2], but also setting up individual spatial analysis upon the raw data. Global coverage and no significant delay between data input und data request characterizes OSM and forms an attractive data source for military geographical applications.

In this spatial data context, the working hypothesis of this paper focuses on the geographical support for the development phase of the plan of action for operations in urban areas. Urban areas are characterized by surface, super-surface and sub-surface elements – geometrical aspects along all three spatial axes – which are assigned to different domains – use and property qualities. All this creates an environment of different geographical complexities respecting the subsequent definition of complexity in a military context:

"It is unknown, unpredictable and constantly changing." (Perkins 2015, time stamp 15:45)

The scale of geographical complexity can reach from an outdoor park-and-ride facility, over a shopping center connected to the on-surface public means of transport, to a hospital multi-level building with helipad, underground car park and access to the subway system.

The earlier the geography and its complexity is known – even in the sense of information superiority – to the operation planning personnel, the higher the quality of a decision can be achieved and surprises for troops on-site avoided (Strauß et al. 2021). Also, the need for different branches to cooperate and be ready for sudden needs in a certain area can be anticipated when the potential battlespace has already been pre-evaluated according to its complexity.

To achieve this pre-evaluation of complexity for a defined area OSM data has to be geographically limited, thematically filtered according to relevant domains, geo-statistically analyzed and cartographically provided to military decision-makers.

[1] https://www.openstreetmap.org [15/05/2023].
[2] https://opentopomap.org [15/05/2023].

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2. The geo-statistical approach

A geographical information system (GIS) allows its user to limit and filter spatial data, apply statistical methods to this data subset and produce cartographic results. For this work the software QGIS[3], a free GIS software, does all this processing steps; for quality and quantity reasons a high ratio of automation is strived for and performed in QGIS Model Designer.

a. Relevant data

To compute finally a representative value for urban complexity firstly relevant feature classes for urbanity need to be found within the OSM that have the potential to create a complex area by increasing quantity. The following OSM feature classes have been selected for that reason: point of interest (POI), transportation (TRA), road network (ROA), railroad network (RAI), subway network (SUB), buildings (BUI). Some of these feature classes only exist in urban areas, e.g. subway, or the density of their appearance imply urban areas, e.g. road network, buildings, bus and tram stops.

b. Statistical analysis

To empower features of the above-identified relevant feature classes for further analyses they have to be collected in geo-spatial diagnosis unit (GDU). Strauß et al. (2022) describe the use of hexagon-shaped features as GDU for geo-statistical analysis and is adapted to the needs for this urban complexity determination: Hexagons are spread in a regular grid across the area of interest, e.g. a city, and the number of appearances, the length of network elements or the base area of plane features are counted per GDU. All length values are normalized by the length of the hexagon's perimeter (PER) (road network, railroad network and subway network) and all area values are normalized by the hexagon's area (base area of buildings). Finally, one single complexity value (C) is calculated for each GDU based on this normalized and counted values. The weight coefficients are empirically determined by use of the Vienna data set:

$$C_{GDU}=count_{GDU}^{POI}+count_{GDU}^{TRA}+\frac{length_{GDU}^{ROA}}{length_{GDU}^{PER}}+\frac{length_{GDU}^{RAI}}{length_{GDU}^{PER}}\cdot 0.3+\frac{length_{GDU}^{SUB}}{length_{GDU}^{PER}}\cdot 2+\frac{area_{GDU}^{BUI}}{area_{GDU}}$$

c. Realization

To gain a sustainable realization the whole process has been created in QGIS Model Designer. The process, as it is shown in Figure 1, is set up by different drag-and-drop functions from a library, defining input and output parameters and is saved as a file that can be shared amongst all QGIS users. In addition to the parameters explained above, the general area of interest and the hexagon size have to be specified by the user. Then it is all about clicking the play-button and nervously waiting for the results.

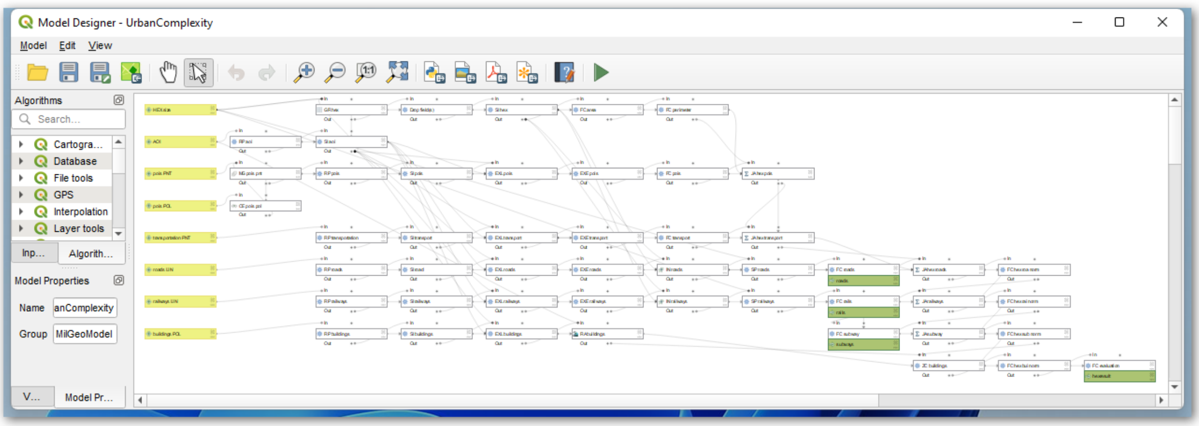

Figure 1: Process of geo-statistical data evaluation realized in QGIS Model Designer. Yellow boxes: Input parametrs. White boxes: Processing steps. Green boxes: Final processing results.

[3] https://qgis.org [15/05/2023]

3. Results

The proof of this geo-statistical concept is done by evaluating three locations in Europe: Vienna in Austria (Figure 2), Vilnius in Lithuania (Figure 3) and Kyiv in Ukraine (Figure 4). The first location, Vienna, is used for empirical adaption of the complexity formula. The other two locations are for applying the complexity process only. As all parameters (size of general area of interest, size of GDU, formula parameters) are equally used for all three locations, they are comparable among one another.

For each location four maps are displayed: Introducing the general situation by a topographic representation in the upper left corner. In the upper right corner, the linear and planar spatial data are shown that are used as base data. The results of the complexity evaluation across the whole area are visualized in the lower left corner. Therefore, the resulting complexity value is divided into classes of low, medium and high complexity. Values under a certain threshold are ignored. The last image in the lower right corner zooms in to the highest complex situation in the whole scene and combines a topographic map (1:50,000-style) with categorized hexagons. The quality of complexity is not represented on any topographic map solely, only the hexagon overlay provides this valuable information!

a. Vienna (Austria)

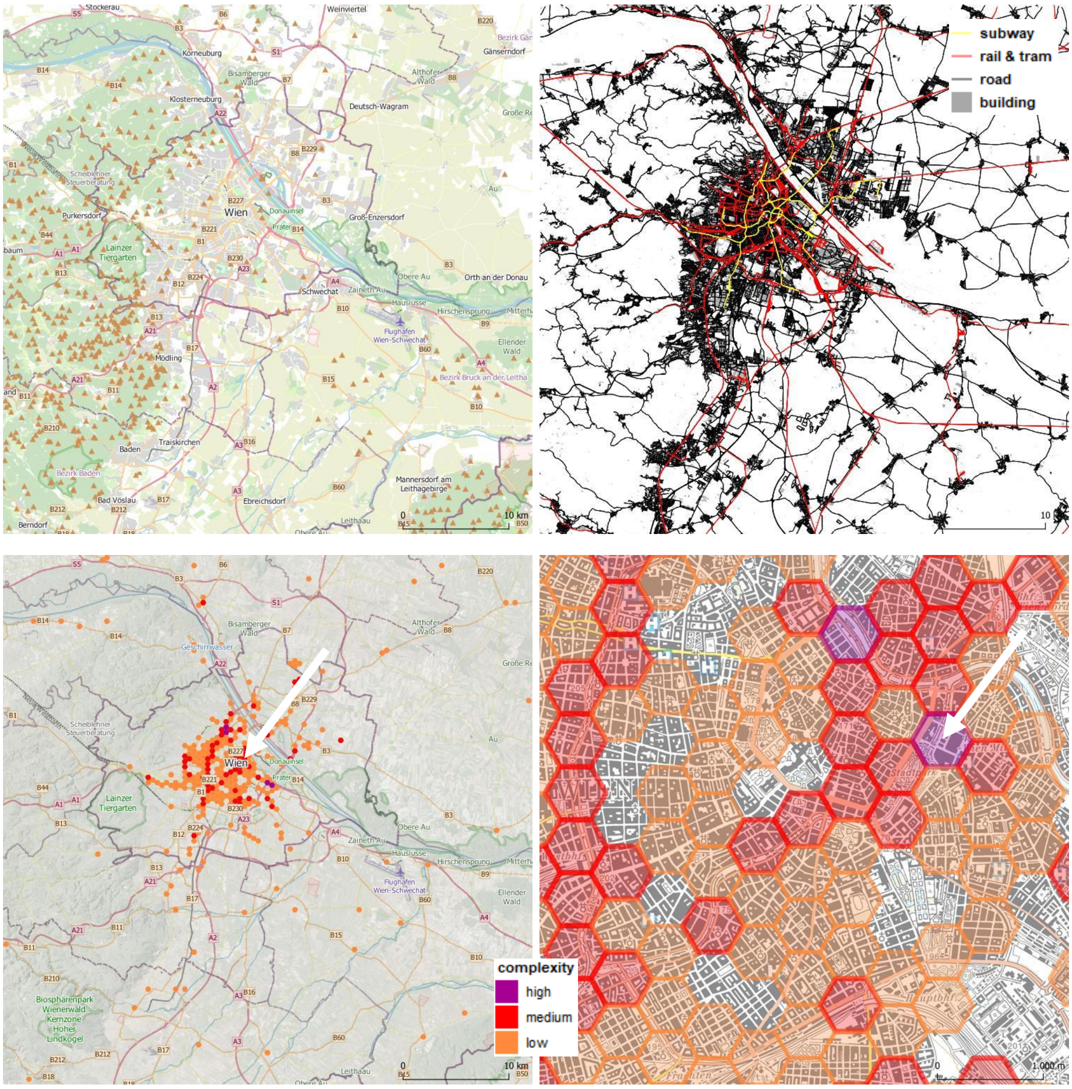

Figure 2: Topographic map of Vienna region in Austria (ESRI OpenStreetMap vector tile service); Vector data used for geostatistical evaluation (OpenStreetMap); Categorized evaluation result (Bing, ESRI OpenStreetMap vector tile service); Detail scene of categorized evaluation result on topographic map (BEV) (ltrttb).

Vienna region in Austria is the first area for this complexity evaluation concept. It covers a narrow road network in the city center, different means of public transportation on- and sub-surface and, according to public administration and international organizations, Vienna hosts many facilities. This mass of complexity relevant content leads to the evaluation results shown in the lower two maps in Figure 2. In the city center complex GDUs are accumulating. One masterpiece of complexity is the area of "Bahnhof Wien Mitte" (white arrow), a junction for two subway lines, municipality railway lines, bus and tram lines and surrounded by shopping malls, the University of Applied Arts Vienna, and the Austrian Federal Computing Center.

b. Vilnius (Lithuania)

Vilnius region in Lithuania is chosen second for evaluating this complexity assessment process. Compared to Vienna[4] only approximately a quarter of people are living in Vilnius[5]. Furthermore, Vilnius manages its public transportation without a subway network. In general, this leads to a less complex situation in total. Nevertheless, there are two clusters appearing in the complexity maps in Figure 3: First the area around the hospital in the norther part of Vilnius (yellow arrow), and the area around the main train station and central bus depot surrounded by shops and restaurants (white arrow).

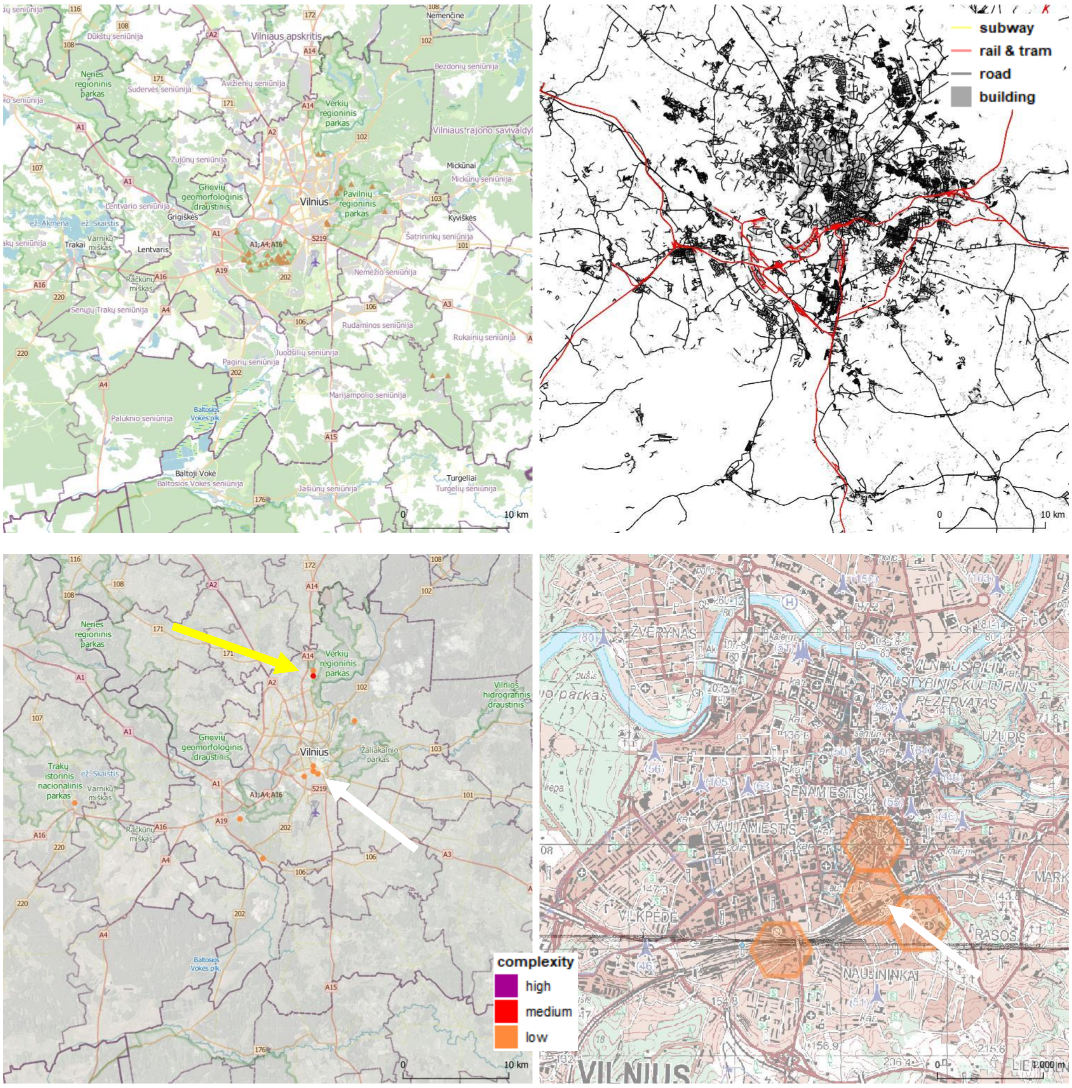

Figure 3: Topographic map of Vilnius region in Lithuania (ESRI OpenStreetMap vector tile service); Vector data used for geostatistical evaluation (OpenStreetMap); Categorized evaluation result (Bing, ESRI OpenStreetMap vector tile service); Detail scene of categorized evaluation result on topographic map (AGI) (ltrttb).

[4] https://en.wikipedia.org/wiki/Vienna [16/05/2023].
[5] https://en.wikipedia.org/wiki/Vilnius [16/05/2023].

c. Kyiv (Ukraine)

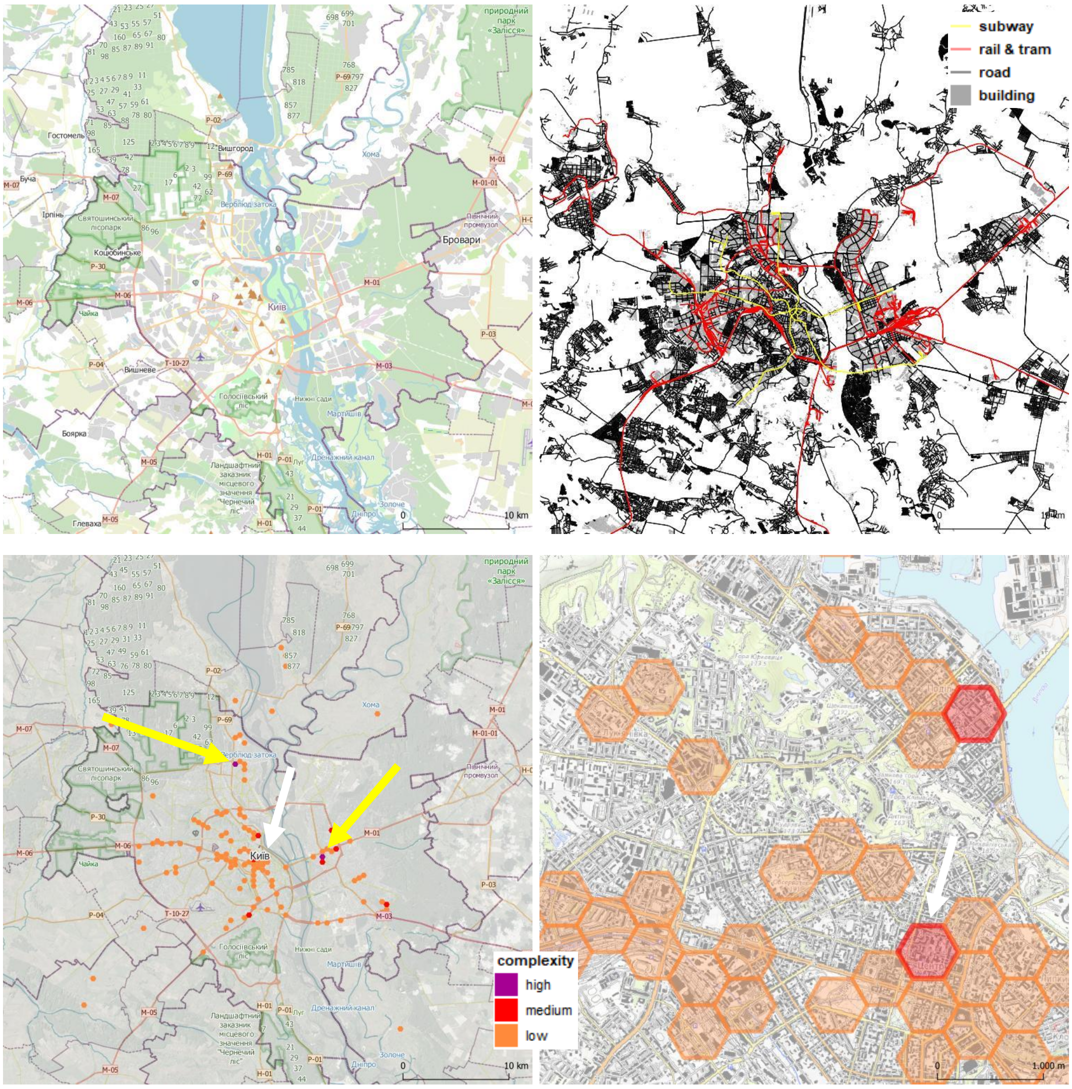

Figure 4: Topographic map of Kyiv region in Ukraine (ESRI OpenStreetMap vector tile service); Vector data used for geostatistical evaluation (OpenStreetMap); Categorized evaluation result (Bing, ESRI OpenStreetMap vector tile service); Detail scene of categorized evaluation result on topographic map (OpenTopoMap) (ltrttb).

The third and last location is Kyiv region in Ukraine. Although the population is larger than 1 million compared to Vienna and a subway network is present, the resulting complexity is lower than Vienna's result. The presumptive reason for that can be found in the population density of Kyiv[6] by approximately 3,299 capita/km² compared to 4,326 capita/km² in Vienna[7].

The most complex areas are identified at maintenance facilities of Kyiv's subway system marked with yellow arrows in Figure 4; this might indicate the need for rebalancing the weight coefficients within the complexity formula. A more reasonable result is pinpointed by a white arrow: It points to the city center close to the Maidan square. A lot of points of interests, like the Kyiv City Council, a hospital cluster of different disciplines, shops and restaurants are located there and the junction of two subway lines are present at this location, too.

[6] https://en.wikipedia.org/wiki/Kyiv [16/05/2023].
[7] https://en.wikipedia.org/wiki/Vienna [16/05/2023].

4. Discussion, Conclusion and Outlook

OpenStreetMap covers a wide range of different spatial features all over the world. A thematical subset of this data convolute appears only in urban regions, others appear in urban and rural regions, but accumulate in urban areas. To successfully identify these themes for representing urbanity and the ones that are responsible to make locations complex in the sense of military operations is a challenging task. Also challenging is to combine the identified themes to a single numerical value to represent complexity.

This work is a step further for automated computation of this complexity value by simply defining an area of interest and a size for the geo-spatial diagnosis unit, which corresponds to the aimed map scale, e.g. GDU size of 500m for a target map scale of 1:50,000. To overlay the resulting hexagons on topographic maps and image maps illustrates a useful method to bring complexity on well-known cartographical products and an additional value for military decision-makers and staff personnel.

More work has to be concretely done according to the formula development to consider railway and subway depots in an appropriate way. Also, an artificial intelligence-based approach for complexity detection seems to be a reasonable option for future work.

Although complex reality challenges decision-makers, it is invaluable to know where these complex locations are instead of being taken by surprise by their sudden appearance!

Publication bibliography

Perkins, David. G. (2015): The Army Operating Concept. U.S. Naval War College, Lecture of Opportunity. Available online at https://www.youtube.com/watch?v=cejIOH-yjIE&t=41s, checked on 15/05/2023.

Strauß, Clemens; Hofer, Peter; Herda, Gerhard (2021): Optimizing the Reactive Event Management based on Geographical Anayses and Products. In *AGIT 7-2021*, pp. 67-72. DOI: 10.14627/537707003.

Strauß, Clemens; Hofer, Peter; Herda, Gerhard; Teichmann, Friedrich (2022): The world is a hexagon – Geospatial statistics – An appropriate tool for military decision making in challenging situations. Poster presented at *GI_Salzburg 2022*.