Delineation of the boundary of an urban agglomeration: evidence from Riga, Latvia

Abstract
Statistical, morphological and functional approaches have long been used to delineate spatial boundaries of urban agglomerations. This research uses data from the Central Statistical Bureau and the State Revenue Service. The results indicate that morphological and functional approaches are essential when defining the agglomeration, however the outcomes are different. The most relevant consistency was observed in the territorial units adjoining the city of Riga due to the fact that they have a common labour market with Riga and share a strong functional linkage. However, the spatial extent based on the morphological approach confirms and highlights the effects of urban sprawl.

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Introduction
The relationship between urban form and travel patterns has been a significant research topic in urban studies (see e.g. Stead & Marshall 2001). Research that examines the relationship between urban spatial structure and commuting patterns has gained importance in Latvia (Krisjane & Berzins 2009; Krisjane et al. 2012). Since the collapse of socialism, the most eye-catching processes in urban spatial structure across Central and Eastern Europe are related to suburban development (Boren & Gentile 2007; Tammaru & Kontuly 2011; Tammaru & van Kempen 2012; Sykora & Stanilov 2014; Szczepanska 2016). Previous research reveals that socio-spatial restructuring due to suburbanisation was more prevalent in the metropolitan areas of capital cities (Novak & Sykora 2007; Ahas et al. 2010; Krisjane & Berzins 2012; Novotny 2016). Regarding urban spatial structure, many studies have shown that the area and shape of an urban agglomeration are significantly correlated with commuting patterns (Morrill, Cromptie & Hart 1999; Kloosterman & Musterd 2001; Schwanen, Dijst & Dieleman 2002). Most of the existing studies on the relationship between commuting patterns and the spatial structure of agglomerations revolves around the process of urban sprawl (Couch, Leontidou & Arnstberg 2007; Travisi, Camagni & Nijkamp 2010; Kabisch & Haase 2011). In Latvia, the effects of commuting in relation to the development of Riga agglomeration were already studied during the socialism period (Bauls 1978; Fuchs & Demko 1978; Bauls & Koziols 1989; Filimonenko 1991).

The urban agglomeration is a highly developed spatial form of a settlement system (Fang & Yu 2017: 1, 8). Development of urban agglomerations is a complex process. Morphological and functional criteria are most commonly used, either separately or simultaneously, to define urban agglomerations (Parr 2007; Thomas et al. 2012).

Therefore, using Riga agglomeration as an example, the aim of this paper is to delineate the boundary of the urban agglomeration by utilising both morphological and functional approaches. Our research relies on statistical information derived from the Central Statistical Bureau (CSB or CSP in Latvian) and the State Revenue Service (SRS; Valsts Ienēmu mu dienests). The novelty of the paper lies in the fact that our approach simultaneously uses both criteria, an approach that has yet to be used in Latvia.

The paper is organised as follows. The next section gives an overview of two main approaches used to delineate urban agglomerations. Then, we present our case study area in terms of historical development and commuting patterns in the Riga agglomeration. The description of data, methods and our research strategy are followed by the results. We conclude and discuss the main findings of our study in the last section.

Defining urban agglomerations
Two main approaches, morphological and functional, are used to measure the spatial structure of settlement systems (Fang & Yu 2017). The most considerable difference of opinion in the academic debate rests on the question of whether the definition of urban agglomeration refers just to functional or to morphological aspects of the settlement system or whether it should incorporate both (Burger & Meijers 2012). We will use an approach summarising both types of indicators, which are available in the case of the Riga agglomeration. The threshold-based analysis is adopted in defining the urban agglomeration for the purpose of this research.

While M. Burger & E. Meijers (2012) refer to polycentric regions and the morphological approach as describing urban spatial structure and the functional approach as describing linkages of territorial units in space, we refer just to the general idea. Therefore, we pinpoint 2 main reasons to justify choosing a different methodological approach to those presented in the body of the literature dedicated to the aforementioned debate:

1) Riga agglomeration is a mostly monocentric entity (in Latvia) from the population distribution and labour market standpoint. In 2017, 55.2% of the total population of Latvia live in the Riga agglomeration. There are 178 944 jobs outside of Riga, along with over 450 000 in the capital (CSB Database).
2) Data availability. It is not possible for us to describe linkages of territorial units in space, since there are no datasets available. Conversely, for this research a functional agglomeration is defined as a functional urban region (see e.g. Klapka & Halas 2016), but paying attention to the interaction between the core city and surrounding areas in both directions (in this commuting to and from Riga). Also, there are no datasets that would allow an in-depth description of urban spatial structure.

Morphological approach
The morphological approach is mostly based on urban spatial structure, defined as the built environment in terms of land use. Consequently, spatial data is key to this approach (Liang, Li & Mao 2010). It can also be defined as a statistical or quantitative perspective (Fang & Yu 2017). Also, population density thresholds have regularly been used. The scales vary – either 1 km² grid cells are utilised, where inclusion/exclusion is conducted by identifying continuous cells that match (or exceed)
Functional approach

This approach, based on various socio-economic characteristics of individuals, analyses functional relationships within the particular settlement system (Liang, Li & Mao 2010). Functional interconnectivity and accessibility are also important for this approach (Fang & Yu 2017). This approach is more commonly used than the morphological one (Liang, Li & Mao 2010) and since socio-economic data is incredibly important, many studies have used various social (Thomas et al. 2012) and economic (activity) indicators and their thresholds (Sykora & Mulicek 2009; Czyż 2011; Fang & Yu 2017; Cottineau et al. 2018). These include, but are not limited to, GDP data, number of workplaces (mostly in the core city), income and tax data.

Studies that use algorithms to delineate local labour markets or urban agglomerations commonly prioritise commuting flows to the core city, often by applying different thresholds (Corvers, Hensen & Bongaerts 2009; Sykora & Mulicek 2009; Cottineau et al. 2018; INSEE Definition of urban area). There are various commuting flows – those to and from the core city, a combination of both, or flows based on motivation, e.g. work, leisure activity (Corvers, Hensen & Bongaerts 2009). In some cases, thresholds are pre-defined, in others they are calculated using various mathematical methods or models (Thomas et al. 2012). Travel time thresholds are also frequently used. Focus is usually placed on the main motorways connecting various settlements and rural areas with the core city or other urban centres (Kauder 2015; Fedorova, Safina & Essuman-Quainoo 2018).

Development of the Riga agglomeration and its delineation

In Latvia, the smallest territorial unit used in statistics is the rural parish (pagasts) or urban area. The highest level of aggregation are five statistical regions. One of the five statistical regions is Pieriga region, which is considered as the metropolitan region of the capital city of Riga. The Pieriga statistical region is a considerably larger territory than the functional area of the Riga agglomeration, indeed the Riga agglomeration has never existed as an administrative or a statistical unit (Krisjane & Berzins 2012).

The area of the Riga agglomeration was first delineated in the mid-20th century, when the primal zone of influence was determined as a result of the spatial planning of the Soviet state by adjusting economic zoning principles to the settlement of Latvia (Filimonenko 1991). During the 1970’s and 1980’s, numerous research papers were published in relation to everyday work and study mobility in the area (e.g. Bauls 1978; Bauls & Koziols 1989). Such studies enabled the intensity of commuter flows to be determined along with functional relations between specific cities and towns of the Riga agglomeration.

In policy documents the Riga agglomeration was identified as a spatial unit for research and sub-/urban planning (Krisjane & Berzins 2009). The territory of the agglomeration has substantially expanded since the 1970’s in relation to the changing nature of the socio-spatial structure, migration and commuting patterns. The latter has had a very important role in determining of the borders of the agglomeration. In the 1980s, the Riga agglomeration was defined as the area adjacent to Riga city (Filimonenko 1991: 83-85). It comprised both urban and rural areas interconnected by commuting flows. Thus, the functional area supported the core city and took advantage of its proximity and economic capacity (Krisjane et al. 2007). At that time the main indicators used for the definition of an urban agglomeration had a particular focus on migration intensity and commuting flows to and from the core city (Bauls et al. 1996). Subsequently the shape of the agglomeration was considered to be a regular circle with a radius of 60-70 km around Riga, with travel times of up to 1.5 hours (Filimonenko 1991: 19). Since the restoration of independence in 1991, a total of four studies have been conducted by the University of Latvia to delineate the territory of the Riga agglomeration (Bauls et al. 1996; Rigas aglomerācijas robežu noteikšana 2004. gada; Rigas aglomerācijas robežu noteikšana 2012. gada; Rigas aglomerācijas robežu noteikšana 2017. gada). Methodically, in all cases, a predominantly functional approach was applied to delineate external borders. The methodology has always suggested following characteristics or spatial units in order to identify or refine the boundaries of the agglomeration: 1) administrative territorial division; 2) distance to Riga; 3) everyday commutes to/from Riga based on survey data (Bauls et al. 1996: 7).

The agglomeration can be characterised by population change and the impact of internal and international...
mobility. However, everyday mobility is a critical factor in the determination of the area. The latest study of the agglomeration boundaries (Rīgas aglomerācijas robežu precizēšana 2017. gadā) used 3 main and 3 additional indicators. Most of them were related to the intensity of everyday work mobility to and from Riga.

1) The share of personal income tax of inhabitants that work in Riga compared to the whole amount of income tax collected from all residents of a parish/city (data from 2016);
2) The number of work commuters to Riga from other territorial units (data from 2016). Based on personal income tax data;
3) The number of work commuters from Riga to other territorial units (data from 2016). Based on personal income tax data;
4) The use of public transportation, and the assessment of the use of private transportation on national and regional level roads;
5) Population mobility (internal) intensity to Riga in 2017 (data from a population survey in 23 territories);

The main everyday mobility characteristics were mostly related to the directions and intensity of the flows. The latter has always been higher in closer proximity to Riga and tends to decrease the farther away one is from the capital city. The shape of the agglomeration has always been closely related to transport infrastructure and its development. Thus, the territory of the agglomeration in the early 2000s expanded due to suburban sprawl and subsequent development of the road infrastructure. Conversely, since the mid-1990s, the area of the agglomeration has increased by more than 1 500 km2 and makes up 11.5% of the total area of Latvia (Tab. 1.). Territorial expansion of the agglomeration (mostly in a northern and southern direction) over the past two decades is explained by the development of the transportation network (Rīgas aglomerācijas robežu precizēšana 2017. gadā).

Data and methods
We have used data derived from the Central Statistical Bureau of Latvia and the State Revenue Service. The data set of commuters has the form of a flow matrix between Riga and the other 586 territorial units of Latvia. Commuters in the statistics are defined as employed persons whose usual place of residence is located in a different territorial unit than their workplace. A similar flow matrix containing information on payments of personal income tax was derived from the SRS. In Latvia, the total amount of personal income tax is divided between the municipalities where a person lives (declared place of residence) and where their workplace is registered. Although these data sources are commonly used in academic studies on commuting patterns in Latvia, both have some limitations. First of all, both registers contain information on ‘formal’ commuters as some people live at a different address than their declared place of residence or may have flexible working hours. Similarly, the registered workplace may differ from the actual address where the job is located. Thus, there is a chance that some commuting flows may be underestimated or overestimated. Secondly, some forms of employment may be excluded from the statistics (e.g. self-employed persons). Finally, the available data does not provide any information on the modal split of commuting, something that would be very useful.

We performed two analyses. First, a threshold analysis was used for conformity of territorial units based on the results of functional and morphological indicators that were obtained (see Tab. 2.). The results obtained for 586 territorial units are attributed to the mean values characteristic for the Pieriga Statistical Region. The mean values of the indicators characteristic for this statistical region are applied where relevant in terms of metropolitan location. Each of the 586 territorial units are compared to given thresholds that are separately defined for urban and rural areas. Based on threshold analysis it is determined whether the unit can be considered a part of the Riga agglomeration.

Secondly, although threshold analysis gives first insights of territories functionally and morphologically linked to the capital city, it requires spatial sorting. To

<table>
<thead>
<tr>
<th>Development of the area and population of the Riga agglomeration</th>
<th>Source: authors’ own calculations based on CSB Database data</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Table 1</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Total area (sq. km)</strong></td>
<td><strong>Total population</strong></td>
</tr>
<tr>
<td>1996</td>
<td>6 008.40</td>
</tr>
<tr>
<td>2004</td>
<td>6 983.80</td>
</tr>
<tr>
<td>2012</td>
<td>7 297.60</td>
</tr>
<tr>
<td>2017</td>
<td>7 596.60</td>
</tr>
</tbody>
</table>

Although, the area of the agglomeration has increased over time, the population has shown a slight decline since 1996. In 2017, the population of Riga agglomeration is slightly over one million, which is approximately 55.2% of the total population of Latvia. This population decline can be linked to the increase of international out-migration and the demographic consequences of ageing. Population change is strongly reflected in the urban spatial structure of the Riga agglomeration. The suburbs adjoining Riga city experience population growth due to residential suburbanisation. More distant territories are facing moderate growth or even population out-flows.
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For the morphological and combined agglomeration, the so-called continuity principle was used (Fang & Yu 2017). Therefore, if a territorial unit does not border any other units that are in the continuous agglomeration, it is excluded.

**Results**

The previous studies adopted the functional approach to delineate the border of the Riga agglomeration. Our research strategy utilises the two common approaches to delineate the urban agglomeration. Both morphological and functional indicators, adjusted to the mean values characteristic of the Pieriga (Metropolitan) Statistical Region, were utilised in order to delineate the border of Riga agglomeration.

**Functional agglomeration**

According to the functional approach, the agglomeration was delineated using the share of commuters and share of personal income tax data, as well as the total numbers for commuters’ tax payments. The results show that 27 territorial units have sufficient functional linkage with the core city and can be considered a part of the Riga functional agglomeration. In total 11 units have received the maximum 4 points, meaning that all their indicator values are equal or surpass the thresholds characteristic of the Pieriga Statistical Region. These territorial units are mainly located in close proximity to Riga and have witnessed the intensification of residential suburbanisation within the area, resulting in the strengthening of the functional linkage with Riga. Thus, the work commuter flows to Riga ($f_1$) are well above the threshold (51.1%). The share of personal income tax of inhabitants working in Riga ($f_2$) among those territorial units with maximum points is less evenly distributed, yet, the ones with the highest shares can still be found among the territories located closer to the capital city. In total, 16 other territorial units have received at least 2 and less than 4 points. These are mainly territories located further away from Riga.

**Morphological agglomeration**

According to the morphological approach, the agglomeration was delineated based on total population, population density and internal migration data. The calculated distance between the urban nodes of territorial units and Riga was also used. This variable had already been used by previous studies as part of a morphological approach (Filimonenko 1991). The results show that 48 units have a sufficient number of characteristics above the threshold to be considered a part of the Riga morphological agglomeration. In all, 8 units have received the maximum 4 points meaning the values of all indicators are equal or surpass the characteristics of the Pieriga Statistical Region.

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**Table 2**

Functional and Morphological indicators, and threshold values used in the study
Source: authors’ calculations based on CSB Database and Valsts ieņēmumu dienesta informācija... data

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Threshold values for territorial units</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Functional (f) indicators</strong></td>
<td></td>
</tr>
<tr>
<td>$f_1$ Share of commuters to Riga among working age residents</td>
<td>49.3% Urban, 51.1% Rural</td>
</tr>
<tr>
<td>$f_2$ Share of personal income tax of commuters to Riga compared to the total amount collected</td>
<td>48.3% Urban, 51.3% Rural</td>
</tr>
<tr>
<td>$f_3$ Total amount of personal income tax (million EUR)</td>
<td>6.1 Urban, 2.4 Rural</td>
</tr>
<tr>
<td>$f_4$ Share of commuters from Riga among all people employed in the territorial unit</td>
<td>17.9% Urban, 16.4% Rural</td>
</tr>
<tr>
<td><strong>Morphological (m) indicators</strong></td>
<td></td>
</tr>
<tr>
<td>$m_1$ Population density (persons per km²)</td>
<td>773 Urban, 19 Rural</td>
</tr>
<tr>
<td>$m_2$ Distance from Riga (km)</td>
<td>60</td>
</tr>
<tr>
<td>$m_3$ Migration intensity (per 1000 persons)</td>
<td>80 Urban, 114 Rural</td>
</tr>
<tr>
<td>$m_4$ Total population</td>
<td>7063 Urban, 2591 Rural</td>
</tr>
</tbody>
</table>
Region. This is similar to the situation in the functional agglomeration; these territorial units are located closer to Riga and have a positive net-migration ratio and a higher population density mainly resulting from residential suburbanisation.

The other 40 territorial units have a sufficient number of points to be considered a part of the Riga agglomeration. However, they have not succeeded in matching the threshold on one or two occasions. For most of the territorial units, this indicator was internal migration intensity ($m_3$). Therefore, these units have a population density ($m_1$) and total population ($m_4$) above the given threshold of Pieriga Statistical Region.

In this case there are 35 territorial units that must be excluded based on the continuity principle. Majority of these territories (21) matched two thresholds, usually population density and total population. It can be explained as an effect of urban sprawl. Another explanation is the fact that most of them are cities/towns, which tend to have higher population density and total population.

Thus, the morphological agglomeration covers an area of 4923.6 km². It can therefore be emphasised that the thresholds of morphological rates and values of the Pieriga region show the prevalence of those units within close proximity to Riga (up to 30 km), whereas many territorial units located relatively close to Riga (up to 60 km) fail to match given thresholds.

Combined approach

Finally, taking into account our research strategy, combined values of morphological and functional indicators were calculated for each territorial unit.

This type of categorisation provides a combined setting including all indicators from both the previous subchapters. The results show that 30 units have sufficient functional linkage with the core city, and appropriate morphological characteristics, to be considered a part of the Riga agglomeration. In a similar manner to the previous two cases, the units with a higher number of points are those in closer proximity to Riga. Therefore, 6 units have matched or surpassed all thresholds (8 points). Another 11 have matched or surpassed at least 6 thresholds.

Remaining 13 territorial units have a score of at least 4 points. Similarly, to the morphological approach, these mostly include territories that are located 30-60 kilometres from Riga. The results of this approach match

![Figure 1](image)

**Figure 1**
Territorial units of the Riga agglomeration according to a) functional, b) morphological, and c) combined indicators

Source: authors’ calculations, based on CSB Maps and spatial data and Valsts ieņēmumu dienesta informācija... data
the south-western borders of those determined in the 2017 study, whereas the eastern and northern parts differ significantly.

In this case there are 6 territorial units that must be excluded based on the continuity principle.

Based on the combined approach, Riga agglomeration covers an area of 3221.5 km2. The results show that from all 30 agglomeration units, 6 have a higher impact of functional rates, meaning that their sum is higher than from the morphological indicators. In contrast, 12 units have higher number of morphological thresholds reached. The former mostly include units that are in close proximity to Riga (up to 30 km), whereas the latter are mostly units located further away (up to 60 km). On one hand, it can be concluded that functional rates are more important for suburbanised areas, which have high numbers of everyday mobility flows with Riga. On the other hand, morphological indicators are crucial for those units that have considerably lower numbers of everyday mobility to Riga, but have a higher population density and total population, than in many other territorial units of Pieriga Statistical Region.

Conclusions

The aim of this article was to delineate the boundary of Riga urban agglomeration by utilising both morphological and functional approaches. This was carried out by emphasising the simultaneous use of morphological and functional indicators. Suburbanisation as a phenomenon, has considerable effect on urban systems, in particular, the hinterlands of capital cities experienced the most dynamic socio-spatial development during the post-socialist transition. Over the past two decades, the Riga agglomeration has become the epicentre of suburban development.

The results clearly illustrate that both morphological and functional approaches are essential and are integral parts in defining the spatial extent of the Riga agglomeration. Several studies have been conducted to delineate the borders of the Riga agglomeration (Bauls et al. 1996; Rīgas aglomerācijas robežu noteikšana 2004. gada; Rīgas aglomerācijas robežu noteikšana 2012. gada; Rīgas aglomerācijas robežu noteikšana 2017. gadā). All these studies mostly applied the functional approach as the most appropriate method to delineate the borders of the agglomeration. The research strategy used in this paper emphasises the advance of the simultaneous use of morphological and functional indicators to delineate an urban agglomeration in the case of Riga.

Our results partially confirm the previous findings. The most relevant consistency was observed in the territorial units adjoining Riga city. These suburbs are the territorial units most functionally linked to the capital city due to the common labour market. However, our research reveals that, based on the morphological approach, the spatial extent of the Riga agglomeration is more similar to the results of 2017 research, while in some parts it exceeded the previously delineated boundaries. This is in fact an interesting finding as it confirms the effects of urban sprawl in terms of the built environment.

Further research is acknowledged and needs to be implemented in more detailed spatial resolution. As an option 1km² grid cells may be adopted as a spatial unit in defining urban spatial structure.

Acknowledgements

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