Measuring Spatial Separation Processes through the Minimum Commute: the Case of Flanders

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The average distance covered by individual commuting trips increases year after year, regardless of the travel mode. The causes of this phenomenon are diverse. Although increasing prosperity is often invoked as the main reason, the discipline of spatial planning also points to the relevance of land-use policies that enable processes of suburbanization and sprawl. By calculating time series of spatially disaggregated theoretical minimum commuting distances, this paper offers a method to identify and quantify the process of spatial separation between the housing market and the job market. We identify the detected spatial separation as one of the possible indicators for the contribution of spatial processes to the growth of traffic.

In the case study area of Flanders and Brussels (Belgium), it is found that over time the minimum commuting distance increased in many municipalities, especially where population is growing faster than job supply, or where traditionally high concentrations of employment still increase. Decreases are noticed in suburban areas that are getting a more urban character by acquiring a considerable functional mix. For the study area in its entirety, we do indeed register an increasing spatial separation between home and work locations. However, this separation evolves less rapidly than the increase in commuting distances itself.

Regarding the methodology, we find that the use of municipalities as a spatial entity is suitable for grasping regional transformations of the economy and intermunicipal forms of suburbanization and peri-urbanization. However, a similar methodology, applied at a more detailed geographical scale, could be used to detect processes of sprawl in the morphological sense.

Keywords: excess commuting, Flanders, sustainable spatial development, urban sprawl

1. Introduction

Over the last century, there has been a mutually reinforcing relation between rising prosperity and a general increase in individual mobility: the growth of traffic volumes are both an effect and a cause of mounting affluence. For instance, faster transport modes (especially but not exclusively, the car) have consistently gained ground because the individual budget spent on transport has in absolute terms continuously been growing. The net result is that the average distance covered per person has been systematically increasing (Bleijenberg, 2003).

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EJTIR 11(1), January 2011, pp. 42-60   43
Boussauw, Derudder and Witlox
Measuring Spatial Separation Processes through the Minimum Commute:
the Case of Flanders

With regards to the commute, this means that, in general, workers have been looking for daily occupations increasingly further away from their home, or – conversely – that they have been moving house further away from their jobs. The logical result is a stronger separation between house and job location: if travel costs decrease, then travel consumption increases (Rietveld and Vickerman, 2003). This is especially true when the spent amount of time can be kept constant by increasing average travel speed, which seems generally to be the case in the Western world (Schafer, 2000).

Interestingly, this evolution apparently has an important spatial component. That is, it looks like changing travel behaviour is partly materialized in suburban and peri-urban developments, implying that possible origins and destinations lost relative proximity to each other. In many regions in the developed world, this materialization may be responsible for a certain degree of irreversibility of the expansion of travel patterns, as this limits the possibility of travel distances being reduced again in the future, even if environmental or congestion policies would aim for this. Since the adverse external effects of traffic are linked to the distance travelled (especially when travel is by car), this evolution makes it harder to address traffic problems at the source. In addition, spatial separation of functions is probably a long term economic disadvantage, since it makes the economic system vulnerable to possible future circumstances where transport costs would increase, for example by rising oil prices (peak oil) (Boussauw and Witlox, 2009) or growing structural congestion.

The perspective of this paper is the study of the mobility component of spatial separation of the job and housing market. Our research question is: how can spatial separation between residential locations and job locations be measured by means of a spatial proximity indicator, and what is the connection with the growth of observed commuting distances? We hereby hypothesize that the well-established line of inquiry on excess commuting (Ma and Banister, 2006) can provide a methodology to quantify evolutions of spatial separation in a functional sense, and to provide better insight in the contribution of spatial structure to the growth of traffic volumes over the last decades.

In practice, this will be done through calculating spatially disaggregated evolutions in minimum commuting distances, defined as the theoretical minimum distance that each worker would have to cover in order to find a job as close to home as possible under the assumption that actual residential locations and job locations are maintained and the total distance travelled (by all workers together) is minimized. After applying the method to a case study area in northern Belgium, we evaluate the observed evolution based on both occurring sprawl and regional-economic shifts in the labour market, aiming to explain regional variations.

Although assessing time series of the minimum commuting distance in order to describe spatial separation between the housing market and the labour market has been done before (Frost et al., 1998; Horner, 2007; Yang, 2008), the approach adopted in his paper is novel for two reasons. First, we adopt a study area which could be qualified as a suburbanized historically polycentric spatial structure - as there are many in Europe - and shows therefore significant spatial variations (i.e. it includes many historical urban areas, suburban and peri-urban developments, and major industrial zones), although it can be demarcated in a fairly consistent way based on economic and political criteria. Second, we refine the method in order to detect variations in the minimum commuting distance in a spatially disaggregated way, which certainly contributes to a critical understanding of the role of the present variations of spatial structure in comparison with Frost et al. (1998), Horner (2007) or Yang (2008) who define only one figure for the entire city or region.

The remainder of this paper is structured as follows. First, we clarify the possible reasons behind evolutions in spatial proximity by putting this in the perspective of the existing literature. Second, we present an overview of the case study area (Flanders and Brussels), including the main socio-economic and spatial processes and changes that may play a role in our analysis.

EJTIR 11(1), January 2011, pp. 42-60   44
Boussauw, Derudder and Witlox
Measuring Spatial Separation Processes through the Minimum Commute:
the Case of Flanders

Then we develop our methodology, including calculation and evaluation methods, and discuss the available data. After applying the method, we present the results, discuss possible biases and draw some final conclusions.

2. Defining spatial separation processes

One can think of several possible reasons leading to changes in spatial proximity between homes and jobs. For planning policies, the most relevant possible causes are suburbanization and sprawl. Ewing (1994) assumes a strong link between sprawl and increased traffic. But also thorough zoning policies may lead to increasing mutual distances. These phenomena are local in nature and manifest themselves at a small geographical scale, meaning that in quantitative analysis, these will particularly manifest when data are available at a detailed spatial division (e.g. traffic analysis zones).

Newman and Kenworthy (1989) and Gordon and Richardson (1989) associate sprawl with a specific morphology, particularly consisting of monotonous suburban districts with a strict separation of functions, characterized by store strips, commercial architecture and large internal distances. However, the extent to which spatial separation leads to an effective increase of distances that need to be covered is less clear, since this cannot be derived from local morphological characteristics. For instance, a monotonous residential lot embedded in a major employment centre could possibly lead to a more sustainable travel pattern than a compact town that is immersed in a rural area.

Therefore it is important to view spatial separation not only in a morphological way but also in a functional sense. Particularly in a context where average trip lengths, and in particular average commuting distances, have become very large in practice, it is hard to tell which kind of spatial developments are problematic in relation to mobility, and which are rather beneficial. Banister (1999) therefore observes the issue at hand in a non-morphological way, and suggests that it is of the utmost importance that new developments are sufficiently large and are located in or immediately subsequent to existing urban areas. As a consequence, local morphology, density and spatial diversity come only in second place.

Another phenomenon that could cause this kind of functional separation processes, although particularly at a larger geographical scale level and consequently only partly related to suburbanization processes, consists of regional economic shifts within the labour market. An economic transformation, e.g. towards a more service-based industry, could lead to a different spatial distribution of jobs, e.g. through centralization. But also an absolute increase in the number of jobs in one zone can lead to a spatial distribution where work locations are on average closer to residences of potential employees. Since these kinds of regional transformations take place at a higher geographical scale than suburbanization processes, these will rather become clear when relatively large zones (e.g. districts or municipalities) are studied.

If we restrict ourselves to commuter traffic, we see that trip lengths have increased systematically over the past decades. This trend was observed in Belgium (see below), the U.S. and the U.K., and we may assume that this evolution is manifest throughout the Western world (Aguilera, 2005). The basic mechanism that underlies this growth is an increase in travel speed. Basically, people do not spend more time commuting than they did before, nor do they spend a greater proportion of their income on transport (Schafer, 2000). Rather, it is the general prosperity growth that has led to an absolute increase in resources devoted to transport, resulting in more car ownership, more car use (at the expense of slower transport modes), an extension of the motorway network and a pushed up speed of public transport. In the surroundings of large agglomerations, congestion has slightly slowed down the overall increase of travel speed, although it did certainly not stop it (Van Wee et al., 2002).

EJTIR 11(1), January 2011, pp. 42-60
Boussauw, Derudder and Witlox
Measuring Spatial Separation Processes through the Minimum Commute:
the Case of Flanders

45

Even though spatial separation processes and increasing trip lengths appear to be associated, this does not necessarily imply a one-way causality. The fact that employees live on average further from their work location than before, a phenomenon which occurs partly in the form of sprawl, is caused by increasing individual mobility, i.e. a wealth-related phenomenon that is the basis of an autonomous growth of traffic. So, we might explain these spatial separation processes as a materialization of this increased mobility, which has itself a mutual reinforcing effect on the growth of traffic.

3. Measuring spatial separation by excess commuting characteristics

The perceived increase in traffic volume due to spatial separation processes, whether or not perceived as sprawl, remains a main concern in most spatial policy plans (Sultana and Weber, 2007). Given the importance attached to mobility, it may be surprising that quantification of this phenomenon is usually confined to measuring morphological characteristics. However, in this paper we want to measure the process of spatial dispersion that results in further separating origins and destinations over the years, or, as might be the case in some areas, decreasing separation between origins and destinations. By measuring this development over a certain time interval, we have a good idea what proportion of the traffic growth in that period is due to spatial expansion. An important methodological issue concerns the definition of these origins and destinations. This obstacle disappears when restricting ourselves to the commute, where origins (residential locations of workers) and destinations (job locations) can be clearly defined.

Cross-sectional analyses that compare travel behaviour of commuting residents or workers in suburban areas with commuting behaviour in areas with urban characteristics are common in the literature. Sultana and Weber (2007), for instance, recorded large differences in actual travel times and trip lengths, depending on the direction of the commuter flow. Flows within urban areas appear to be the shortest, both in distance and in time. Commuting trips within the suburban areas, however, appear shorter than commuting trips from the suburbs towards the city.

In order to map the spatial separation between the housing market and the labour market, regardless of actual commuting patterns, other methods are needed. An elementary indicator of the spatial distribution of housing and jobs with an alleged impact on mobility is the jobs-housing balance (the ratio between the number of jobs in an area and the number of workers living in the same zone). In its simplest form, this indicator is measured by zone, making it sensitive to variations in zoning and insensitive to effects of embeddedness in the surrounding region or the presence or absence of transport infrastructure. Peng (1997) tried to overcome these problems partly by calculating the jobs-housing balance based on the surrounding area of which every considered zone is the centre.

A more advanced line of inquiry is the field of 'excess commuting', which originally focuses on the study of spatial structure in relation to commuting behaviour by comparing observed commuting distances with theoretical calculated minimum commuting distances. An overview of existing research on this topic is given by Ma and Banister (2006). One of the spatial characteristics, provided by the excess commuting literature, is the minimum commuting distance, which incorporates both the spatial distribution of jobs and housing, and the infrastructure network. It is related to the job-housing balance, but is a more sophisticated indicator as it also takes into account the embeddedness of the study area in the wider region, as well as the transport network (Horner and Murray, 2003). We consider the minimum commuting distance as a measure of the proximity of the housing market to the labour market (Horner, 2004), or as a variable that indicates to what extent the system could absorb shrinkage of commuting distances. The latter is relevant when we want to understand the potential impact of the

EJTIR 11(1), January 2011, pp. 42-60   46
Boussauw, Derudder and Witlox
Measuring Spatial Separation Processes through the Minimum Commute:
the Case of Flanders

commute getting more expensive, e.g. under the influence of rising fuel prices (Boussauw and Witlox, 2009).

The calculation of the minimum commuting distance implies that the existing residential and job locations are retained, but that workers are assigned to jobs in a way that leads to a minimization of the total distance travelled. More formally:

$$\text{minimize } H = \sum_{i=1}^{n} \sum_{j=1}^{n} d_{ij} t_{ij} \qquad (1)$$

$$\text{given: } \sum_{i=1}^{n} t_{ij} = D_j \qquad (2), \qquad \sum_{j=1}^{n} t_{ij} = O_i \qquad (3), \text{ and} \qquad t_{ij} \geq 0 \qquad (4)$$

in which: H = total distance travelled within the system by matching workers and jobs

n = number of zones

O_i = number of workers living in zone i

D_j = number of jobs in zone j

d_{ij} = network distance between centroids of zone i and zone j

t_{ij} = number of trips between zone i and zone j

Ma and Banister (2007) published an in-depth study on the relationship between excess commuting and urban form. Horner (2007) and Yang (2008) used also the maximum commuting distance as a measure of spatial dispersion, while Charron (2007) and Yang (2008) introduced the terms "proportionally matched commute" and "random average commute", based on a more extensive theoretical exploration on possible commuting ranges, and proposed as more realistic alternatives to the maximum commuting distance.

The maximum commuting distance should be seen as the conceptual inverse of the minimum commuting distance: it is the value obtained when all employees within the study area simultaneously would exchange jobs or houses aiming to live as far as possible from their jobs. In an urban system consisting of a single city that is isolated from neighbouring cities, this measure is a good complement to the minimum commuting distance. In the context of our assessment, however, the notion of maximum commuting distance is rather abstract. Not only will employees never be inclined to spontaneously maximize home to work trip length, also outcomes seem to be largely dependent on the considered region frontier and are highly correlated with the size of the study area (Charron, 2007). Moreover, the amount of traffic that is associated with a maximized commuting distance is not compatible with the existing transport infrastructure or any form of pursuing economic efficiency. In this paper, we will calculate the global value of the maximum commuting distance as an additional support of the observed trends in minimum commuting distance, but we will not elaborate on spatially disaggregated values.

The contribution of a time series approach of the proportionally matched commute is mainly in quantifying the extent to which a regional system evolves from mono-centric to dispersed (Yang, 2008). Since the possible interpretation of the meaning of spatially disaggregated values of the proportionally matched commute in a polycentric region is subject to further research that is beyond the scope of this paper, we will no further elaborate on this.

In the literature, the average minimum commuting distance is usually calculated as a single measure for an entire city or region (Ma and Banister, 2006). However, it is also possible to calculate this in a spatially disaggregated way in order to reveal regional variations. In the latter case, for each zone (traffic analysis zone, municipality, district ...) the distance outcome is calculated twice: once for the outgoing commute, and once for the incoming commute.

EJTIR 11(1), January 2011, pp. 42-60   47
Boussauw, Derudder and Witlox
Measuring Spatial Separation Processes through the Minimum Commute:
the Case of Flanders

Niedzielski (2006) elaborated on a spatially disaggregated analysis of Warsaw on the basis of minimum commuting distances. When taken the locations of residence as a viewpoint, the largest minimum commuting distances were recorded in areas with suburban characteristics. Viewed from the perspective of job locations, the highest values are recorded downtown (CBD). Yang and Ferreira (2009) included spatially disaggregated values in their information system for planners in the Boston area. A similar analysis, albeit on a regional scale, was made for Flanders and Brussels (Belgium) by Boussauw et al. (2011). A spatially disaggregated calculation of the minimum commuting distance on cross-sectional data allows obtaining these values per zone for a given point in time. In a next step, a similar analysis based on time series data would then reveal trends, indicating for a certain zone if the housing market moved on average further away from the job market over the chosen time span, or if, maybe, the opposite has happened.

Horner and Murray (2002) devoted considerable attention to the impact of the underlying zoning system on the calculated minimum commuting distance, both with regard to size and to location. This issue is known as the modifiable areal unit problem (MAUP). The use of larger zones means that more trips become intrazonal, leading to an overestimation of the minimum commuting distance (Horner and Murray, 2002). Both interzonal and intrazonal trips originating in large zones can only be simulated with limited precision, leading to significant inaccuracies. However, when excess commuting is studied, this problem can partly be accommodated by recalculating observed commuting distances using the same origin-destination matrix that is used to calculate the minimum commuting distance.

For our research, however, the main problem associated with the selection of zone sizes is the geographical scale at which the studied developments occur. This means that the spatial separation between jobs and housing can both be caused by sprawl (at a small geographical scale) and by regional economic shifts within the labour market (at a large geographical scale). The first phenomenon will particularly manifest when detailed zoning (e.g. traffic analysis zones) is used, while the second phenomenon will become clear when relatively large zones (e.g. districts) are studied.

While a considerable volume of research on excess commuting has been published yet, the literature is still fast evolving. Recent inquiries include attainability of trip length reductions (O'Kelly and Niedzielski, 2008), differentiation in excess rate depending on mode choice (Murphy, 2009), the relationship with the jobs-housing balance as a suitable indicator for measuring spatial expansion (Layman and Horner, 2010), the influence of uncertainties in travel time measurements when minimizing time distance (Horner, 2010) and optimization of spatially disaggregated calculation methods (Boussauw et al., 2011).

Based on the properties of the excess commuting framework, we find a time series approach of the minimum commute useful to study processes of suburbanization. Existing research in this field is rare, however. Frost et al. (1998) described the evolution of the minimum commuting distance for a set of demarcated British cities. They compared the 1981 situation with 1991. Yang (2008) reported on similar research in the metropolitan areas of Boston and Atlanta, based on data from 1980, 1990 and 2000. Both studies find an increase of both minimum commuting distances and actual commuting distances, in all involved cities. Horner (2007) compared commuting data from Tallahassee, Florida, from 1990 and 2000. The average reported commuting distance and maximum commuting distance increased during this period, while the minimum commuting distance showed only a statistically non-significant increase. However, neither Frost et al. (1998) nor Horner (2007) or Yang (2008) applied a spatially disaggregated method, so it is not clear which parts of the urban areas are the most affected by spatial separation. Furthermore, no typical peri-urban areas, which are relatively far from the CBD, were incorporated in the analyses. As stated in the introduction, our approach consists of an extension to the empirical diversity of the three aforementioned authors by including suburban and rural areas and an extension of their methodology by applying a spatially disaggregated method.

EJTIR 11(1), January 2011, pp. 42-60   48
Boussauw, Derudder and Witlox
Measuring Spatial Separation Processes through the Minimum Commute:
the Case of Flanders

4. Spatial development and commuting in Flanders and Brussels

The case study area consists of the administrative regions of Flanders and Brussels, which together form the northern part of Belgium (Map 1). Historically, the area is built around three major cities (Brussels, Antwerp and Ghent), a dozen regional cities and several dozen smaller towns and central municipalities. The economic core is borne by the wide surroundings of the axis Brussels-Antwerp, a region known as the Flemish Diamond. The rapid development of an extensive railway network in the nineteenth century and the introduction of cheap season tickets formed the backbone of a policy aimed at an industrialization of the country based on limited urbanization (Verhetsel et al., 2010). The new working class was able to continue living outside major cities, in a house with a garden and under the watchful eye of the village priest, while commuting every day to the factory or the office. This form of institutionalized commute laid the foundation for the spatial separation between housing and work locations that has only developed more distinctly since the advent of the motorway and general car ownership. In the period before World War II, this phenomenon has materialized in the form of spatial developments that were strongly clustered around the railway stations. In the post-war period, however, this structure fanned out into a network of suburbanized and peri-urbanized areas around the ancient settlements.

In this context, suburbanization refers to sprawl that is occurring in or adjacent to urban areas, while peri-urbanization consists of developments in the countryside, free-standing or in line with existing villages. These postwar developments gradually led to the emergence of a variety of forms of urbanization, ranging from historical densely populated cities and sparsely populated suburban residential belts to commuter areas and pure countryside (Vanneste et al., 2008). Depending on the definition, 57% (Vanneste et al., 2008) to 97% (Antrop, 2004) of the Belgian population lives in urbanized areas.
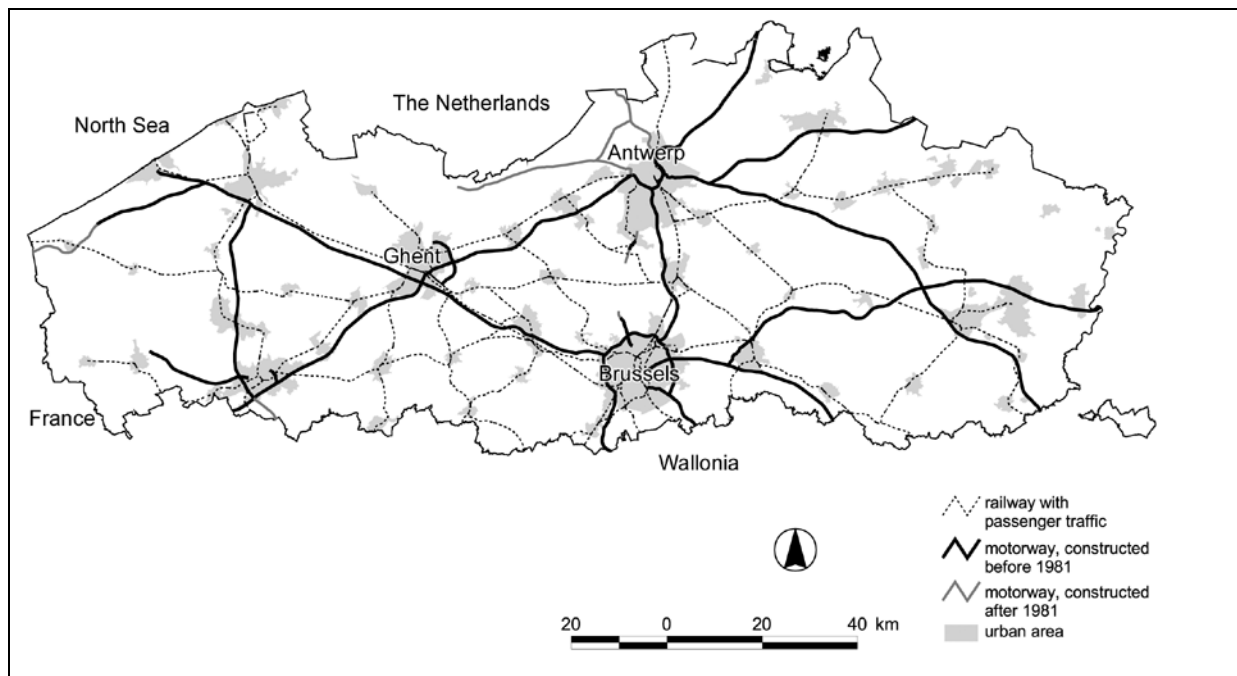
Map 1. Situation of infrastructure and urban areas

The problem of spatial separation, supposedly mainly in the form of sprawl, is not a new issue in Flanders. In the period between 1980 and 2000 planning became a major political topic, as open space became scarce, and urban flight appeared to feed a wave of suburban and peri-urban

EJTIR 11(1), January 2011, pp. 42-60
Boussauw, Derudder and Witlox
Measuring Spatial Separation Processes through the Minimum Commute:
the Case of Flanders
49

development. Newly emerging issues in the field of landscape ecology, water pollution, increasing distribution costs, road safety, congestion and social segregation were partly attributed to sprawl. The political response, in the form of the Spatial Structure Plan for Flanders (RSV, 1997/2004) had to wait until 1997, but did offer an answer in the form of the demarcation of urban areas and the focus on encouraging additional building in the cities and existing settlements.

The policy measures that are imposed by this plan are based on a rather intuitive analysis of the problem, with often no thorough scientific rationale behind it. Since then, several quantitative spatial analyses have been carried out. The main research report on sprawl, which was issued by the Flemish Environmental Agency (Gulinck et al., 2007), approaches the phenomenon mainly from a landscape-ecological perspective. It focuses on morphological changes that are related to spatial fragmentation. In the process, sprawl detection is based on maps and satellite images from different periods. The main indicator is the overall total built-up area, which for Flanders increased over the period 1990-2000 from 13.2% to 14.6%. Other indicators were the length of the road network (increasing by 6.4% between 1991 and 2001), morphological grain size and global proximity to buildings and infrastructure. A time series analysis of these indicators points to a systematic increase in sprawl.

The successive censuses show that commuting distances in Belgium systematically increase. Based on an assessment of the respondents, the perceived average distance between home and workplace evolved from 11.9 kilometres in 1970 (Mérenne-Schoumaker et al., 1999) to 19.0 kilometres in 2001 (Verhetsel et al., 2007), an increase of no less than 60%. Although non-commuting trips and freight transport grew even faster over this period, it is clear that the increase in trip length is largely responsible for the overall growth in traffic.

5. Data

The decennial census, organized by the Belgian federal government, assesses the municipality of residence and the work municipality of all working citizens. Furthermore, the (perceived) distance travelled every day to work is also registered. Commuting data for 1981, 1991 and 2001 is available in the form of origin-destination matrices, with the municipality as a spatial unit. The small municipalities of the Brussels Capital Region were combined into one zone, in order to avoid biases in relation to the two other metropolitan municipalities of Antwerp and Ghent. As a result, the study area is divided into 309 zones with a mean area of 44 km² (standard deviation: 29 km²).

For the particular purposes of our research, the matrices were cleaned by removing all trips that have their origin or destination outside the study area (Wallonia and the neighbouring countries). Apart from these inter-regional commuters, also home workers (including teleworkers) were removed from the matrices, as well as respondents with an itinerant occupation. The exclusion of these records is justified because we only want to measure the extent to which residential and labour structure separate within Flanders-Brussels.

Although the method of data collection in the three survey moments was performed in a similar manner, there are rather large differences between the three data sets. Important variations in the number of commuting trips are found, as well as in the number of unknown or incomplete registrations. Moreover, the number of home workers declined dramatically over the three consecutive survey moments, and the structure of the inter-regional commute (between Flanders-Brussels and the neighbouring region and countries) changed. Possibly more important is the influence of the regional economic transformations that occurred. In the period 1981-2001 the economy shifted towards a more service-based system, and lost a number of important industrial employment centres such as the Kempen coal mines in the east of Flanders and the Hainaut steel

EJTIR 11(1), January 2011, pp. 42-60
50
Boussauw, Derudder and Witlox
Measuring Spatial Separation Processes through the Minimum Commute:
the Case of Flanders

industry south of the study area. Also, the port of Antwerp and the airport of Brussels went through an era of major growth, and a high standard service industry (especially in information technology and international public institutions) developed in the urban areas, in particular in the Brussels agglomeration. This restructuring of the labour market cannot be separated from the suburbanization of the residential structure: both transformations add to the spatial separation that we want to assess.

Regarding the development of sprawl in the studied period, also the growth of the infrastructure network is undoubtedly important. Although most motorways that exist today where constructed in the period prior to 1981 (roughly between 1961 and 1981, see Map 1), it can be expected that many developments along the motorways have been built in the period 1981-2001.

6. Method

To answer the research question, we investigate the evolution of the spatial distribution of residential locations of workers and job locations in Flanders and Brussels (Belgium), mainly relying on the minimum commuting distance concept, and comparing the trend found with the evolution of observed commuting distances. To this end we first take the study area as a whole, then we reiterate the calculation in a spatially disaggregated way (for each municipality separately). Regarding indicators for the study area as a whole, we will also provide the global maximum commuting distance.

As we consider the minimum commuting distance as a measure of spatial proximity between job market and housing market, the possible mismatch between qualifications and job preferences of workers and requirements of employers is not taken into account, which is an important deviation from reality. Although in the literature attempts were made to disaggregate excess commuting characteristics based on a classification of workers and jobs (O'Kelly and Lee, 2005), this approach falls outside the scope of our paper. Nevertheless it is important to keep this constraint in mind when interpreting the results. O'Kelly and Lee (2005) found e.g. that service workers are subject to shorter minimum commuting distances than industrial workers, but that actual commuting behaviour of the former group gives rise to larger excess rates than the latter. However, it is unclear whether these findings also apply outside the surveyed American cities, e.g. in a Belgian context. Also, the unemployed population and home workers do not affect the results since they are excluded from the dataset, which is important to keep in mind when interpreting the results.

An increase of the minimum commuting distance towards or from a certain area is usually indicative of the spatial expansion of the residential market or a trend of concentration in the labour market, while a decline usually will point to a greater functional mix. The underlying causes may be both of spatial development nature (sprawl), and of regional-economic nature (e.g. the economic shift towards service industries, increased tertiarisation).

According to our hypothesis, the rate at which the minimum commuting distance increases is an indicator for the impact of spatial transformations on the actual average commuting distance. The difference between the growth rate of the minimum commuting distance and the growth rate of the actual commuting distance is a measure of the non-spatial component in the overall growth of the commute. Consequently, an increase in commuting distances that would develop faster than the increase of the minimum commuting distances points to a mobility growth that is relatively independent of changes in spatial structure. In the opposite case, we would be dealing with a spatial evolution that is in and by itself responsible for the entire growth in commuter traffic volume.

EJTIR 11(1), January 2011, pp. 42-60
Boussauw, Derudder and Witlox
Measuring Spatial Separation Processes through the Minimum Commute:
the Case of Flanders

51

To calculate the minimum commuting distance, most authors make use of one of the minimization algorithms for the so-called "transportation problem", as available in various software packages. However, we applied an alternative method that has been used before for a cross-sectional analysis of the same study area, and is explained in Boussauw et al. (2011). This method is conceived as an iterative process that simulates the behaviour of commuters who simultaneously look for a job closer to home. The disadvantage of this method is that the achieved "optimum" remains slightly higher than the mathematical minimum. The advantage of the method is that the produced origin-destination matrix holds a much greater realism, since it is not influenced by algebraic tricks that are applied to find the mathematical minimum but do not make sense in a real world approach. An example is the allocation of all resident workers from one zone to jobs in only one corresponding zone. Moreover, the structure of origin-destination matrices that are produced by the iterative process on the basis of various data sets (representing different points in time) is similar, meaning that comparing these matrices using statistical methods (such as Student's t-test) makes sense. This is not necessarily true when applying a standard "transportation problem" algorithm, where the structure of the resulting origin-destination matrix depends on the used software package.

Confronting the minimum commuting distance for an area with the observed (calculated) commuting distance is known as the study of excess commuting. In practice we implement this confrontation by calculating the excess rate, defined as the quotient of the mean observed commuting distance and the mean minimized commuting distance.

The mean observed distance used in the analysis is actually a calculated (thus not perceived by the respondent) distance. For each municipality, the centre of gravity (centroid) is determined. Then a shortest-path matrix is calculated by means of a skeleton file of the Belgian road network, making the shortest network distance between each possible pair of municipalities available. Intra-municipal distances are simulated by taking for every municipality half of the network distance to the centroid of the nearest municipality. Given that the road network in 1981 was already very dense, we use the same skeleton file for the three time periods.

7. Results

7.1 Evolution of the mean observed commuting distance

We calculate for each municipality the mean trip length for both outgoing (outbound mean calculated distance: *omcd*) and incoming (inbound mean calculated distance: *imcd*) commuting trips. A weighted average can be found in Table 1, along with the commuting distance as perceived by the respondents (mean perceived distance: *mpd*).

Table 1. Observed commuting trips and commuting distances

|	1981	1991	2001
number of commuting trips (matrix)	1,950,477	2,331,090	1,907,197
mcd (matrix)	12.2 km	12.6 km	14.7 km
mpd (Belgium)	14.6 km[a]	17.2 km[b]	19.0 km[b]

[a] source: Mérenne-Schoumaker et al. (1999), p. 80

[b] source: Verhetsel et al. (2007), p. 60
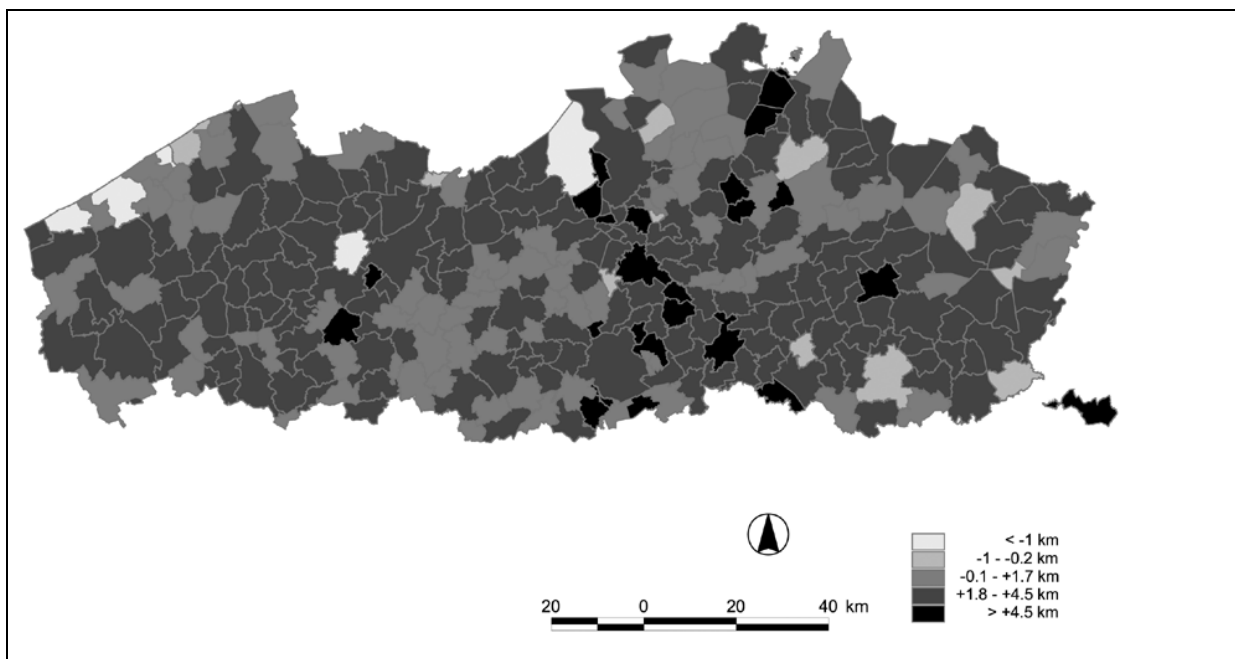
The important differences between the calculated (*mcd*) and the observed mean commuting distance (*mpd*) can be explained as follows:

EJTIR 11(1), January 2011, pp. 42-60
Boussauw, Derudder and Witlox
Measuring Spatial Separation Processes through the Minimum Commute:
the Case of Flanders

52

- *mcd* is calculated based on the shortest network distance while the shortest route is usually not the fastest, and thus not the path that is chosen by the commuter;

- *mcd* is calculated from centroids of municipalities, which is an important simplification, particularly with regard to intra-municipal trips;

- *mcd* ignores interregional, usually relatively long, commuting trips;

- *mpd* includes commuting trips in the south of Belgium, which are longer on average.

Other possible biases in perceived trip length are discussed by Witlox (2007).
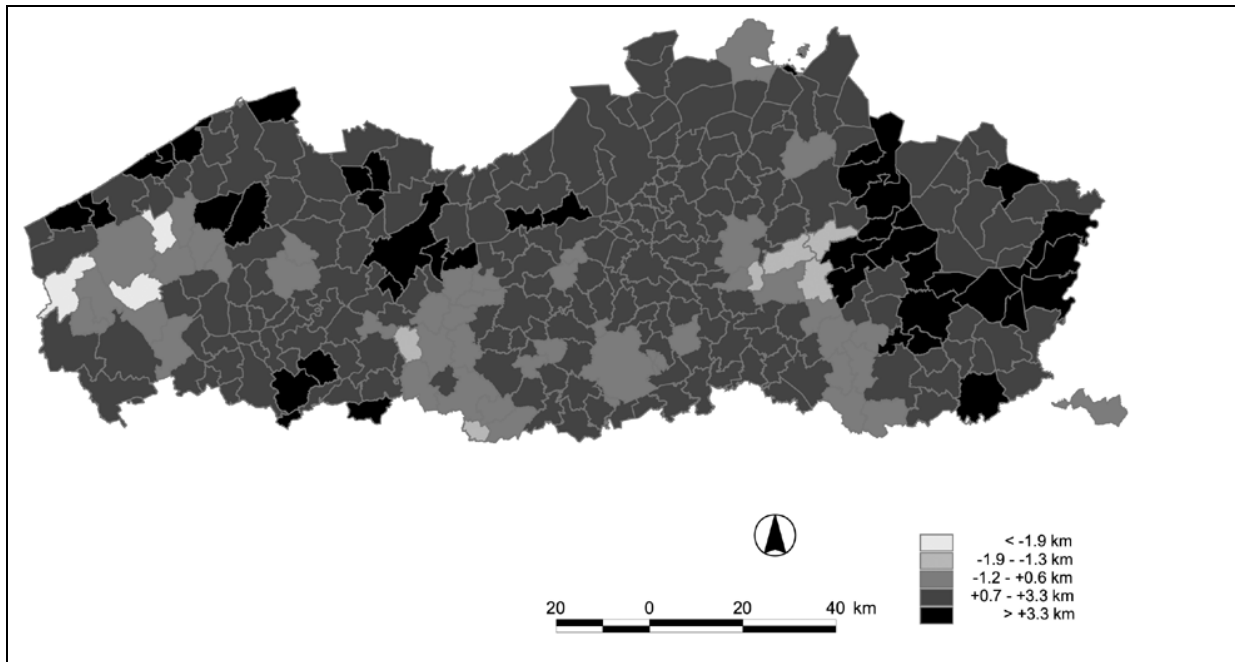
Map 2. Evolution of the commuting distance (1981-2001) based on municipality of residence

Map 3. Evolution of the commuting distance (1981-2001) based on municipality of workplace

EJTIR 11(1), January 2011, pp. 42-60
Boussauw, Derudder and Witlox
Measuring Spatial Separation Processes through the Minimum Commute:
the Case of Flanders
53

Taken together, the *mcd* variable should therefore be regarded as a theoretical measure, which only makes sense when compared to similar calculations, such as the minimum commuting distance. For comparison with survey data from other countries, *mpd* will naturally be better suited. More important than the absolute figure is the trend that both quantities exhibit.

A closer look reveals that over the period 1981-2001 *mcd* increases in 280 of the 309 municipalities when considering the outbound commute (Map 2), and increases in 291 of the 309 municipalities when looking at the incoming commute (Map 3). Although municipalities with a relative growth show a certain spatial clustering, the virtually general upward trend suggests that at least some of the causes of the growth in trip length are of non-spatial nature.

7.2 Evolution of the mean minimum commuting distance

Given the significant variation in the number of recorded trips between the three snapshots (1981, 1991 and 2001), we first examine whether this sample variation affects the calculated mean minimum commuting distance (*mmid*). We did this by weighing commuting trips for the year 1981 and 1991 so that the three tables on which the minimization procedure was then performed all contain 1,907,197 trips (equalling the number of trips in the origin-destination matrix for 2001, see Table 1). The obtained results are thereupon compared with the results that are based on the unweighted tables. No significant differences were found, and Pearson's correlation coefficient between the two sets of spatially disaggregated results is 1.00. Next, the global *mmid* for the entire study area is calculated for the three different points in time. The obtained figures are presented in Table 2, along with the evolution of *mcd*, and the maximum commuting distance (*mmad*).

Table 2. Evolution of the global minimum commuting distance and excess rate

	1981	**1991**	**2001**
Mmid	9.0 km	8.9 km	9.4 km
evolution *mmid* (base 1981)		-1.4%	+4.3%
Mcd	12.2 km	12.6 km	14.7 km
evolution *mcd* (base 1981)		+3.4%	+20.1%
excess rate (*mmid/mcd*)	1.36	1.43	1.57
evolution excess rate (base 1981)		+4.8%	+15.1%
Mmad	19.5 km	18,6 km	21.6 km
evolution *mmad* (base 1981)		-4.5%	+10.8%

A salient element in Table 2 is the negative evolution of *mmid* over the period 1981-1991 (-1.4%), which is associated with an increase of *mcd* (+3.4%). So, the studied residential locations and job locations would have come 1.4% closer together over this period, while commuting distances continuously increased. Nevertheless, over the entire period under investigation (1981-2001) we find, as expected, an increase in *mmid*.

The second striking result is the growth rate of *mmid*: this is much lower (+4.3%) than the growth rate of *mcd* (+20.1%). Logically, this trend is in line with an increase of the excess rate. This result suggests that over the studied period the average worker became less inclined to seek a job close to home, or to look for a home close to work. This also means that only a small part of the increase in commuter traffic can be attributed to the expansion of the spatial structure.

The evolution of *mmad* confirms the observed trend of *mmid*, although the differences are more pronounced. For a theoretical approach to the possible interpretation of the differences between *mmid* and *mmad*, which is beyond the scope of this paper, we refer to Charron (2007) and Yang (2008).

EJTIR 11(1), January 2011, pp. 42-60   54
Boussauw, Derudder and Witlox
Measuring Spatial Separation Processes through the Minimum Commute:
the Case of Flanders

Note that in our literature overview only three papers (i.e. Frost et al., 1998, Horner, 2007 and Yang, 2008) studied time series of minimum commuting distance. The results of Horner (2007) and Yang (2008) are analogous with our findings: in Tallahassee, in Boston and in Atlanta both minimum commuting distances and observed commuting distances grew, while the former increased more slowly than the latter. Frost et al. (1998), however, found for all analysed British cities that the growth of the minimum commuting distance was faster than the growth of the observed commuting distance, suggesting that changes in the spatial structure could be held fully responsible for the increase in commuter traffic volume, along with an improved efficiency in the commute itself (given the reduction of the excess rate). In contrast to our research, however, Frost et al. (1998) limited their study area to demarcated cities, to which only incoming commuting trips were added. So, the spatial structure of the commuter area around the considered cities was not fully grasped. Within these demarcated cities urban sprawl hardly occurs, and also the growth in traffic itself is far more constrained by congestion than is the case in the suburban areas. While this alternative approach may explain the difference in results, apparently great caution in interpreting the results is needed.

7.3 Evolution of the spatially disaggregated minimum commuting distance

A second step in the analysis is the calculation of spatially disaggregated values of *mmid*. For each municipality and for each of the three points in time *mmid* was calculated twice: once for the outgoing commute (*ommd*) (these are the outgoing and internal trips together) and once for the ingoing commute (*immd*) (these are the incoming and the internal trips together). So, for each municipality we obtain two time series.

Then, for each time series the existence of a clear trend for the period 1981-2001 was examined. First, a Student's t-test was applied to compare columns and rows of the produced origin-destination matrices. Non-significant differences (significance level: $p < 0.05$) are considered as a status quo. The decision rules that were used to determine the existence of a trend are presented in Table 3. As a general principle it is assumed that a trend is only acknowledged if the evolution over the period 1981-1991 is not contradictory to the evolution over the period 1981-2001. Moreover, the differences have to be statistically significant in at least one of the two periods.

Table 3. Decision table trend

evolution 1981-2001	evolution 1981-1991	evolution 1991-2001	conclusion
+	+	+ / - / not sig.	+
+	-	+	0
+	not sig.	+	+
-	-	+ / - / not sig.	-
-	+	-	0
-	not sig.	-	-
not sig.	+ / - / not sig.	+ / - / not sig.	0

For the municipalities where a significant trend was found, the absolute differences in *mmid* over the period 1981-2001 were mapped (Map 4 and Map 5). The following applies:

$$ommd_{81-01} = ommd_{01} - ommd_{81} \quad (5)$$

and $\quad immd_{81-01} = immd_{01} - immd_{81} \quad (6)$

EJTIR 11(1), January 2011, pp. 42-60   55
Boussauw, Derudder and Witlox
Measuring Spatial Separation Processes through the Minimum Commute:
the Case of Flanders

7.4 Outbound minimum commuting distance by municipality

Map 4 shows the evolution of the minimum commuting distance over the time frame 1981-2001 for those municipalities that contain more working residents than jobs. Municipalities with a job surplus are omitted since the applied method implies that the minimum commuting distance for workers living in such a municipality remains constant as long as the job surplus exists. Following issues on the map stand out:

- Most municipalities in the economic core around the triangle Antwerp-Brussels-Leuven (A) show a decrease of *ommd*. Exceptions are some municipalities with a more rural character that are located on the edge of the conurbation and have received a large share of housing suburbanization (Kapellen (B), Nijlen and Berlaar (C), Zemst (D), Oud-Heverlee (E), Beersel and Sint-Pieters-Leeuw (F)).

- The former mining region in the Kempen (G) shows a sharp increase of *ommd*, perhaps due to economic transformation processes that have led to a decline of job supply in this area.

- In some areas apparently the construction of the motorway has indeed led to a suburban housing development that entailed only few jobs. This is clearly the case along the E40 between Ostend and Ghent (H), and in some municipalities in the Voorkempen (Brecht and Zoersel (I)) and Limburg (such as Maasmechelen (J), Riemst (K), Heers (L)).

- In other municipalities also a lot of employment developed in the proximity of the motorway. This is the case in Leie valley south of Ghent (M), or in Lummen (N).
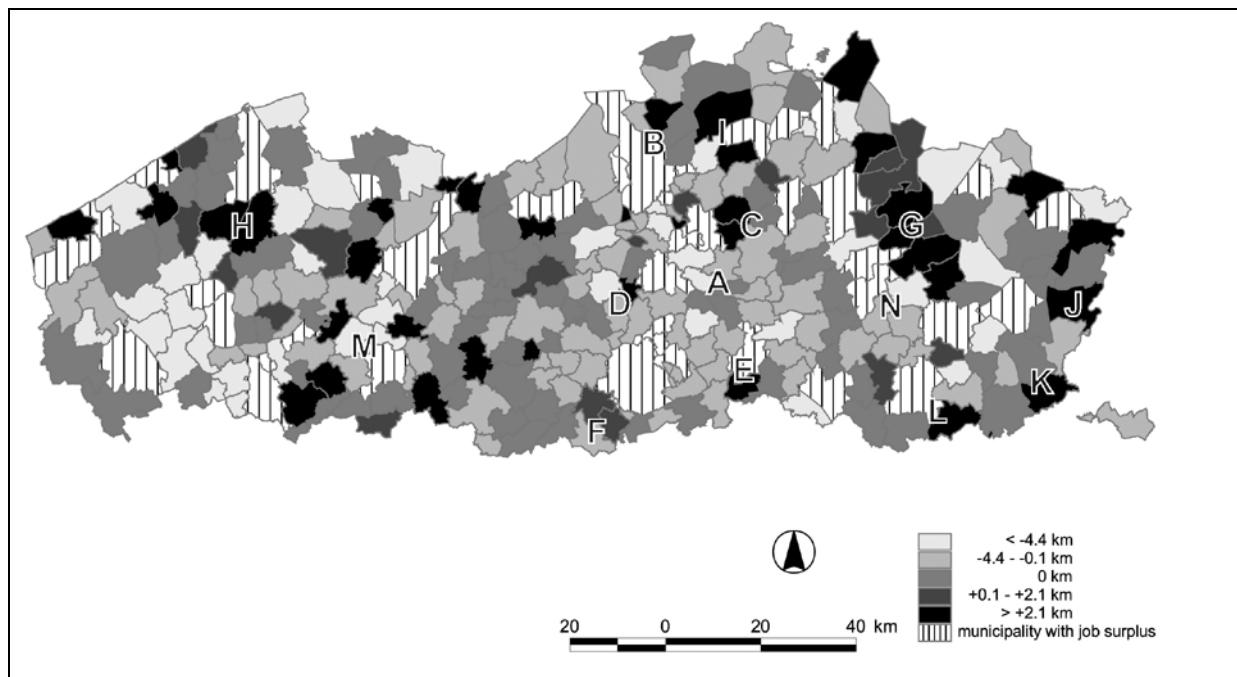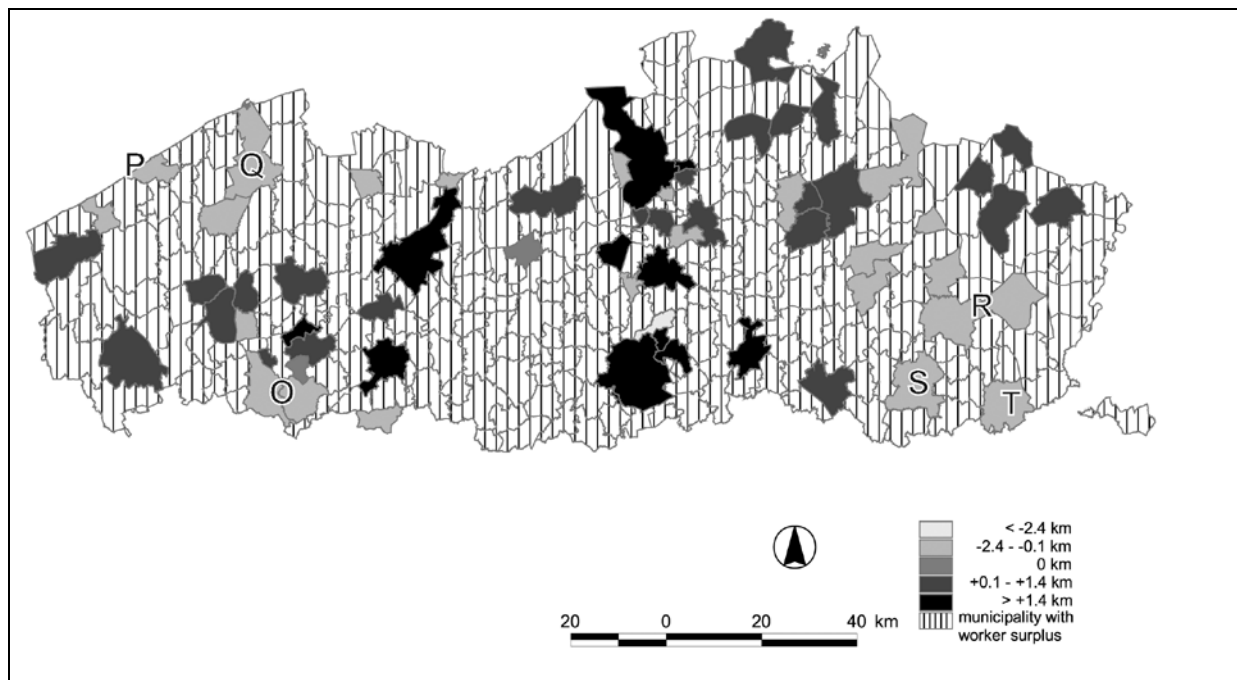

Map 4. Evolution of the minimum commuting distance (1981-2001) based on municipality of residence

7.5 Incoming minimum commuting distance by municipality

Map 5 shows the evolution of the minimum commuting distance over the period 1981-2001 for those municipalities that contain more jobs than working residents. In this case, municipalities with a surplus of workers are omitted since the applied method implies that the minimum

EJTIR 11(1), January 2011, pp. 42-60   56
Boussauw, Derudder and Witlox
Measuring Spatial Separation Processes through the Minimum Commute:
the Case of Flanders

commuting distance for workers employed in such a municipality remains constant as long as the worker surplus exists. Following issues on the map stand out:

- The value of *immd* increases in almost all non-peripheral cities, and the Brussels region has the strongest growth. This means that these cities need to cover an expanding recruitment area to have their available jobs occupied.

- A number of cities in the more remote areas, however, show a reduction of the minimum commuting distance. Thus, in these places the concentration of employment is proportionally shrinking. This is the case in the cities Kortrijk (O), Ostend (P) and Bruges (Q) in the west, and in the cities of Hasselt and Genk (R), Sint-Truiden (S) and Tongeren (T) in the east.

Map 5. Evolution of the minimum commuting distance (1981-2001) based on municipality of workplace

7.6 General interpretation and possible biases

The results of our analysis seem to indicate that at the macro level the distance between job locations and residential locations of the working population did not dramatically increase, and that commuter traffic shows an autonomous growth that can only partially be explained by changes in the spatial structure.

There are two, possibly complementary, explanations for the relatively limited detected increase of the average distance between home and work locations. First, jobs have partly followed the suburbanization process of housing. Sprawl does not simply consist of new residential allotments, but equally of new business parks. Moreover, many new jobs engrafted onto the additional residential areas, e.g. new employment that developed in schools, childcare, local health care, supermarkets and public services in growing municipalities. At the macro level, suburban areas are relatively multifunctional: sprawl does not necessarily imply the absence of a functional mix, even if it is at a lower density in comparison with the city. Nevertheless, the regional job market remains more spatially concentrated than the housing market. This is the case in many industrial activities, but in particular the growth of specialized services (such as financial services, technology and consultancy) led to an increase in the number of jobs in the Brussels

EJTIR 11(1), January 2011, pp. 42-60   57
Boussauw, Derudder and Witlox
Measuring Spatial Separation Processes through the Minimum Commute:
the Case of Flanders

region. This growth explains a significant portion of the found increase in the general minimum commuting distance.

A second, perhaps equally important reason is the large-mesh nature of the used dataset. Our analysis cannot possibly grasp the sprawl that occurs within a municipal boundary. Although, given the rather small area of an average municipality, suburbanization certainly plays a role too at an intermunicipal scale level, it appears that the intramunicipal share of these transformation processes cannot be detected from a low resolution data set. To identify sprawl on a lower scale level time series data at a much denser spatial aggregation level is needed. Thus, the discrepancy between our analysis and the morphological analyses mentioned above is mainly due to the difference in scale. It is likely that the increase in the minimum commuting distance, and therefore the expansion of the functional space, would be better reflected in the figures when examining this micro level. This is due to the modifiable areal unit problem (MAUP) of which the consequences for the minimum commuting distance were discussed above. What is certain is that the use of a fine-mesh data set leads to lower absolute figures for the minimum commuting distance. On the basis of cross-sectional approximate data for 2007 available for the same study area (Flanders and Brussels) at the level of (fine-meshed) traffic analysis zones, and using the same algorithm as we did, Boussauw et al. (2011) found a mean minimum commuting distance of 6.9 kilometres (to be compared with our calculated 9.4 kilometres (2001)). Unfortunately, time series data are not available at this microscopic scale level, so it is not possible to verify our assumption that spatial separation may be mainly taking place at this smaller geographical scale level.

The inability to outline developments based on fine-mesh data might lead to an overrepresentation of the impact of regional economic transformations in the results, pushing the effect of the spatial shift in the housing stock to the background. The decline of some industrial activities, the development of logistics in the port areas and the general shift towards service industries play perhaps a more important role at the studied scale level with respect to spatial proximity between home and work locations than the suburbanization of the housing stock does.

When we consider the spatially disaggregated evolution of the minimum commuting distance, we notice that the major conurbations in the economic core of Flanders and Brussels gain importance in terms of employment, while a reduction of jobs in more peripheral industrial sectors has led to a local increase of the minimum commuting distance. The phenomenon of residential suburbanization in the municipalities along the motorways has led only here and there to spatial separation, particularly where jobs did not follow the spatial shift in housing.

8. Conclusions

The applied method detects spatially disaggregated evolutions in minimum commuting distance, identifying local increases or decreases in spatial separation between home and work locations at the level of the municipality. The results show that there is indeed a general loss in spatial proximity between housing and jobs for the study area in its entirety, although the pace of this separation process is on average much lower than the growth in observed commuting distances. It is found that the minimum commuting distance increased in many municipalities, especially where population is growing faster than job supply, or where traditionally high concentrations of employment still increase. Furthermore, there are also municipalities where a decrease is noticed, especially in suburban areas that are getting a more urban character by acquiring a considerable functional mix.

The development of the motorway network has undoubtedly contributed significantly to the growth of actual commuting distances. In those municipalities where mono-functional planning practice has facilitated residential development with access to the motorway, the minimum

EJTIR 11(1), January 2011, pp. 42-60
58
Boussauw, Derudder and Witlox
Measuring Spatial Separation Processes through the Minimum Commute:
the Case of Flanders

commuting distance increased, with negative consequences for the spatial proximity between residential and work locations. In municipalities where a better balance between different functions was achieved, the development of multifunctional sprawl has not necessarily led to an increase of the minimum commuting distance at the supra-municipal scale level.

Nevertheless, the influence of sprawl on commuting behaviour seems to be only secondary to the effects of regional-economic transformations, which for example led to the loss of employment in the Kempen region and an increase in employment concentration in Brussels and (to a lesser extent) in Antwerp. Still, in spatial and economic planning it is important to ensure the local balance between jobs and inhabitants as good as possible. Horner and Murray (2003) argue that the most effective way to do this is raising residential density in areas with a decent job supply: through the deliberate reallocation of workers' residences a significant decrease of the minimum commuting distance can be attained. However, Yang (2008) shows that job decentralization may also be responsible for the growth of the excess rate itself, and thus for a weakening land use-transport connection. From this finding Yang (2008) argues that a policy of ensuring a good job-housing balance is insufficient: concentrations of employment both in cities and in suburbs should take the form of compact, yet relatively large, centres and subcentres.

In order to draw valid conclusions, the degree of detail and the consistency of the used data is crucial. We find that the use of municipalities as a spatial entity is suitable to grasp regional transformations of the economy, but is far from perfect to detect sprawl in the morphological sense. If the same analysis could be repeated at a lower scale level, probably more concrete guidelines for spatial planning could be given. This is particularly true when mode choice would be taken into account too. In that case, concentration of activities around the stops of public transport would remain equally important. For cyclists, at the other hand, proximity and the availability of infrastructure are also of interest at the micro level.

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EJTIR 11(1), January 2011, pp. 42-60   59
Boussauw, Derudder and Witlox
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the Case of Flanders

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EJTIR 11(1), January 2011, pp. 42-60
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