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Rule versus Interaction Function: Evaluating Regional Aggregations of Commuting Flows in Sweden

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The aim of this paper is to evaluate the performance of two divergent methods for delineating commuting regions, also called labour market areas, in a situation that the base spatial units differ largely in size as a result of an irregular population distribution. Commuting patterns in Sweden have been analyzed with geographical information system technology by delineating commuting regions using two regionalization methods. One, a rule-based method, uses one-way commuting flows to delineate local labour market areas in a top-down procedure based on the selection of predefined employment centres. The other method, the interaction-based Intramax analysis, uses two-way flows in a bottom-up procedure based on numerical taxonomy principles. A comparison of these methods will expose a number of strengths and weaknesses. For both methods, the same data source has been used. The performance of both methods has been evaluated for the country as a whole using resident employed population, self-containment levels and job ratios for criteria. A more detailed evaluation has been done in the Göteborg metropolitan area by comparing regional patterns with the commuting fields of a number of urban centres in this area. It is concluded that both methods could benefit from the inclusion of additional control measures to identify improper allocations of municipalities.

Keywords: commuting field, commuting region, Intramax analysis, functional region, local labour market area, self-containment

1. Introduction

Commuting patterns provide information on important daily movements in urban areas, their surroundings and the linkages between them. To know how large commuting flows are, where they come from, where they go to and what is the sphere of influence of an employment centre, can be of great value to businesses which recruit their labour force there. It can also be of value to authorities who define, implement and monitor labour policies and to transportation planners who study trip patterns. National statistical offices often possess large amounts of micro data that can be used to obtain flow figures for specific moments in time. Raw data can be aggregated and processed to such an extent that commuting patterns emerge, which can be further analyzed with regard to their relationship with local economic development.

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Sweden is a country with huge differences in population density. Most of the population is concentrated in urban centres in the southern part, especially in the largest three metropolitan areas of Stockholm, Göteborg and Malmö. As employment is mainly concentrated in a few areas and large parts of the country are thinly populated, this distribution strongly affects commuting flows (see figure 1). Municipal areas differ largely in size, with the smallest area 9km^2 and the largest 19,447km^2.

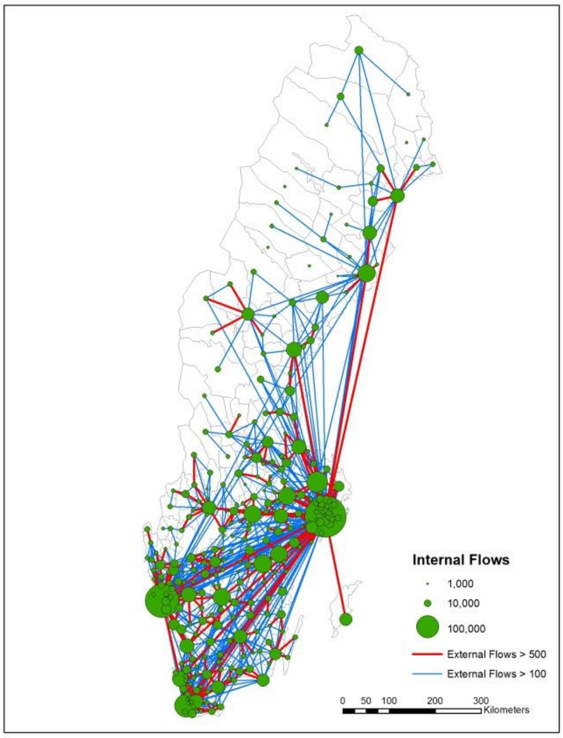

Figure 1. Major commuter flows in Sweden, 2008

The aim of this paper is to compare the performance of the rule-based method used by Statistics Sweden to delineate local labour market areas (LLMAs) with that of intrazonal maximization (Intramax), an interaction-based method for the delineation of functional regions in Sweden, based on origin-destination data of commuting trips for the year 2008, and indicate how this performance can be improved. LLMAs are delineated with one-way flows in a top-down aggregation procedure starting from predefined employment centres, whereas Intramax regions are delineated with two-way flows applying an interaction function in a bottom-up procedure. As these methods have very different characteristics and the LLMA delineation method has not yet been critically assessed, an evaluation of their performance using the same data source can expose strengths and weaknesses when applied in a situation where base spatial units mainly differ in size resulting from an irregular population distribution.

The LLMA delineation of Sweden for 2008 produced 75 regions from a dataset comprising 289 municipal areas. Therefore, the Intramax analysis was halted at a step which also produced 75 regions. Criteria used in the evaluation are resident employed population, self-containment and job ratio. These criteria are generally used in labour market delineation.

The necessary data for the Intramax analysis have been extracted from the LISA database of Statistics Sweden and processed to such an extent that complete sets of intra- and inter-municipal commuting flows in Sweden for the year 2008 could be obtained. The total number of origin-destination (OD) pairs in 2008 was 34,573 and total number of daily trips was 5,186,604. The number of trips increased with 6.5% between 2000 and 2008. Centroids have been determined for all municipal areas in Sweden. Flows then occurred between origin and destination centroids. Necessary data for making comparisons between results from Intramax analysis and those from the LLMA delineation undertaken by Statistics Sweden have been obtained from tables in a guide on the construction of labour market areas published by Statistics Sweden (2010).

The paper is structured as follows: First, the method of hierarchical clustering as applied in functional region delineation is evaluated. Next, an exposition is given of different types of delineation methods, with an explanation of the criteria used.

The delineation process using Intramax analysis is explained in more detail, also to provide insight in the way geographical information system (GIS) tools have been used with this method. Comparisons are then made between the results obtained with Intramax analysis and those from the method used by Statistics Sweden to delineate LLMAs. An additional evaluation of the results of both methods is done by comparing the LLMAs and Intramax regions with the commuting fields of urban centres in the Göteborg metropolitan area. Finally, conclusions are made about the differences found and a recommendation is made how the performance of both methods can be improved.

2. Hierarchical clustering

A general problem of hierarchical clustering, used in Intramax analysis, is that it is not able to make adjustments once a regionalization step has been executed. Therefore, it cannot correct what was done in previous steps. With methods based on predefined employment centres, a general problem is that the size and self-containment constraints used in delineation procedures are arbitrarily chosen. Figures in this regard have to be critically assessed as commuting data are affected by the modifiable areal unit problem (MAUP). This problem appears when point-based spatial objects are aggregated in areal units of variable size. For example, the use of self-containment as a criterion causes problems in situations where base spatial units differ mainly in size, as is the case in Sweden. In southern Sweden, comprising 83% of all municipalities in Sweden, a strong, positive correlation has been found between municipal land area and the two types of self-containment ($r = 0.60$ for demand-side self-containment and $r = 0.63$ for supply-side self-containment), with both correlations statistically significant ($p < 0.001$).Only a few comparative studies of delineation methods exist. Masser and Scheurwater (1980) evaluated three regionalization methods, namely the functional distance method, the iterative proportional fitting based procedure and Intramax analysis. They found that Intramax analysis was the only method that features regions that have more interaction with each other than with other regions at each step in the regionalization process. Intramax analysis also has some practical advantages, the most important of which are that it can handle large datasets and can deal with sparse matrices (Nel et al., 2008). A shortcoming identified by Hirst (1977) is that smaller regions tend to be aggregated before larger regions. Therefore, it favours grouping of small zones (Brown & Holmes, 1971).

Watts (2009) has compared the results from Intramax analysis and the travel-to-work area (TTWA) algorithm for Australia using fuzzy set theory (FST). The latter means that an area can simultaneously belong to different groups of functional regions to various degrees. It could therefore identify potential misallocations. The TTWA algorithm produced a much larger number of functional regions than Intramax analysis, whereas levels of self-containment, a major criterion for delineation, were about the same. According to the biased FST membership function, the number of misallocated areas was very low for both methods. However, the corrected specification of the membership function revealed major errors in the grouping process, with Intramax analysis scoring higher than the TTWA algorithm.

When comparing some results of Intramax analysis and the TTWA algorithm applied in studies of Scotland and Australia, a major difference is that with Intramax analysis former metropolitan areas are broken down in several functional regions, while this is not the case with the TTWA algorithm. Glasgow, for example, consists of four sub-areas amalgamated with surrounding areas when the Intramax algorithm is used (Feldman et al., 2005). A review of travel-to-work areas in the United Kingdom (Coombes and Bond, 2007) shows that with the TTWA algorithm, Glasgow is one region. The same difference is noticed in Sidney, where its TTWA is broken down in four functional regions (Mitchell et al., 2007). Up to now, these different results have never been questioned.

3. Delineation methods

Commuting regions or journey-to-work areas can be delineated with different regionalization procedures. Coombes (1996) has identified three approaches: manual methods based on the selection of employment centres according to one or more criteria, methods based on numerical taxonomy principles and hybrid methods. Cladera and Bergadà (2005) distinguish two basic approaches: an approach that emphasizes attraction experienced by peripheries with respect to urban centres, and an approach that emphasizes interaction between different centres. A similar distinction is made between the local labour market approach and the commuting zone approach (Karlsson and Olsson, 2006). We will distinguish between rule-based methods, i.e. methods that start top-down from preselected employment centres on the basis of one or more criteria and use one-way flows, interaction-based methods, i.e. methods that start bottom-up from an interaction function and therefore use two-way flows, and hybrid methods, i.e. methods that have characteristics of rule-based as well as interaction-based methods.

From a historical perspective, regionalization was strongly motivated by the need to define the borders of a local labour market, a region where the majority of the local population seeks employment or from within which the majority of local employers recruit their labour (Farmer and Fotheringham, 2011). This triggered the search for procedures allowing an objective delineation of functional regions. Brown and Holmes (1971) define a functional region as an area that has more interaction within its boundaries than with outside areas. Information about journey-to-work trips is often used to delimit such regions and a commuting area or labour market may then be defined as an area in which there is a high degree of interactivity and which is therefore suitable to function as a region that can “capture the interplay between labour supply and demand” (Mitchell et al., 2007, p. 3).

A municipality, if used as base spatial unit, receives flows from outside its area i.e. has a certain amount of in-commuting, and produces flows that go to other municipalities i.e. a certain amount of out-commuting. From the point of view of the single municipality and looking at one-way flows, one can delineate a commuting region by determining the orientation of in-commuters to this municipality.

A classic approach is to consider employment centres as central places, having a surplus of jobs in order to serve their hinterlands. Commuting regions are nodal regions with a core and periphery. Smolin (Taaffe et al., 1996) has delineated commuting regions in central Ohio based on this approach. He called these regions commuting fields in order to indicate that he had obtained zones of influence proportional to the percentage of commuters in other nodes that are oriented at the core of the commuting field. He allowed these regions to overlap each other by fixing the boundary of the commuting field at a relatively low percentage. Non-overlapping commuting regions can be created by finding the "influence divide" between nodes, thereby delineating, what Smolin called, commuting hinterlands.

The concept developed by Smolin has been extended by regionalization procedures using one-way dependency of areas in order to create direct as well as indirect links between them. These links are expressed by flow size. Such a procedure originates with predefined employment centres using size and self-containment criteria.

3.1. Size and self-containment criteria

Size criteria often used in commuting studies are residents employed locally (REL) resident employed population (REP), day employed population (DEP), and job ratio (JR). REL is the population working within the area where they live, which is equal to internal commuting. REP is the population working within or outside the area where they live, which is equal to internal commuting plus out-commuting. DEP is the population working within the area or number of jobs, which is equal to internal commuting plus in-commuting.

Self-containment refers to the ability of an area or zone to provide employment to its own residents, whereby a distinction is often made between residence-based or demand-side self-containment (RBSC) and workplace or supply-side self-containment (WBSC) (Casado-Diaz, 2003). RBSC is the share of residents employed within a zone, i.e. the internal commuting flow divided by the number of employed residents, expressed as a percentage:

$$RBSC = \frac{T_{ii}}{\sum_j T_{ij}} \times 100 \tag{1}$$

where T_{ii} = internal flow in zone i

T_{ij} = flow from zone i to zone j, and

$\sum_j T_{ij}$ = total outflow from zone i to zone j (including internal flow)

WBSC is the share of jobs inside a zone occupied by residents of this zone, i.e. the internal commuting flow divided by the number of jobs:

$$WBSC = \frac{T_{ii}}{\sum_j T_{ji}} \times 100 \tag{2}$$

where T_{ii} = internal flow in zone i

T_{ji} = flow from zone j to zone i, and

$\sum_j T_{ij}$ = total inflow from zone j to zone i (including internal flow)

Job ratio (JR) is the ratio between DEP and REP:

$$JR = \frac{\sum_j T_{ji}}{\sum_j T_{ij}} \tag{3}$$

A job ratio higher than 1 indicates that there is more inflow of workers than outflow. This criterion is therefore related to net in-commuting.

3.2. Rule-based methods

Statistics Sweden (2010) has been delineating labour markets in Sweden using commuting flows in and between municipal areas. The procedure starts with identifying independent local centres, i.e. strongly self-contained municipalities with two criteria. The first is that a municipality is considered self-contained if less than 20% of the resident employed population commutes to another municipality. The second is that no more than 7.5% of this population commutes to any specific municipality. These limits have been used in several cases (Karlsson and Olsson, 2006). The procedure then continues by attaching non-self-contained municipalities to the self-contained ones. Interaction plays therefore a role, but it is one-way and no interaction function is used. The main constraint here is that a non-self-contained municipality, called dependent municipality, is allocated to the self-contained municipality to which it has the largest commuting flow. However, there are non-self-contained municipalities that have their largest flow to other self-contained municipalities. The method allows a maximum chain of three links.

Konjar et al. (2010) have used a similar method to delineate commuting regions in Slovenia. However, their self-containment constraint is different. A municipality in Slovenia is self-contained if less than 35% of the resident employed population commutes to other municipalities. In addition, they have a constraint that such a municipality must have more than 15,000 jobs. Where pairs of municipalities have their largest flows towards each other, they are linked to the municipality with the second largest flow (Drobne et al., 2010).

3.3. Interaction-based methods

Smart (1974) has defined the original interaction function by weighting the sum of squares of flows between origins and destinations by the product of the numbers of residents employed locally (REL). He could then obtain an interaction or link value (IV) for an OD pair as follows:

$$IV = (T_{ij}^2 + T_{ji}^2)/(REL_i \times REL_j) \quad (4)$$

Interaction functions are used as objective functions in hierarchical clustering algorithms. One such algorithm is intrazonal maximization or Intramax. This algorithm identifies functional regions by hierarchically aggregating spatial base units in order to create homogeneous clusters. Intramax is an agglomerative or bottom-up clustering algorithm that starts with as many clusters as base units. Clusters are then successively amalgamated until finally one cluster is left. A contiguity constraint is thereby taken into account (De Jong & Van der Vaart, 2010). Masser and Brown (1975, p. 510) define in this context a functional region as an area that is delimited by maximizing the proportion of total interaction occurring within the aggregation of base units that form the diagonal elements of the origin-destination matrix, thereby minimizing “the proportion of cross-boundary movements in the system as a whole”.

Intramax analysis is a stepwise procedure where with N spatial units after N-1 steps all spatial units are aggregated into a single region. All interaction is then intrazonal. The procedure can be visualized by means of a dendrogram. Every pair of regions that could be merged is investigated at each step in the regionalization process. “The objective of the Intramax procedure is to maximize the proportion within the group interaction at each stage of the grouping process, while taking account of the variations in the row and column totals of the matrix” (Masser and Brown, 1975, p. 510). The objective function of the version of the algorithm used here is:

$$\frac{T_{ij}}{O_i \times D_j} + \frac{T_{ji}}{O_j \times D_i} \rightarrow max \quad (5)$$

where T_{ij} = interaction between origin *i* and destination *j*

$$O_i = \sum_j T_{ij} \quad (6)$$

where O_i = total outflow from region *i*

$$D_j = \sum_i T_{ij} \quad (7)$$

where D_j = total inflow into region *j*

The pair for which the objective function has the highest value is merged. This means that the two regions are merged for which the objective function is maximized. The flows between regions are, of course, two-directional as indicated by T_{ij} and T_{ji}. The objective function can only be calculated for all $D_j > 0$ and for all $O_i > 0$ (Mitchell et al., 2007).

Intramax analysis is part of the spatial analysis software package Flowmap developed at Utrecht University (De Jong & Van der Vaart, 2010). The input consists of an origin file, a destination file and a flow file providing for each OD-pair its flow size, i.e. number of movements. Output of Intramax analysis is, besides the dendrogram, a fusion report, showing the aggregation history and two tables that are built while processing the Intramax fusion report. The first table shows for each base unit the region that this unit belongs to at a specified step. By joining this table with the polygon file of the base units, regional divisions for a step can be shown on a map by dissolving on this step's field. The second table shows the flows within and between regions.

Due to the inclusion of the Intramax algorithm in Flowmap, it has been widely used for the delineation of labour markets and commuting regions. It has been used to identify travel-to-work areas in Ireland (Meredith et al., 2007). The Centre of Full Employment and Equity (CofFEE) in Australia has used the algorithm for the delineation of CofFEE functional economic areas for that country (Mitchell et al., 2010). Krygsman et al. (2009) have used it to delineate functional transport regions in South Africa). It has been used for the delimitation of functional regions in England, Wales and Scotland (Feldman at al., 2005), in Newfoundland and Labrador (Canada) (Celtic Rendezvous, 2010) and in Switzerland (Killer and Axhausen, 2010). The algorithm has not yet been used in Sweden.

3.4. Hybrid methods

A number of rule-based delineation methods apply two-way dependency using an interaction function. In Greece, Kallioras et al. (2011) have used size criteria with regard to resident employed population, day employed population and job ratio. In this way, they distinguished first- and second-order employment centres according to the constraints set for these criteria. Local administrative units (LMAs) that do not meet the criteria are then allocated to such centres on the basis of an interaction function.

Coombes et al. (1986) have also applied size and self-containment criteria together with an interaction function, but used a trade-off between self-containment and resident employed population. They have introduced the concept of travel-to-work area (TTWA), an area with a large resident employed population and a high self-containment value, that they could delineate using a complex algorithm, called the Coombes or TTWA algorithm.

The TTWA algorithm has a number of stages (Coombes et al., 1986). First, employment foci are identified by selecting the 20% highest base units with regard to job ratio and residence-based self-containment. Next, foci are amalgamated by ranking them according to their levels of in-commuting and applying a number of constraints. In a further stage, foci are expanded into proto TTWAs. Here all individual or amalgamated foci as well as non-foci are investigated as candidates for amalgamation into proto TTWAs applying an objective function that combines the size and self-containment constraints and includes the trade-off between them. Finally, TTWAs are created. Proto TTWA's that do not reach the minimum value of the objective function are dismembered and reallocated to form TTWA's.

The Coombes algorithm has been applied in different forms and is used as a standard method for labour market delineation in European Union countries. Casado-Diaz (2003) has applied this algorithm in the Valencia region of Spain, while Newell and Papps (2001) have delineated local labour market areas in New Zealand using the version explained above. Coombes and his associates have changed the algorithm and the self-containment and size criteria over the years. For example, the self-containment constraint decreased from 69.5% to 66.67% whereas the size constraint increased from 20,000 to 25,000 (Coombes and Bond, 2007).

Taking into account the trade-off between size and self-containment, a TTWA now has to meet the following conditions (Persyn and Torfs, 2010):

- at least 25,000 employed residents, with both residence-based and workplace-based self-containment higher than 66.67%
- between 3,500 and 25,000 employed residents, with minimum self-containment increasing from 66.67% to 75% as numbers of employed residents get smaller.

4. Intramax analysis of commuting data

*Intramax analysis has been used he*re to create commuting regions on the basis of commuting trips made in 2008. Tables are produced after processing the fusion report to obtain regional maps for a number of fusion steps in the algorithm. The output of the Intramax analysis has been used as input in a geoprocessing model, *the commuting region builder tool*[1]*, that creates a map of commuting regions related to a specific fusion step.*

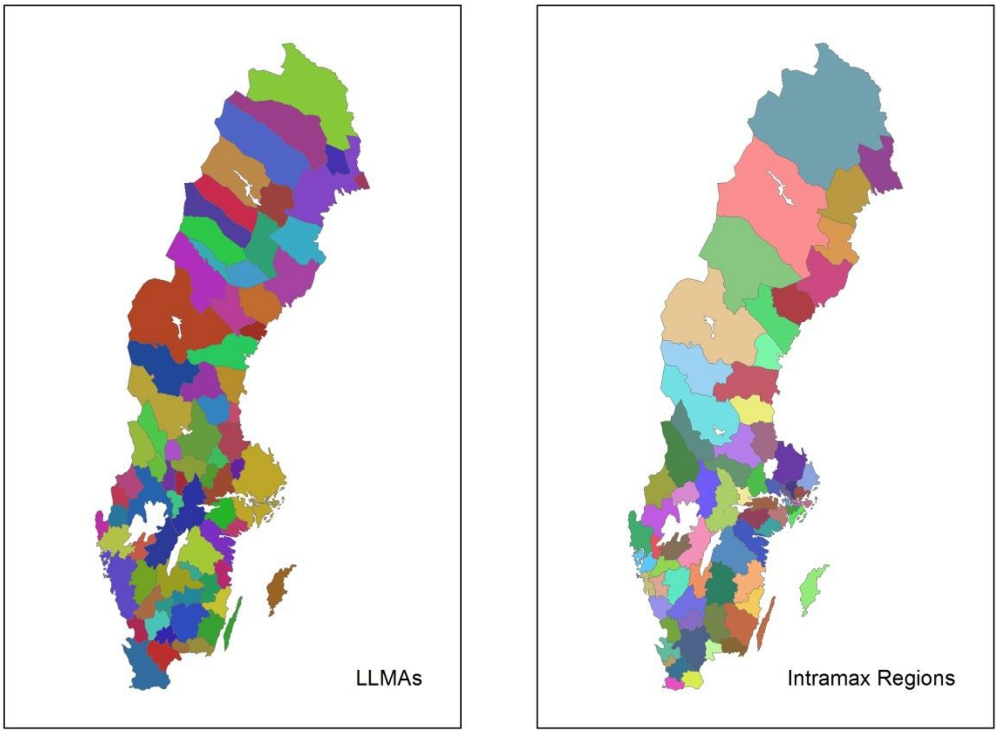

Figure 2. LLMAs and Intramax regions

To start the Intramax analysis in Flowmap, one needs a table containing the coordinates of the centroids of all municipalities and a flow table containing the scores for each OD pair. The fusion report shows the increases in cumulative intrazonal interaction while the number of regions is decreasing. At step 214, the number of regions is 75, the same as in the delineation of local labour markets (LLMAs) undertaken by Statistics Sweden, with 78.86% of trips internal. Figure 2 shows the differences between the delineation of Statistics Sweden and the one resulting from the Intramax algorithm.

5. Intramax regions compared with local labour market areas

The LLMAs differ less in size than the Intramax regions, with the standard deviation for LLMAs 5,654km^2 and for Intramax regions 9,977km^2. In northern Sweden especially, the differences are large. Marked differences are also found in the metropolitan areas. Where LLMAs cover these areas completely, they are broken up in several regions in the Intramax delineation. Remarkably, the same differences can be seen in Australia and Scotland, where Intramax regions have been compared with TTWAs (Feldman et al. 2005, Mitchell et al. 2007).

Resident employed population and residence-based self-containment have been classified utilizing the constraints used for TTWAs: 3,500 and 25,000 for the resident employed population and 66.67% and 75% for self-containment. None of the Intramax regions has less than 3,500 residents, whereas 11 LLMAs (15%) have less, and therefore would not qualify as a TTWA. The smallest Intramax region has more than 6,000 residents, which is significantly more than the TTWA limit.

With 75 regions in both cases, the percentage of internal flows in the LLMA delineation is substantially higher than in the Intramax delineation: 92.62% against 78.86%. This difference is reflected in the self-containment figures. Figures 3 and 4 show that a number of Intramax regions have a self-containment level equal to or below 66.67% and would therefore not qualify as a TTWA. With regard to residence-based self-containment, there are 15 such regions (20%), mainly in the Stockholm and Göteborg areas. With regard to workplace-based self-containment, 10 regions (13%), mainly in Stockholm area, would not qualify. However, both methods generally score very well with regard to residence-based as well as workplace-based self-containment, although the values for LLMA's are, on average, somewhat higher (see table 1). Low levels of self-containment in the Intramax regions of metropolitan areas result in a relatively large standard deviation. For most of the country, there is less variation than in the case of LLMAs, with levels of self-containment more than 90%.

There are substantial differences between Intramax regions and LLMAs in the metropolitan areas. Each metropolitan area is one LLMA, but comprises a number of Intramax regions: five in the Malmö and Göteborg metropolitan areas, and 13 in the Stockholm metropolitan area. If we view the country with these areas excluded, the means and workplace-self-containment levels do not differ that much anymore (see table 2). However, despite the similarity that has arisen between the two delineations, the Intramax procedure reaches not much higher levels outside the metropolitan areas, with 52 Intramax regions against 72 LLMAs.

The job ratios derived from the two methods only differ substantially in the metropolitan areas (see figure 5). Regarding the Intramax regions, for Stockholm and Göteborg, we note a situation that is typical of large metropolitan areas as the urban cores and their satellites with job ratios more than 1, are surrounded by zones with job ratios less than 1.

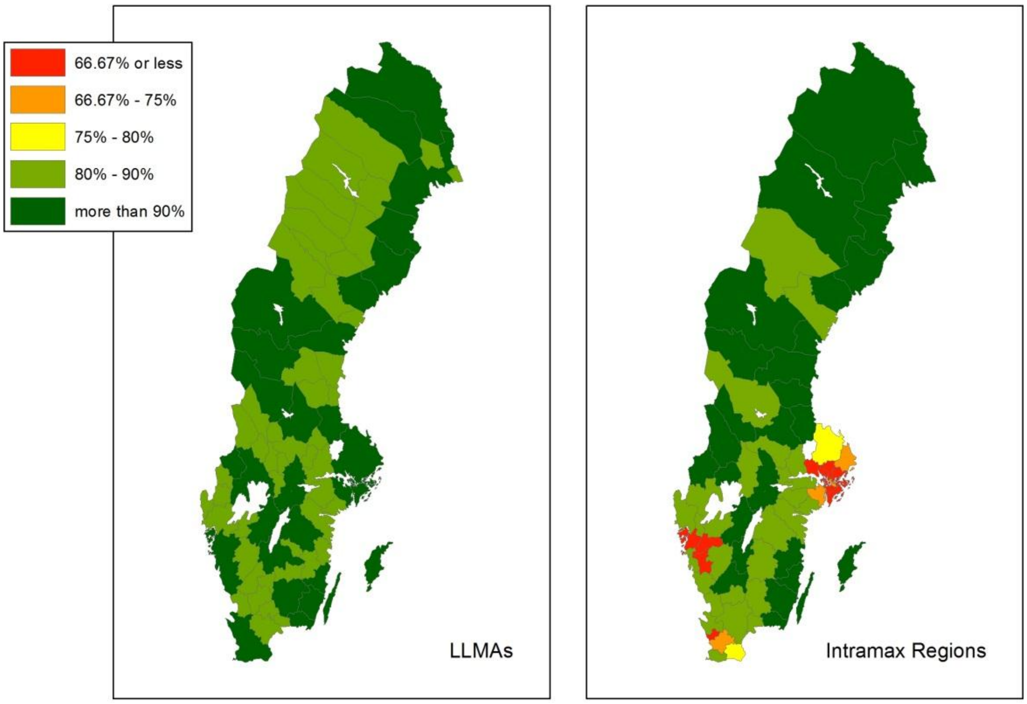

Figure 3. Residence-based self-containment in LLMAs and Intramax regions

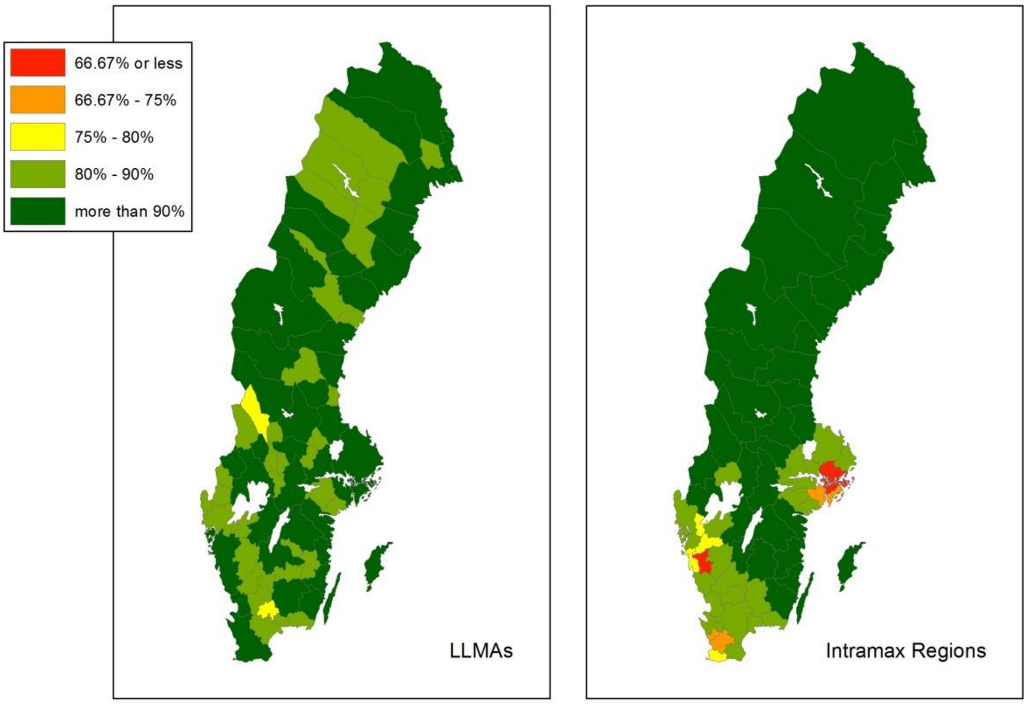

Figure 4. Workplace-based self-containment in LLMAs and Intramax regions

Table 1. RBSC and WBSC in LLMAs and Intramax regions for the whole country

Self-Containment	Residence-Based (%)		Workplace-Based (%)	
Method	**LLMA**	**Intramax**	**LLMA**	**Intramax**
Mean	88.1	79.0	89.6	83.9
Confidence Level (95.0%)	0.93	4.28	0.92	3.26
St Dev	4.0	18.6	4.0	14.2
10%	82.9	42.5	84.4	63.0
25%	85.3	75.6	87.2	81.1
50% (Median)	87.8	87.6	90.3	89.5
75%	91.0	90.9	92.7	92.2
90%	93.7	92.7	94.7	94.6

Table 2. RBSC and WBSC in LLMAs and Intramax regions outside metropolitan areas

Self-Containment	Residence-Based (%)		Workplace-Based (%)	
Method	**LLMA**	**Intramax**	**LLMA**	**Intramax**
Mean	87.8	87.6	89.36	90.47
Confidence Level (95.0%)	0.90	2.90	0.93	1.44
St Dev	3.8	1.45	3.9	5.2
10%	82.9	83.6	84.4	87.1
25%	85.1	87.4	87.0	88.7
50% (Median)	87.6	90.1	89.8	91.1
75%	90.7	91.6	92.2	93.8
90%	92.9	93.6	93.5	94.9

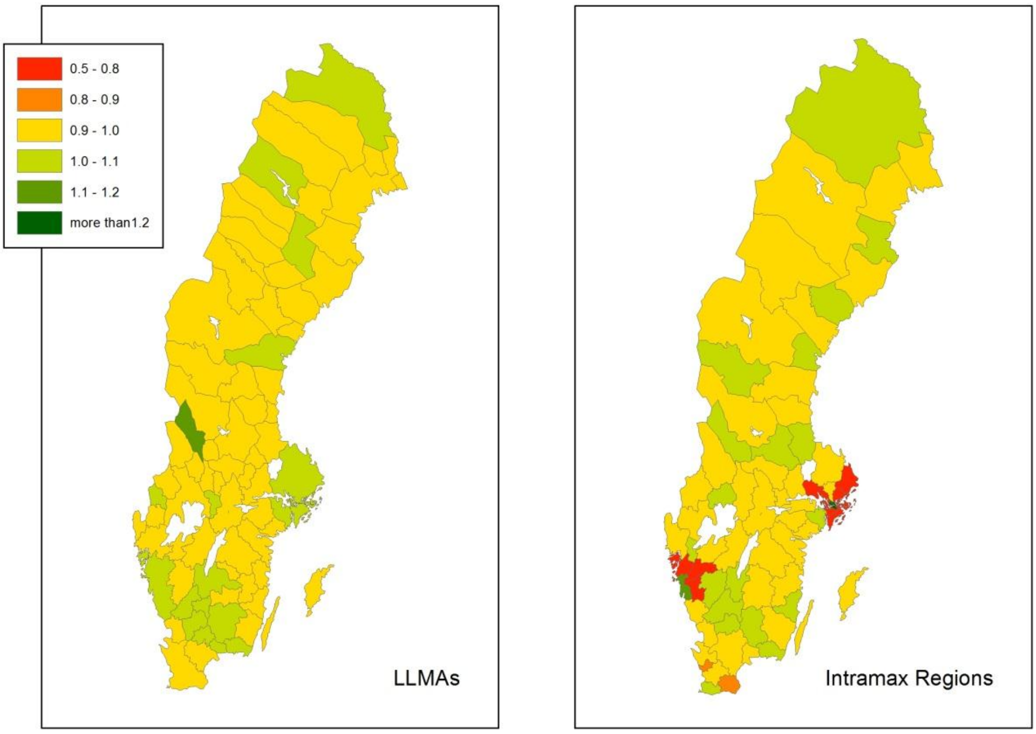

Figure 5. Job ratios in LLMAs and Intramax regions

6. Commuting patterns in the Göteborg metropolitan area

It is in the metropolitan areas where the differences between the two methods are the largest. The performance of Intramax analysis and the method used to delineate local labour market areas is therefore evaluated in more detail in the Göteborg metropolitan area by comparing the respective delineations with commuting fields. These fields are nodal regions and flows are one-directional from periphery to core. They are not the result of regional aggregation, but, as explained earlier, spheres of influence of a node based on the employment orientation from the periphery to that node (Taaffe et al., 1996).

Commuting fields can be constructed in a number of steps using a number of techniques and tools available in ArcMap[2]. The most time-consuming steps (steps 12 and 13) have been included in a geoprocessing model using ArcGIS ModelBuilder, the commuting field builder tool[3] in order to calculate a municipality's commuting field.

Commuting fields have been built for five municipal areas around Göteborg with a resident employed population (REP) larger than 25,000. Together they contain a REP of 427,857, which is 53.2% of the REP of the eight Intramax regions under consideration. Orientation at the core of the commuting field, i.e. the percentage of employed residents commuting to it from its periphery, has been classified to identify a moderate to weak orientation (between 15 and 30%), a moderate orientation (between 30 and 45%), a moderate to strong orientation (between 45 and 60%) and strong to very strong orientation to the commuting field's core (higher than 60%).

The commuting fields of Göteborg, Uddevalla, Trollhättan, Borås and Varberg are shown in figure 6. When the relationships between commuting fields and the two delineations are analyzed, a number of conclusions can be drawn immediately. The inclusion of Trollhättan and Uddevalla in one LLMA is questionable as the commuting orientations to each other are weak (lower than 15%). The same applies to the inclusion of Varberg in the Göteborg LLMA. They are separate regions in the Intramax delineation. In the case of Borås, there is a clear similarity between the commuting field and the Intramax region. As the Intramax regions of Uddevalla, Trollhättan, Varberg and Borås have self-containment levels higher than 75% (see figure 7), their status as commuting region can be justified.

The situation northeast of Göteborg is more complicated. Where the municipalities of Lilla Edet, Stenungsund, Kungälv and Ale together form the main body of an Intramax region, they belong to the Göteborg LLMA. Although the orientation of Lilla Edet and Stenungsund to Göteborg is moderate to low, their Intramax region does not fulfill the self-containment criterion. Their inclusion in the Göteborg LLMA seems therefore be justified. The same applies to the municipalities of Partile, Lerum, Alingsås and, which form the main body of another Intramax region near Göteborg. They are also part of the Göteborg LLMA, although the orientation of Alingsås to Göteborg is moderate to weak and that of Vårgårda weak. Including orientation to other major employment centres nearer to Göteborg, such as Mölndal and Kungsbacka, does not affect this. Their Intramax region also does not meet the self-containment criterion. Their inclusion in the Göteborg LLMA seems therefore be justified too. Finally, with the same arguments, the inclusion of Härryda, Bollebygd and Mark in the Göteborg LLMA can be accepted.

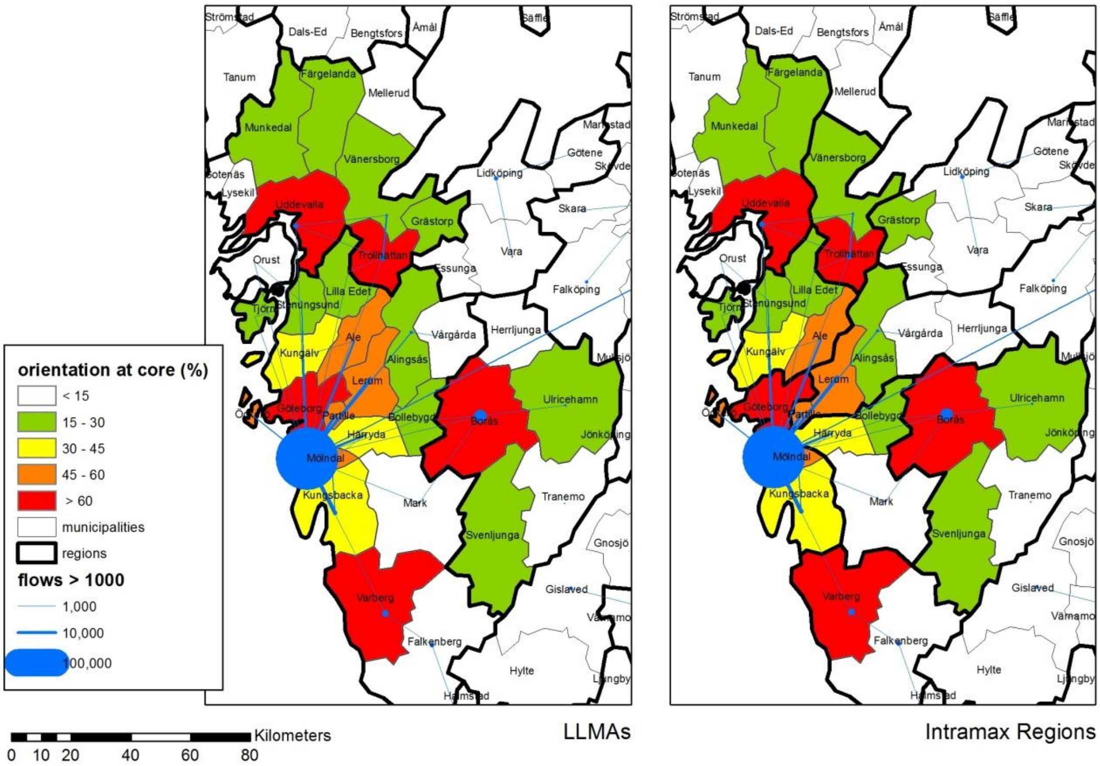

Figure 6. Commuting fields of major urban centres in the Göteborg metropolitan area

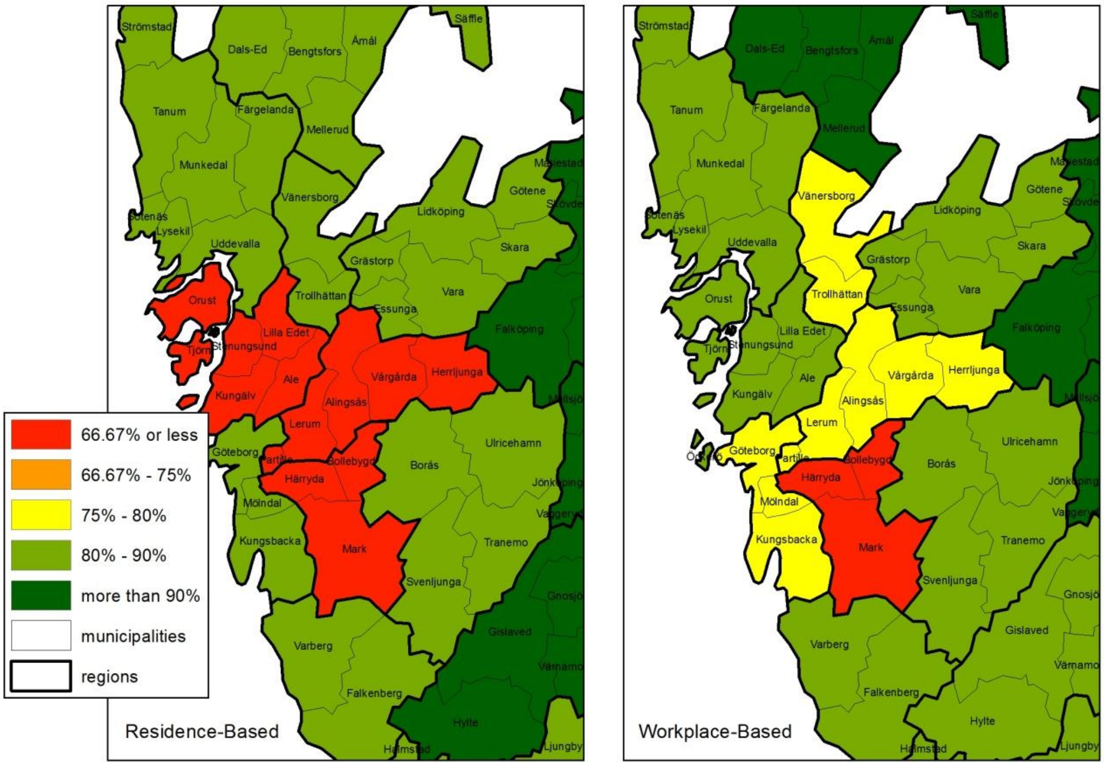

Figure 7. Intramax self-containment levels in the Göteborg metropolitan area

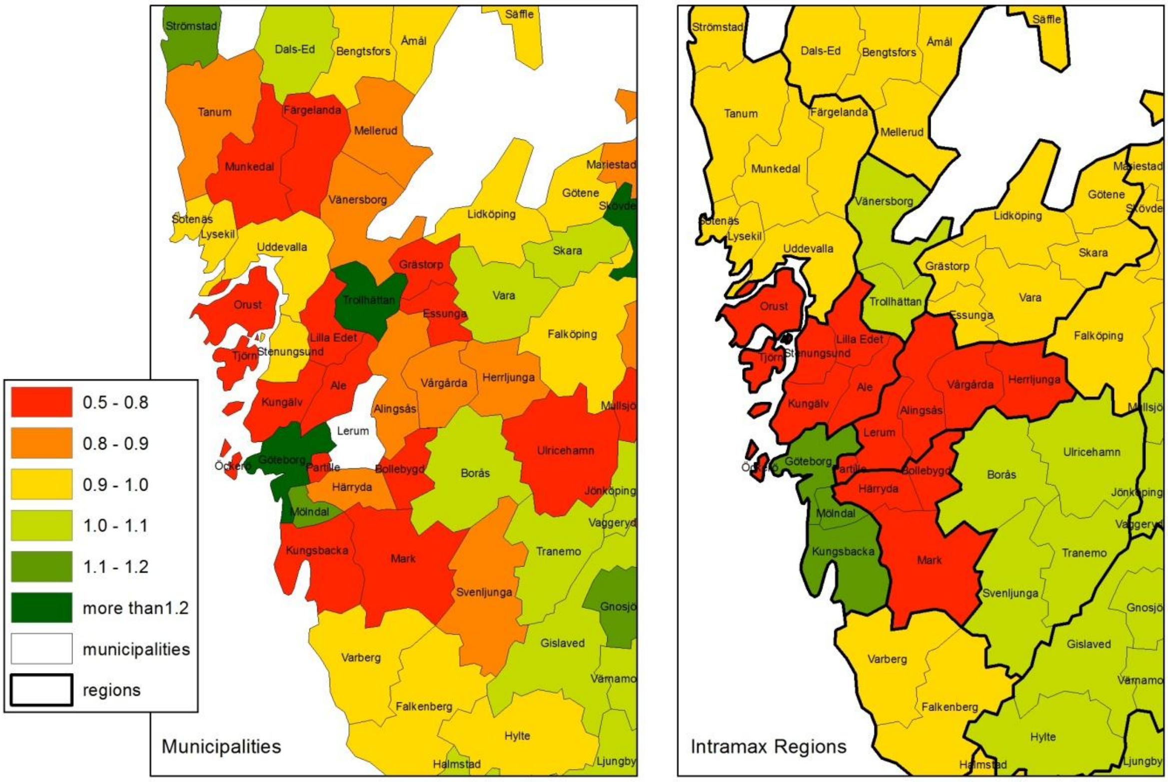

Figure 8. Job ratios in municipalities and Intramax regions, Göteborg metropolitan area

If the four Intramax regions adjacent to the Göteborg region, which do not meet the self-containment criteria, are allocated to the latter, their two-way flows are internalized, resulting in an internal flow in the extended Göteborg region comprising 519,462 trips (see table 3). Residence-based self-containment in that region will then be 93.6% and workplace-based self-containment 92.9%, well-balanced and well above the constraints.

Table 3. Commuting flows in the constituent parts of the extended Göteborg region

Subregion	Göteborg	Öckero	Lilla Edet	Partile	Härryda	Total
Göteborg	314,403	501	6,416	7,276	5,894	334,490
Öckero	3,564	2,726	69	71	65	6,495
Lilla Edet	27,223	50	44,050	928	501	72,752
Partile	28,113	24	683	37,757	1,353	67,930
Härryda	15,180	15	224	956	21,420	37,795
Total	388,483	3,316	51,442	46,988	29,233	519,462

Table 3 shows a pattern that the Göteborg region, as a high order central place, attracts many commuters from surrounding regions. This attraction is reflected in the large job ratio difference between core and periphery (see figure 8). If we view job ratios in the Göteborg region at municipal level, a clear pattern emerges, with Göteborg-Mölndal and Trollhättan as attractors with regard to employment.

7. Conclusion

Although the procedure used for the construction of LLMAs differs considerably from that of Intramax regions, the results obtained are quite similar for most of the country. However, there are some striking differences in metropolitan areas. There, LLMAs have much higher self-containment levels than Intramax regions. However, patterns outside metropolitan areas are very similar. As for the size criterion, LLMAs differ less in land area than Intramax regions. The latter are smaller in metropolitan areas and larger outside.

In the eight Intramax regions of the Göteborg metropolitan area that have been selected for the commuting field analysis, average residence-based self-containment is 73.5% against a national average of 79.0%. In small regions, more workers tend to commute to other regions as distances are relatively small. Small size makes it also more likely that in employment centres day employed population is substantially larger than resident employed population. This strengthens the differences in metropolitan areas with regard to job ratio. The Intramax regions still show the broad circular pattern typical for metropolitan areas, with the core having a job ratio larger than one and its periphery lower than one. The larger Intramax regions, especially in northern Sweden, avoid a situation where a number of regions have a very low resident employed population as is the case with a number of LLMAs in that part of the country.

Despite many similarities, the two methods differ fundamentally with regard to self-containment levels and the construction of regions in metropolitan areas. In the latter, Intramax analysis results in a fragmented pattern with unacceptable low levels of self-containment in a number of regions. However, LLMAs are clearly too large there, as indicated by the situation in the Göteborg metropolitan area, where Trollhättan and Uddevalla form one region and Varberg is included in Göteborg, although their respective commuting fields suggest a weak relationship. Intramax analysis, by contrast, provides a delineation that is more consistent with that of commuting fields. However, the LLMA method creates far more regions outside the metropolitan areas, with self-containment levels that are almost the same as those obtained with Intramax analysis. In conclusion, Intramax analysis tends to create too many regions in metropolitan areas and the LLMA method too few. The LLMA method creates far more regions outside the metropolitan areas, although a number of these regions have a very small resident employed population, which is, for example, not acceptable in the case of TTWAs. Both methods could benefit from additional controls in their procedures, especially when applied in situations where differences in land area are large, as is the case in Sweden. For the LLMA method, it could be a comparison of the initial delineation with commuting fields. For Intramax analysis, it could be the application of self-containment constraints resulting in the amalgamation of regions if these constraints are not met.

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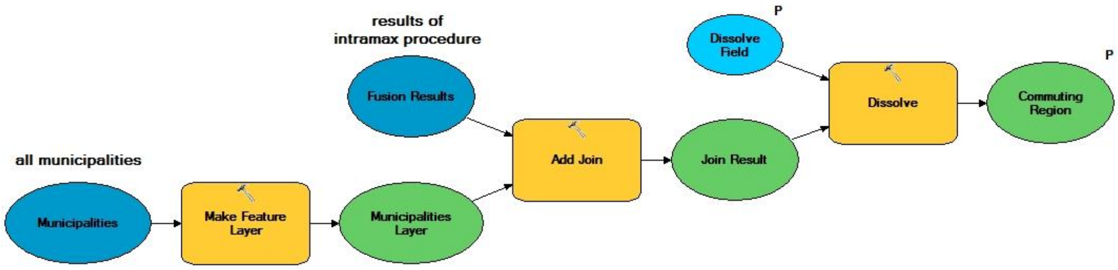
Notes

1: Commuting region builder tool



2: Steps used in ArcMap for the construction of commuting fields

Download a flow file (polyline feature class) with origin municipality (code), destination municipality (code) and number of trips.

Calculate out-commuting plus internal (within municipality) trips by dissolving on origin municipality in flow file and sum trips using number of trips as statistical field. Save the result in a new polyline feature class. The number of employed residents will be shown for each municipality.

Calculate in-commuting plus internal trips by dissolving on destination municipality in flow file and sum trips using number of trips as statistical field. Save the result in a new polyline feature class. The number of jobs will be shown for each municipality.

Calculate internal trips doing an attribute selection on the flow file where origin municipality equals destination municipality. Export the selected features to a new polyline feature class.

Join the dissolved internal trips polyline feature class to the polygon feature class of origin municipalities where origin municipality (key in destination table, i.e. table receiving the appended data) equals origin municipality (key in source table, i.e. table containing the data to be appended).

Join the dissolved jobs polyline feature class to the extended polygon feature class of origin municipalities where origin municipality equals destination municipality.

Join the dissolved employed residents' polyline feature class to the extended polygon feature class of municipalities where origin municipality equals origin municipality.

Three new fields have been added to the initial polygon feature class of municipalities, namely internal trips, jobs and employed residents. Two more fields can be added now: in-commuting by deducting internal trips from jobs, and out-commuting by deducting internal trips from employed residents.

Join the extended polygon feature class of municipalities to the flow file where origin municipality equals origin municipality, keeping only matched records. Save the result in a new polyline feature class with the following fields: origin municipality, destination municipality, trips and employed residents.

Calculate % employed residents by dividing trips by employed residents and multiplying the result by 100.

Choose 5% employed residents as a boundary for the commuting field, do an attribute selection on the polyline feature class where % employed residents is larger than or equal than 5 and save the result in a new polyline feature class.

The latter feature class can now be used to delimit the commuting field of a municipality by doing an attribute selection on destination municipality and saving the result in a polyline feature class.

Join this feature class of selected flows to the initial polygon feature class of municipalities where origin municipality equals origin municipality, keeping only matched records. Save the result in a polygon feature class.

3: Commuting field builder tool