Attempts to delineate functional regions in Hungary based on commuting data

Gábor Pálóczi and János Pénzes and Pavol Hurbánek and Marián Halás and Pavel Klapka

University of Debrecen, Catholic University in Ruzomberok, Palacký University Olomouc

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Gábor Pálóczi

University of Debrecen,
Hungary
E-mail:
paloczig@gmail.com

János Pénzes

University of Debrecen,
Hungary
E-mail:
penzes.janos@science.unideb.hu

Pavol Hurbánek

Catholic University in
Ruzomberok
Slovakia
E-mail:
pavolhurbanek@gmail.com

Marián Halás

PalackýUniversity Olomouc,
Czech Republic
E-mail:
marian.halas@upol.cz

Pavel Klapka

PalackýUniversity Olomouc,
Czech Republic
E-mail:
pavel.klapka@upol.cz

The issue of defining functional regions in Hungary is presented in this paper, which contains detailed methodological description with the help of relevant studies from the Czech Republic and Slovakia. The use of Smart's measure together with the CURDS algorithm and the relatively new concept of trade-off constraint function with four different sets of parameter values provided four optional solutions for this issue, based on the analysis of daily travel-to-work flows from the 2011 census. The resulting regions correspond to the micro-regional level and give valuable additions to the discussion about regionalization. The paper provides basic descriptive statistics for each of the four variants of functional region systems, which enables their overall evaluation (seeing advantages and disadvantages) and mutual comparison (seeing similarities and differences), and thus facilitates an informed debate on future work in functional regionalisation in Hungary carried out with respect to different purposes.

Introduction

Delineation of territorial units is one of the most important and crucial issues for experts of human geography, regional science or regional development planning. Numerous approaches and methodologies were developed and invented in order to create formal and functional regions. The term of functional region has been

introduced into human geography by American geographers such as Philbrick (1957) and Nystuen–Dacey (1961).

The challenge of delineating functional regions is well expressed by Hartshorne (Hartshorne 1939: 275 – cited by Paasi 2009: 4736):

'The problem of establishing the boundaries of a geographic region presents a problem for which we have no reason to even hope for an objective solution. The most that we can say is that any particular unit of land has significant relations with all the neighbouring units and that in certain respects it may be more closely related with a particular group of units than with others, but not necessarily in all respects'.

Functional, nodal regions can be regarded as open systems. Investigation of the build-up of such systems would first require an analysis of movements (channels along which movements occur), networks, nodes and their hierarchical organisation, acknowledging that this complex system ultimately forms surfaces. According to the orientation of the flows and interactions, four types of functional regions can be identified (oriented, channelled, circular and nodal) besides the random structure (Klapka et al. 2013a).

The objective of the delineation of functional regions is to maximise the ratio of within-region and between-region flows, so the analysis is based on relational dataset (Haggett 1965). During the delimitation process, the horizontal functional relations should be maximised within a region and minimised across its boundaries in order to fulfil the principle of internal cohesiveness and external separation (Smart 1974; Karlsson–Olsson 2006; Farmer–Fotheringham 2011; Klapka et al. 2014).

Administrative or political territorial divisions are not able to reflect the rapid changes in geographical reality, thus correctly defined functional regions can be more appropriate as a geographical tool for normative use (Haggett 1965) than administrative regions.

The interactions most commonly used in functional region delineations are travel-to-work flows, particularly the daily ones. Commuting to work or labour commuting is one of the most frequent and regular movement of the population with daily or rare periodicity. Functional regions based on these relations and flows are referred to as local labour market areas (LLMA) or travel-to-work areas (TTWA).

This study contributes to the discussion of the functional regional system in Hungary by applying a sophisticated regionalisation algorithm using daily travel-to-work flow data. A significant part of the current study emphasises the filtering process of the dataset. Current delimitation is the first attempt to delineate functional units based on the census data with the help of this methodology.

Methods of functional regionalisation

A functional region is an abstract spatial concept, which is why there is no sole correct method for the delineation of functional regions and why different analyses of the same data can provide considerably different results (Laan–Schalke 2001).

From all possible combinations, the literature tends to favour three approaches to functional regional taxonomy: clustering methods using numerical taxonomy (e.g. Smart 1974) or graph theory procedures (e.g. Nystuen–Dacey 1961; Karlsson–Olsson 2006; Benassi et al. 2015) and the multistage (or rule-based) procedures (e.g. the approach developed by the Centre for Urban and Regional Development Studies [CURDS] in Newcastle, UK – see Coombes et al. 1986 and Coombes–Bond 2008 for more information).

The approach developed by the research team at CURDS became one of the most successful and acknowledged approach to functional regional taxonomy. Considerable European experiences are available from Italy (Sforzi 1997), Slovakia (Bezák 2000; Halás et al. 2014), Spain (Casado-Díaz 2000; Flórez-Revuelta et al. 2008), Belgium (Persyn–Torfs 2011), Poland (Gruchociak 2012), and the Czech Republic (Klapka et al. 2013b; Tonev 2013).

The measure proposed by Smart (1974) [1] is the most frequently used as, mathematically, it is the most appropriate way for the relativisation and symmetrisation of statistical interaction data. It was also used by the second and third variants of the CURDS algorithm (Coombes et al. 1986; Coombes–Bond 2008); its notation is as follows:

Smart's measure:
$$\left[\frac{T_{ij}^2}{(\Sigma_k T_{ik} * \Sigma_k T_{kj})} + \frac{T_{ji}^2}{(\Sigma_k T_{jk} * \Sigma_k T_{ki})} \right],$$
[1]

where T_{ij} denotes the flow from spatial zone i to spatial zone j and T_{ji} denotes the flow from j to I; $\Sigma_k T_{ik}$ denotes all outgoing flows from i; $\Sigma_k T_{kj}$ denotes all ingoing flows to j; $\Sigma_k T_{jk}$ denotes all outgoing flows from j; and finally $\Sigma_k T_{ki}$ denotes all ingoing flows to i.

The second interaction measure was proposed by Coombes et al. (1982) in the first variant of the CURDS algorithm [2], and its notation is as follows:

CURDS measure:
$$\left[\frac{T_{ij}}{(\Sigma_k T_{ik})} + \frac{T_{ij}}{(\Sigma_k T_{kj})} + \frac{T_{ji}}{(\Sigma_k T_{jk})} + \frac{T_{ji}}{(\Sigma_k T_{ki})} \right],$$
[2]

In the current analysis, the adjusted and simplified second variant of the CURDS algorithm is applied (Coombes et al. 1986). The objective of the investigation is to apply the adaptability of the methodology and parameters tested in the Czech (Halás et al. 2015) and Slovak (Halás et al. 2014) case studies to the Hungarian settlement network. This version of the second variant of the algorithm is favoured over the more recent one for several purposes. First, it provides the possibility for some international comparability of the procedure and results. Second, it might be appropriate to identify a set of potential regional cores, a possibility that the newest variant (Coombes–Bond 2008) does not provide.

Regionalisation attempts in Hungary

It is important to emphasise that the methodology used in the current analysis represents a new approach among the Hungarian regionalisation attempts even though numerous considerable delimitations were published during the last few decades. This is why it is relevant to overview the previous studies and methods to delineate functional regions in Hungary (some part of these were briefly summarised in a preceding paper about Local Labour Systems – Pénzes et al. 2015).

The issues of territorial division in Hungarian literature are generally discussed by Dusek (2004), Nemes Nagy (2009), and Barancsuk et al. (2014), among others.

As early as the 1960s, the definition of functional regions appeared in the Hungarian human geography (Mendöl 1963), followed by additional researches focusing on the spheres of influences of larger towns (Beluszky 1967). However, this approach avoided the utilisation of commuting data. Functional urban regions were delimited for the whole of Hungary by using commuting relations that assigned each settlement to a single centre and conforming to the hierarchical scheme of the national development concept (Lackó et al. 1978). The country's territory was segmented based on the public transport connections forming spheres of influences (Szónokyné Ancsin–Szinger 1984) that could also be regarded as functional units. Commuting to work purposes was used as the basis for the dynamic examination of catchment areas (Erdősi 1985). Numerous functional analyses were made for the limited extent of the area – typically for towns and their hinterlands, for example, with the help of inter-urban telephone calls (inter alia Tóth 1974), commercial relations (Kovács 1986) or complex approaches (Timár 1983; Bujdosó et al. 2013).

After the year 2000, as a part of the Regional Polycentric Urban System (RePUS) project, local labour market systems, or the Local Labour Systems (LLSs), were delineated based on the commuting for work data of the 2001 census (Radvánszki–Sütő 2007). Functional Urban Districts (Sütő 2008) were aggregated by utilising these results. The LLS delimitation was updated and modified according to the last census data from 2011 (Pénzes et al. 2015). This approach provided a two-stage model in which the centres were assigned first and then the catchment areas were identified. In this approach, employment centres were in the core of the delimitation, and commuter's flows were simplified to those oriented towards them. In this respect, the methodology can be regarded as appropriate to identify nodal regions (Klapka et al. 2014). Complex and combined aspects were applied in an extended case study comprising gravity-based theoretical investigations (Hardi–Szörényiné Kukorelli 2014).

It is important to emphasise that alternative approaches also appeared besides the utilisation of the dataset of commuting to work. Commuting to school was also analysed to discover the inter-municipal relations by the example of the agglomeration of Budapest (Keserű 2013). The investigation of road traffic played an outstanding

role in the study of inter-municipal relations (e.g. Szalkai 2010 and Tóth 2013). Some recent analyses delineated the functional regions based on the online social network (Lengyel et al. 2015).

Methodology of the applied functional regionalisation and parameters during the procedure

The current delimitation analysis is the first attempt to adapt a methodology tested previously in other Central European countries listed above. This is why we disregarded the detailed description of the methodology. See Klapka et al. (2014) and Halás et al. (2015) for more information on this. However, some of the steps of the calculation need to be reviewed in order to understand the current analysis.

The process of the algorithm's application can be separated into three stages, which includes four steps and other operations. As part of the first stage, the process starts with the identification of proto-regions (by critical values of the interaction measure), followed by the assignment of remaining spatial zones and finally the assessment of the validity of the solution.

A potential regional core – as part of the interaction measure – must fulfil the criteria of job ratio function (the ratio of total ingoing flows of commuters and total outgoing flows above 0.8) and supply-side (or residence-based) self-containment (ratio of the inner flow and total outgoing flows above 0.5). If these potential cores do not fulfil the criteria, they are identified again based on the mutual relations between them and the value of the interaction measure. This iterative process is repeated until every basic spatial zone is attached to some of the proto-regions. The resulting set of cores and multiple cores is considered as a set of the proto-regions.

Constraint function is used in the following step to set a minimum size and self-containment criteria for the resulting regions. The constraint function is an essential part of the regionalisation algorithm and determines which regions will be maintained and will appear in the resulting regionalisation through the optimisation of the size and self-containment. The constraint function controls these two parameters of the resulting regions and the so-called trade-off between them.

At the same time, the *minimum size* of the functional region is modifiable. The size of a region can be defined by different criteria. The most general feature of a region is its population size, which is a standard and easily accessible indicator.

The self-containment definitions produced significantly differing values, and the index of unidirectional self-containment in some cases (when its value is lower than 0.66) resulted in inadequate concepts that did not conform to the basic definition of a functional region (Halás et al. 2015). Self-containment is a critical parameter, and its value cannot be allowed to drop under 0.5 – this means that at least 50% of all interactions (commuters) to a region should occur within the region.

The constraint function applied in the current research has the form of a continuous curve (Figure 1), and its shape is determined by four parameters that can be easily set by the user: the upper and lower size limits and the upper and lower self-containment limits (Klapka et al. 2014). The referred methodology of the continuous constraint function is a modified version of the formula –see Halás et al. (2015) for details.

Plotting the resulting regions on a graph is the following step as part of the delineation process. Each region, according to the values of its size and self-containment, can be plotted on an x–y graph as a point (β_1 and β_2 are lower and upper limits of the self-containment; β_3 and β_4 are lower and upper limits of the size in Figure 1). Regions will appear in the upper-right part of the graph from the curve of the constraint function. In practice, the plotting of regions on the graph provides a refinement tool that can help identify more appropriate values for the parameters.

Figure 1

Continuous constraint function
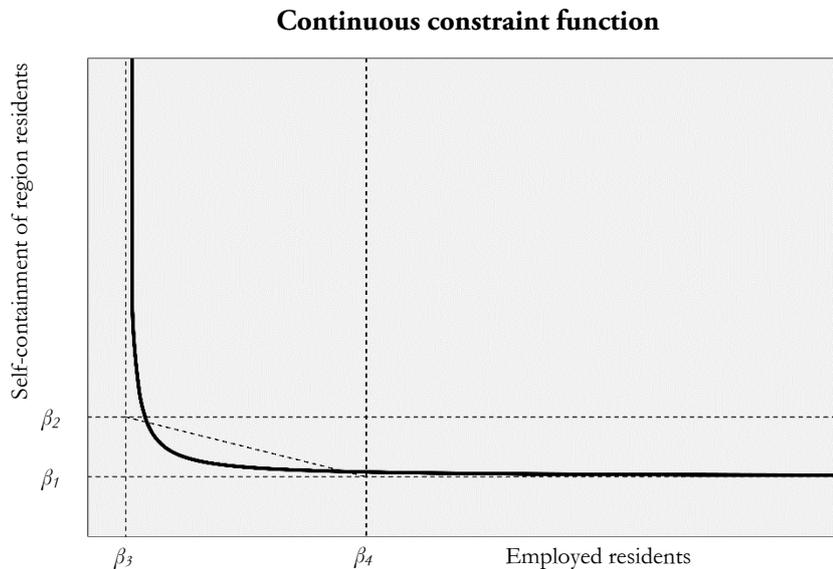
Source: Halás et al. 2015, Figure 3.

The refinement process of testing parameters should start with lower values of size and self-containment. The algorithm produces more regions when smaller parameter values β_1–β_4 are used, but their position on the x–y graph and knowledge of the settlement and regional system of a given territory help to make an informed decision as to which regions should be eliminated by setting the size and self-containment parameters to higher values. A graphical assessment of the results can help identify the course and position of the constraint function on the graph. If there is a significant gap in the field of points, that is an area with relatively small density of points, then it is the area of discontinuity of the size and self-containment values of the individual regions, in which a new trade-off constraint function can be located

without placing it too close to the size and self-containment values of too many regions. This concept is similar to the one behind the graphical cluster analysis methods or behind the methods for identification of natural breaks in data distribution (e.g. for choropleth map intervals).

Dataset and data corrections within the analysis

The analysis was based on the commuting dataset of the Hungarian census in 2011 carried out by the Central Statistical Office (for the characteristics of the commuting, see Kiss–Szalkai 2014). The survey was realised using harmonised international methodology in which commuting data were derived from the residence and locality of the workplace. The dataset contains aggregated data for the level of settlements (not personal microdata).

Some modifications were necessary. First of all, employees working abroad (83,822) and in more or changing localities (153,410) were filtered out. The districts of Budapest and existing commuting relations were unified. The dataset contains relations that do not conform to the possibility of daily commuting, because of great geographical distance and inadequate transport connections (similar errors were indicated in the Czech dataset as well – see Tonev 2013). In order to use an appropriate value as criteria, the relating literature was necessary to be overviewed.

There is characteristic distribution in the time of travelling, with daily periodicity regarded as constant in time and space since the Neolithic period (Marchetti's constant), apart from the location, way of travelling and other different conditions in the lifestyle. Regional scale analyses since the 1960s defined the characteristic travel time as 1.1–1.3 hours per day (e.g. Zahavi 1976). This suggests that increasing travelling speed is accompanied by increasing travelling distance instead of time-saving. Newest results tend to confute theories about travel time budget (Barthélemy 2011). As a consequence, universal travelling distance or time cannot be determined expressly as a threshold for daily commuting in a given relation.

Commuting with outstanding distance or time is called extreme commuting. The definition of extreme commuting is varied country by country – it is 100 miles (167 km) for the United States, 50 miles (83 km) for the United Kingdom, 100 km for Sweden and Norway, according to the European long-distance travel mobility survey (Vincent-Geslin–Ravalet 2016). Five to ten per cent of the active European population is assumed to commute more than two hours per day, at least three days a week on average (Lück–Rupperthal 2010).

Different thresholds can be found in Hungarian literature. The lowest value – 45 km – appeared in the case of commuters with minimum wage for whom travel costs mean the difference between available wage and the amount of social transfers (Bartus 2012).

It is important to emphasise that modelled travelling time is generally lower than the real values, as the optimised conditions were calculated using the maximum legal speed, and quality of road infrastructure or traffic jams were not considered. At the same time, commuters using public transport facilities must necessarily expect even greater travelling time (disregarding some main railways where public transport is competitive against individual transport).
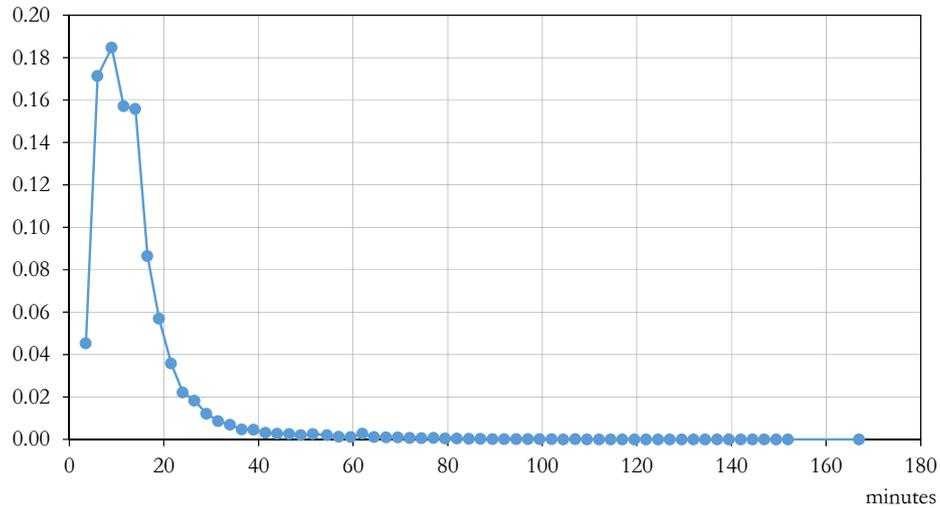
<div align="right">Figure 2</div>

Relative frequency of travelling time and number of relations
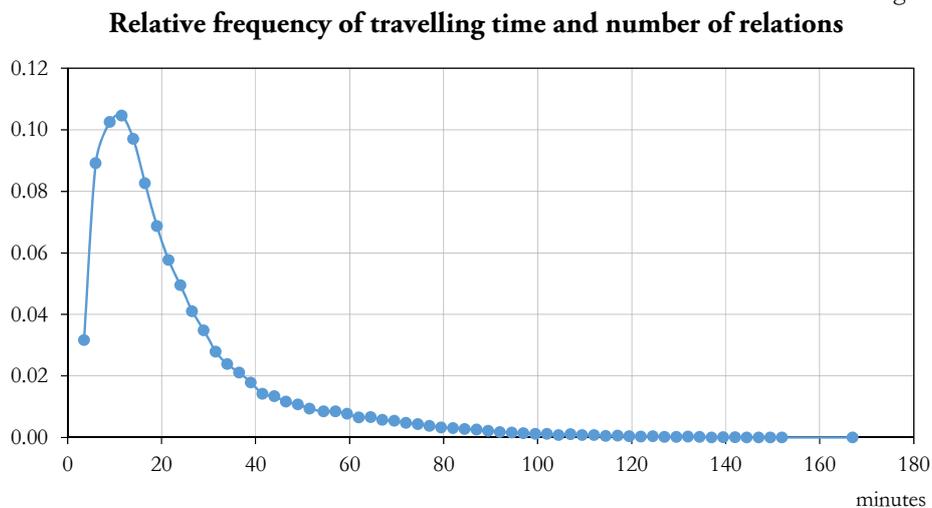
Source: Calculated by the authors based on the census dataset.

In order to separate the daily and weekly commuting, the relative frequency of the relations between settlements and number of commuters was analysed in the context of travelling time and distance. Travelling time and the number of relations represent a characteristic peak at five minutes of travelling time in the frequency followed by a steep increase (Figure 2). The curve flattens at 40 minutes of travelling time, and commuting became incidental from 90 minutes. Additional features regarding commuters are provided by the numbers in the context of travelling time. It is clear that large-scale commuting radically decreases between the 15 and 20 minutes interval of travelling time and becomes marginal after 40 minutes of travelling time (Figure 3). The most intensive sphere of employment centres can be generally delimited at the 20 minutes travelling time isochron.

Travelling distance was also analysed. The relative frequency of the relations represented a similar distribution to the previous ones. The maximum distance value was 10 km, presenting a steep increase after. However, the number and ratio of relations was regarded as significant between 50 km and 100 km (Figure 4). At the same time, the number of commuters was negligible over 50 km (Figure 5).
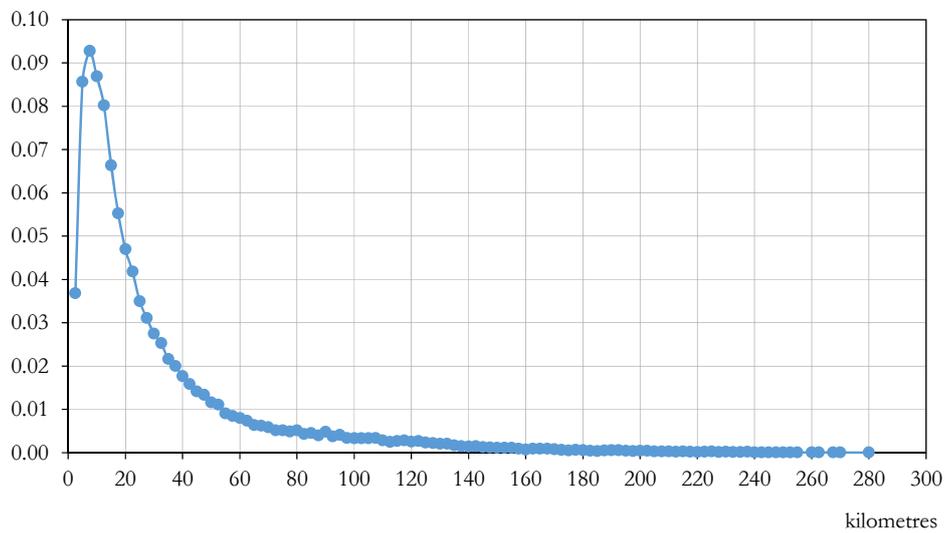
Figure 3

Relative frequency of travelling time and number of commuters

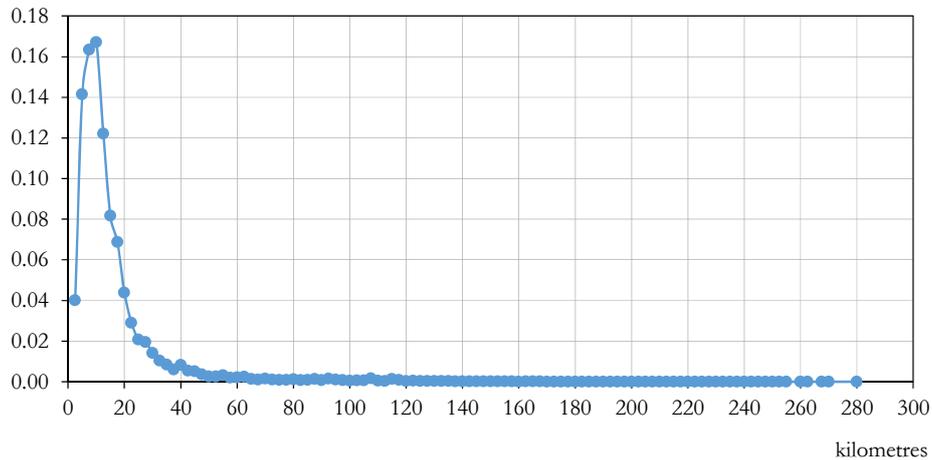*Source:* Calculated by the authors based on the census dataset.

Figure 4

Relative frequency of travelling distance and number of relations

Source: Calculated by the authors based on the census dataset.

Figure 5

Relative frequency of travelling distance and number of commuters

kilometres

Source: Calculated by the authors based on the census dataset.

According to the listed features, commuters who were non-daily commuters with place of residence further than 100 km and travelled 90 minutes by car from their place of work were filtered out of the matrix. These thresholds ensured the involvement of not only the most intensive part of the commuting but also the considerable relations assumed as daily periodicity. As the result of this approach, weak connections in terms of network analysis were also involved in the investigation. Relations of over 90 minutes (hypothetically, three hours of travelling per day) and a 100-km distance were assumed as non-daily commutes.

The accessibility and distance matrix was created based on the road network layer of Geox Ltd. from 2013. Travelling time and distance were optimised to the quickest solution between settlements based on the maximum speed of personal cars by running the ArcGIS Network Analyst application (Tóth 2014). Before filtering, the commuting matrix contained 84,747 flows (directional pairs of settlements between which at least one person commutes) and 3,705,491 interactions (commuters); after the filtering, it contained only 70,459 flows (83.14%) and 3,660,953 interactions (89.80 %), of which the inner (within a settlement) commuting amounts to only 3,151 flows (0.04 % of the filtered matrix), but up to 2,545,198 interactions (69.52 % of the filtered matrix), i.e. persons having both residence and employment in the same settlement.
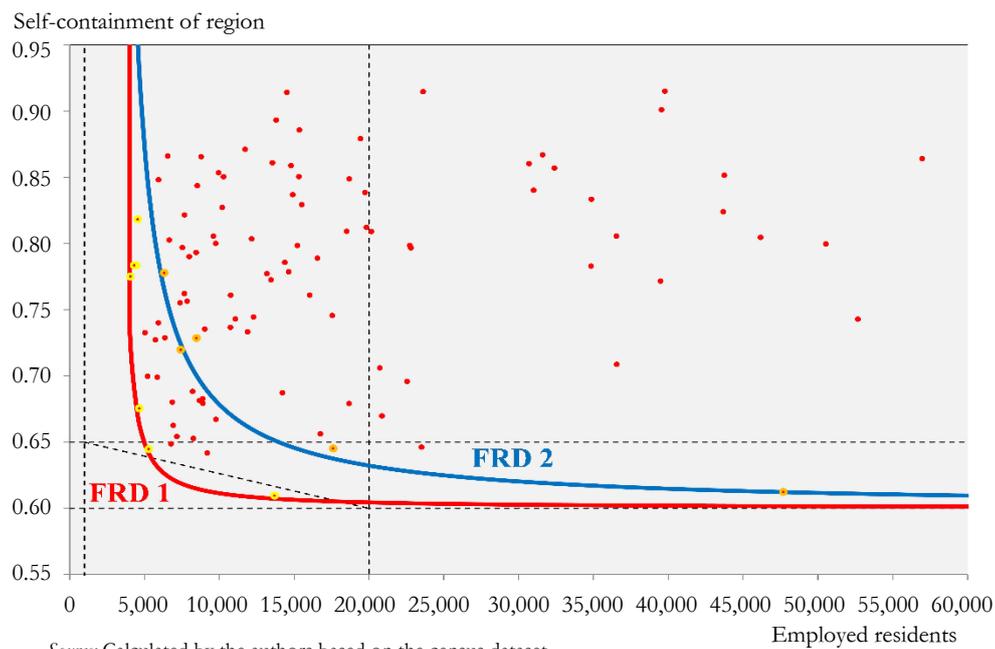
Daily and non-daily periodicity commuting could be detected using microdata of the census, but it was not possible to analyse this case in this way.

Results of the analysis by the case study of Hungary

The algorithm was run four times (1, 2, 3a and 3b versions) based on the commuting dataset using four different sets of parameter values pertaining to the size and self-containment of the regions – in the following, the resulted variants of the regional system are denoted as 'FRD' standing for functional regions based on daily interactions (Figure 6). The first run resulted in a general overview of the features of potential functional regions in the Hungarian settlement system due to the set of very small parameter values. During subsequent runs of the algorithm, regions that did not meet the criteria set by the constraint function were dissolved into individual settlements/municipalities and then assigned to other regions (a small village – Gagyapáti – was not assigned to any region because of its local labour isolation). The decrease in the number of functional regions resulted in an increase in their average size regarding the number of settlements and number of employed residents (Table 1).

Figure 6

Use of the constraint function on x–y graph by the example of FRD 1 and 2

Self-containment of region

Source: Calculated by the authors based on the census dataset.

The algorithm provides contiguous regions without the need for further adjustments with several insignificant exceptions (the step of elimination exclave and enclave settlements is not part of the present analysis).

In the second variant, the constraint function is moved up and right to the most distinct visual gap within the red dots in the graph (Figure 6). The modification of the

parameters in creating a new trade-off constraint function curve (blue line in Figures 6 and 7 with parameters β_1=0.60, β_2=0.65, β_3=3,000 and β_4=125,000) served as basis for the new functional region system FRD 2 with medium-size regions (blue dots in Figure 7). Twenty-four functional regions were present between the red and blue curves. The heuristic character of the methodology is indicated by the fact that Tokaj FR and Szentgotthárd FR (the two orange-red dots closest to the blue line in the left part of Figure 6) might have made it to FRD 2 and/or Komárom FR, Tiszavasvári FR and Vác FR (the other three orange-red dots relatively near the blue line in Figure 6) might have not made it to FRD 2, only if slightly different parameters for the new trade-off constraint function curve were chosen. Subjective decisions appear during the acceptance of the parameters.

Table 1

Parameters of the constraint function in the case of variants

	FRD 1	FRD 2	FRD 3a	FRD 3b
Self-containment lower limit (β_1)	0.60	0.60	0.60	0.60
Self-containment upper limit (β_2)	0.65	0.65	0.65	0.65
Size lower limit (β_3)	3,500	3,000	10,000	11,000
Size upper limit (β_4)	20,000	125,000	125,000	125,000
Self-containment (average)	0.780	0.811	0.829	0.832
Self-containment (median)	0.789	0.814	0.846	0.849
Self-containment (variation coefficient)	0.101	0.083	0.086	0.086
Number of employed residents (average)	32,114	40,677	52,299	53,837
Number of employed residents (median)	14,017	18,199	25,079	25,762
Number of employed residents (variation coefficient)	3.255	2.892	2.523	2.484

Source: Calculated by the authors based on the census dataset.

Table 2

Basic features of the function regions in the case of variants

Feature	FRD 1	FRD 2	FRD 3a	FRD 3b
Number of functional regions	114	90	70	68
Average number of settlements in the FRs	28	35	45	46
Maximum number of settlements in the FRs	129	137	201	201
Minimum number of settlements in the FRs	1	1	5	5
Average number of employed residents	32,504	41,172	52,935	54,492
Maximum number of employed residents	1,190,256	1,196,851	1,196,851	1,196,851
Minimum number of employed residents	3,689	5,917	12,185	13,586
Weight of the centre (average, %)	60	58	54	53
Weight of the centre (maximum, %)	100	100	88	88
Weight of the centre (minimum, %)	13	20	24	24

Source: Calculated by the authors based on the census dataset.

According to the third variant, the constraint function is moved up and right to the most distinct visual gap again (just slightly to the right of the red-blue dot representing Kunszentmárton FR in Figure 7). As the most distinct visual gap has two dots (representing the Mezőkövesd FR and Nyírbátor FR orange-blue dots in Figure 7) in its centre this time, two variants of the FR system with large-sized regions are proposed (FRD 3a and 3b). FRD 3a preserves the two mentioned functional regions (dark green line with parameters $\beta_1=0.60$, $\beta_2=0.65$, $\beta_3=10,000$ and $\beta_4=125,000$), whereas FRD 3b (light green line with parameters $\beta_1=0.60$, $\beta_2=0.65$, $\beta_3=11,000$ and $\beta_4=125,000$) does not contain these two functional regions (Cegléd FR, represented by the third orange-blue dot near the green lines in Figure 7, remained undissolved). Settlements from Mezőkövesd FR were primarily included into Eger FR and partly into Tiszaújváros FR. Settlements from Nyírbátor FR became part of Mátészalka FR (except for Ófehértó; Figures 10 and 11).

The largest functional regions integrating more than 100 settlements were Budapest FR and Pécs FR as the result of the first variant (FRD 1; Table 3). The modified parameter caused a significant increase in the size of the functional regions in the territories with micro and small villages. Zalaegerszeg FR in the second variant (FRD 2) and Miskolc FR and in the third and fourth variants (FRD 3a and 3b) also surpassed the number of 100 settlements. Pécs FR was the largest region by number of settlements after integrating the remaining parts of Komló FR, Szigetvár FR, and Siklós FR.

Figure 7

**Use of the constraint function on x–y graph
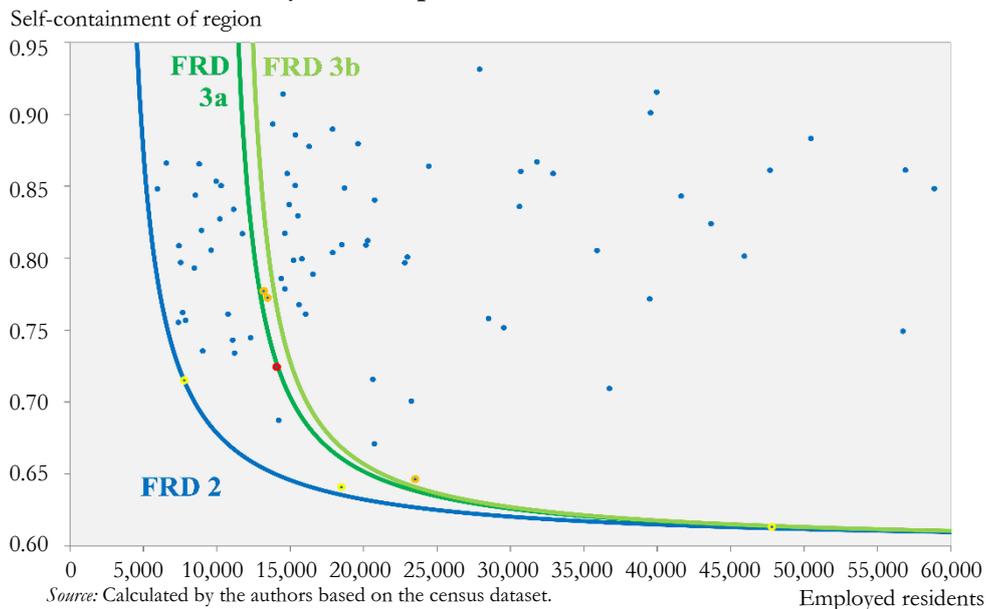by the example of FRD 2, 3a and 3b**

Distribution of the functional regions and participation of persons employed locally categorised by number of persons employed locally

Categories by number employed residents	Number of functional regions				Percentage of the total number of employed residents in Hungary			
	FRD 1	FRD 2	FRD 3a	FRD 3b	FRD 1	FRD 2	FRD 3a	FRD 3b
1,000,000–	1	1	1	1	32.1	32.3	32.3	32.3
100,000–999,999	3	3	5	5	8.9	8.9	14.9	14.9
50,000– 99,999	9	11	10	10	18.0	21.9	19.5	19.8
20,000– 49,999	21	22	27	27	18.8	18.9	21.6	22.0
10,000– 19,999	36	37	27	25	14.2	14.7	11.7	11.0
– 10,000	44	16	0	0	7.9	3.3	0.0	0.0
Total	*114*	*90*	*70*	*68*	*100*	*100*	*100*	*100*

Source: Calculated by the authors based on the census dataset.

Budapest FR was unambiguously the largest territory in light of the number of employed residents followed by Debrecen FR, Székesfehérvár FR, and Miskolc FR (in the first parameter variant – FRD 1). The size of Pécs FR and Szeged FR also exceeded 100,000 employed residents in the FRD 3a and FRD 3b variants. The number and proportion of the smaller functional regions (less than 20,000 employed residents) shrank significantly as the critical parameter values increased from the first to the fourth variant.

Debates about the most appropriate version of these delimitations and comparative spatial analysis with other territorial divisions (administrative or statistical units) were not involved in the current study. These issues might be the most important objectives of further studies.

Conclusions

The objective of the current analysis was to implement the broadly applied methodology in Hungary in order to delineate functional regions based on daily commuting to work. The international experiences – especially those from Central Europe (Czech Republic and Slovakia) – provided valuable information to adapt the methodology. Several attempts could be detected in the Hungarian literature to delimit functional regions; however, the CURDS algorithm employing Smart's measure was not used so far to utilise the travel-to-work flows for regionalisation. Filtering was necessary in order to receive daily commuting data from the dataset. The chosen thresholds regarding the commuting time and distance were investigated accurately.

In the analysis, the Smart's measure and second variant of the CURDS algorithm were used. Optimisation and tests could be conducted using the modification of the size (number of employed residents) and self-containment of regions. The usage of the continuous constraint function allowed the consideration of the trade-off between the two parameters. The only subjective components within the whole complex procedure were the choices of the exact position of gap within points on the graph and of the exact position of the trade-off function curve within that gap. Except for that, the method provided precise quantitative results that facilitated informed decisions with respect to the desired scale of functional regionalisation. The Hungarian results provide the possibility to continue the discussion about the delimitation of micro-regional level territorial units.

Acknowledgement

Figure 8

Functional regions in 2011 by the FRD 1 variant
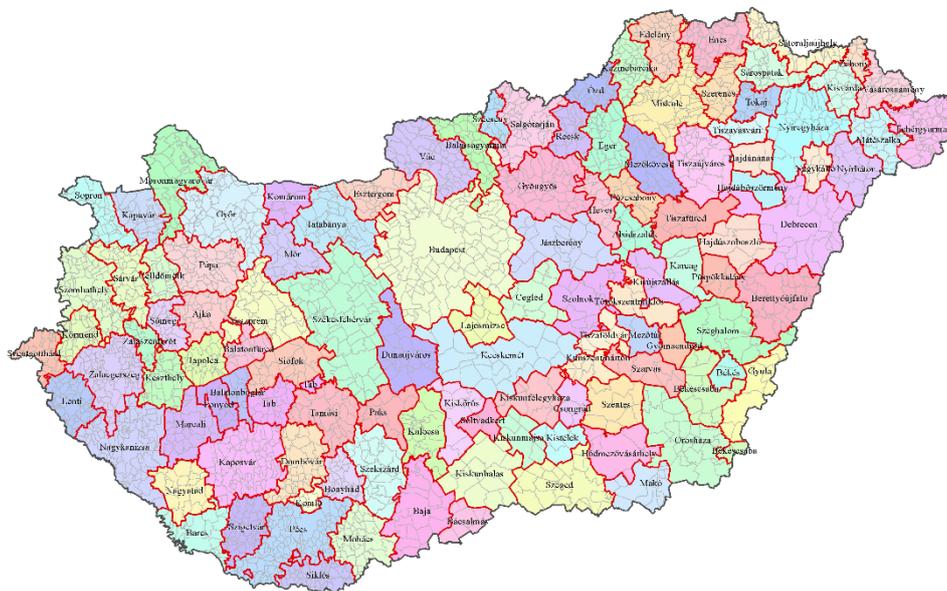
Source: Edited by the authors based on the census dataset.

Functional regions in 2011 by the FRD 2 variant

Source: Edited by the authors based on the census dataset.

Functional regions in 2011 by the FRD 3a variant

Source: Edited by the authors based on the census dataset.

Figure 11

Functional regions in 2011 by the FRD 3b variant

Source: Edited by the authors based on the census dataset.

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