Development in hierarchy in the Dutch urban system

on the basis of flows

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Summary

In this study the 1992, 1995, 1999, and 2002 Netherlands National Travel Surveys are employed to examine the change in the level of hierarchy in the urban system on the basis of commute flows between twenty-three urban areas in the Netherlands. The change in urban hierarchy has been analysed through four dimensions of spatial interaction: strength, connectivity, symmetry, and hierarchy. The urban system can be described as having a polycentric structure. The results provide evidence of a decline in the level of hierarchy in the Dutch urban system for commuting flows over the ten-year period. Friction of physical distances still plays an important role in the urban development process. The result also suggests that the spatial integration process has taken place in the national urban system, but very slowly.

1. Introduction

Spatial integration processes play important roles in the evolution of contemporary urban systems (Davoudi, 2003; Nordic Centre for Spatial Development, 2004). One consequence of the spatial integration process experienced in many countries worldwide is the transformation of the constellation of the urban system from monocentrism to polycentrism. The differences between nodes in terms of their role in the network of urban areas have become smaller. This implies that the extent of hierarchy in the urban system has decreased.

This is particularly true for the Randstad Holland that has been functioning as the major centre in the Dutch urban system (Figure 1). This urbanised area in the western part of the Netherlands comprises four major cities of which each has its own economic niche: financial and business services and cultural activities in Amsterdam; financial and business services, healthcare and logistics in Utrecht; petrochemical, port activities and logistics in Rotterdam; and the government functions in The Hague (Van Der Laan, 1998).

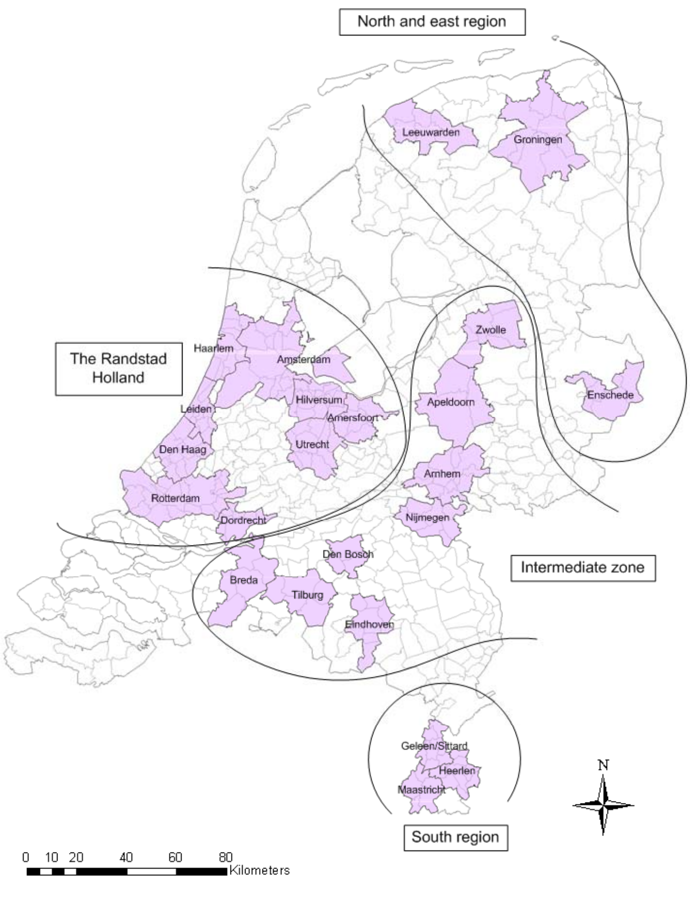

Figure 1 Twenty-three urban areas in the Netherlands

Although one might expect relations between urban areas in the Netherlands to have become more intense and balanced, particularly between the Randstad and other urban areas, there is as yet little empirical evidence support for these claims. To this end, the aim of this study is to examine to what extent the Dutch urban system has become less hierarchical in the period between 1992 and 2002. For this we employ and extend a theoretical framework proposed in Limtanakool *et al.* (2005) to examine changes in the pattern of commuting flows between urban areas.

The remainder of the paper starts with theoretical discussion. Section 3 describes methodology and data description is presented in section 4. The empirical results on the development of interaction between urban areas in the Netherlands between 1992 and 2002 for commuting networks are presented in sections 5. The paper concludes with a discussion of the results.

2. Theoretical framework

Despite the wide usage of the term spatial integration, it has been used in many different ways; there is no generally accepted definition. In this study, we define spatial integration as a process that increases equalities or decreases inequalities between spatial units through the interaction between them. From the literature, spatial integration is often operationalised via spatial interaction and we can advance our understanding of the spatial integration from a dynamic viewpoint by examining the pattern of interaction at different points in time. Taking a relational perspective, we study the degree of hierarchy in the urban system through three dimensions, namely the strength, symmetry, and hierarchy (Limtanakool *et al.*, 2005). In this study, we identify the *connectivity* of nodes in the network as the fourth dimension that is pertinent to the understanding of the level of hierarchy in the urban system. Because the intensity and directionality of interaction are at the core of spatial integration processes, the former is captured through the dimensions of strength and connectivity, and the latter through symmetry. In the hierarchy dimension the other three come together. These four dimensions are presented schematically in Figure 2.

The dimension *strength of interaction* concerns the intensity of interaction between areas; and it is one of the defining characteristics of urban systems (Bourne and Simmons, 1978; Friedmann, 1978). When nodes are intensely related to one another, changes, new ideas, innovations, and so forth can be transmitted from one node to the other more readily (Simmons, 1986; Smith, 2003). Therefore, intense interaction is not only a precondition for the development of urban network; at the same time it also facilitates the development of specialisation of urban areas within the system, which allows multiple urban areas to play an important role in the network. In a non-hierarchical or a fully polycentric network, one might expect the presence of intense relations between all urban areas.

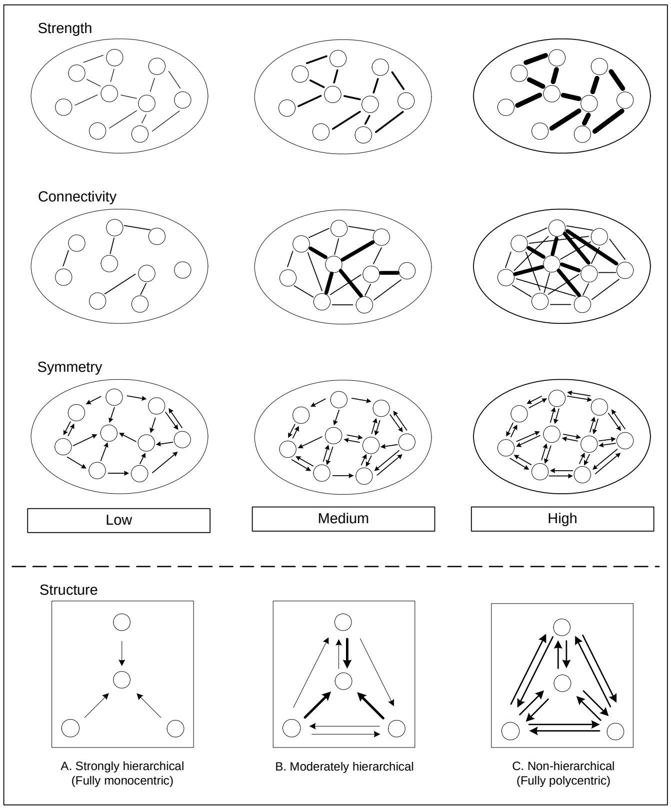

Figure 2 Dimensions of spatial interaction

Related to the dimension of strength is the *connectivity* of nodes in the network. In this study, the connectivity of a node is viewed in terms of the intensity of connections, which enable us to take into account the differences in the level of intensity across different links. The connectivity is employed in this study because the differentiation in the intensity of connections is crucial to the spatial integration process. When considered at the level of nodes, connectivity indicates the level of participation and influence of nodes in the network (Alderson and Beckfield, 2004).

However, in real-life situations, the interaction between urban areas can range from a uni-directional or dependent relationship to a completely bi-directional or reciprocal relationship. This suggests that the direction of flows should be taken into account. This is because the interaction from A to B does not necessarily have the same meaning as the interaction from B to A (Van Der Laan, 1998; Van Nuffel, 2005). The directionality of flows is captured through the dimension of the *symmetry of interaction*. In a non-hierarchical or fully polycentric network, where urban nodes tend to be equally important, reciprocal rather than dependent relationships between cities are expected (Nordic Centre for Spatial Development, 2004; Van Der Laan, 1998).

It can be said that these three dimensions provide the building blocks for the spatial configuration of every network. Therefore, the *hierarchy* of the urban system, the final dimension, can be revealed by assessing the first three dimensions all together. The hierarchy in the urban system can range from a strong hierarchical urban system, as observed in the monocentric system to a non-hierarchical urban system, as observed in the fully polycentric system (Figure 2).

3. Spatial interaction indices

In this section, we introduce six interaction indices to measure the aforementioned dimensions of interaction. The indices are discussed per dimension of spatial interaction identified previously. We propose a set of indices rather than a single index because to the best of our knowledge the latter that can capture every important dimension does not exist (Table 1).

The strength of interaction is measured through the Dominance Index (DI_i) and the Relative Strength Index (RSI_{ij}). Both indices are relative measures but the former is operationalised at the node level, and the latter at the link level. DI_i indicates the importance of node in terms of the magnitude of flow it receives in relation to the average size of flow received by other nodes in the network. A node with a high value for the dominance index has an important position in the network because it contains the opportunities that are sought for by people residing in other urban areas in the network (Alderson and Beckfield, 2004). The RSI_{ij} concerns the magnitude of interaction between nodes as a percentage of the total interaction within the network. The RSI_{ij} values for all links in the network thus sum to one hundred percent. Since the level of urban hierarchy will be lowest if every node is equally important, it can be said that the network is non-hierarchical if every node in the network has a DI_i value of one and every link has the same RSI_{ij} value. For both indices, the larger the differences in the values between are, the greater is the level of inequality in the network.

The connectivity dimension is measured by two indices, namely the Entropy Index of the network (EI) and the Entropy Index of the node (EI_i). The EI is the only index operationalised at the network level. It measures intensity differences within the network, or the degree to which the total magnitude of interaction on each link is equal across all links in the network. This index value varies from zero to one: a value of zero indicates that the interaction in the network concentrates only on one link given that there is more than one possible link in the network, while a value of one indicates that the distribution of interaction across all links in the network is even. Thus, a non-hierarchical or a fully polycentric network possesses an EI value of one. Connectivity is also analysed at the node level. The EI_i measures the evenness of the distribution of the interaction across all links associated with a node. It also varies from zero to one, with one indicating that the interaction on all links associated with a node is equally strong. From this, it follows that, in a non-hierarchical or a fully polycentric network, every node has an EI_i value of one.

The Node Symmetry (NSI_i) and the Link Symmetry (LSI_{ij}) indices are employed to take the dimension of symmetry into account. At the node level, the NSI_i measures the difference between the incoming flow and the outgoing flow to and from the node in question. If a node has a surplus net flow, it is more important as a receiver than as a sender. The surplus thus indicates that a node contains the opportunities sought after by people residing in other nodes in the network, while its own residents are less likely to do the same in other nodes possibly because they can find ample opportunities in the urban area where they reside. At the link level, the LSI_{ij} describes whether the interaction between two nodes is a uni-directional or bi-directional, and if it is a bi-directional to what extent the one-way interaction equals the interaction in the other direction. This index varies from zero to one: a value of one shows that the amount of interaction from node i to j is exactly the same as from j to i, while zero indicates that the interaction is uni-directional. In sum, with respect to the symmetry dimension the network is non-hierarchical or fully polycentric when all nodes and links in the network are symmetrical.

All dimensions considered, the network is non-hierarchical or fully polycentric when the indices proposed here have the following values: the value of RSI_{ij} for every link is equal; the value of DI_i for every node is one; the value of EI for the network is one; the value of EI_i for every node is one; the value of NSI_i for every node is zero and; the value of LSI_i for every link is one. A fully polycentric network is of course an ideal type configuration. Means, medians and standard deviations, as well as complete distributions of index values, for actually observed configurations can be used to assess the extent to which actually occurring interaction patterns approximate this ideal type. If a process of spatial integration is taking place, then we would expect values for interaction patterns to become more similar to this ideal configuration over time.

4. Data description

The data used for the empirical analysis are the 1992, 1995, 1999, and 2002 Netherlands National Travel Surveys (NTS). This survey was started in 1979, and has been conducted annually since then. For all the years, weight factors have been calculated by Statistics Netherlands to make the data representative for the whole population of the Netherlands. The weights are based on a number of variables and some of their interactions: the degree of urbanisation, age, gender, household size, car ownership, fuel type, and the month in which households participated in the survey (more details in Statistics Netherlands, 2002). The sample size was increased between 1993 and 1995 and a new data collection method was implemented in 1999. The major changes are the use of municipality as a sampling unit, and the use of telephone call to motivate the respondents. To make the data from all years comparable, Statistics Netherlands provides correction factors to correct for the differences in data sampling and data collection method. The NTS data includes information on the purpose, self-reported distance and time, and mode (excluding airplanes), as well as the geographical location of origin and destination (measured at the municipal level) of each trip of respondents for a single day; overnight trips have not been included in the data (Statistics Netherlands, 2002).

In 1992, around (unweighted) 77,000 trips were recorded in the database. The number of (unweighted) trips increased to about 610,000 trips in 1995. However, due to decreasing in response rates, in comparison to 1995 the number of trips recorded dropped by 30% and 50% in 1999 and 2002, respectively. To make the data comparable across all years, we applied both the weight and the correction factors provided by Statistics Netherlands mentioned earlier.

Table 1 Spatial interaction indices: Description, formula and their relations with dimensions of spatial interaction

	Relative Strength (*RSI_{ij}*)	Dominance (*DI_i*)	Entropy (*EI* and *EI_i*)	Node Symmetry (*NSI_i*)	Link Symmetry Index (*LSI_{ij}*)
Equation	$RSL_{ij} = \frac{t_{ij}}{\sum_{i=1}^{I}\sum_{j=1}^{J} t_{ij}}$	$DI_i = \frac{I_i}{\left(\sum_{j=1}^{J} I_j \big/ J\right)}$	$EI = -\sum_{i=1}^{L} \frac{(Z_l)Ln(Z_l)}{Ln(L)}$ $EI_i = -\sum_{l=1}^{L} \frac{(x_l)Ln(x_l)}{Ln(N-1)}$ for z,*x* = 0 holds that (*z*,*x*)Ln(*z*,*x*) = 0	$NSI_{ij} = \frac{\sum I_i - \sum O_i}{\sum I_i + \sum O_i}$	$LSI_{ij} = -\left(\frac{(f_{ij})Ln(f_{ij}) + (f_{ji})Ln(f_{ji})}{Ln(2)}\right)$
Min/ Max value	$0 \le RSI_{ij} \le 1$	$0 \le DI_i \le \infty$	$0 \le EI$ and $EI_i \le 1$	$-1 \le NSI_i \le 1$	$0 \le LSI_{ij} \le 1$
Relations between dimension of spatial interaction and indices					
Strength	-	0: a node does not involve in the network ∞: a node dominating the network as every interaction in the network is associated with this node		-	-
Connectivity	-	-	0: flow is concentrated on only one link 1: flow is evenly distributed across all links in the network/ or all links attached to a given node		
Symmetry	-	-	-	-1: a node is asymmetrical by having a maximum deficit of net flow 0: a node is highly symmetrical in terms of its net flow 1: a node is asymmetrical by having a maximum surplus of net flow	0: a link is highly asymmetrical. An interaction only exists in one direction 1: a link is highly symmetrical. There are two-way interaction and the magnitude of flow in opposite direction is equal
Hierarchy	0: the interaction concentrates only on one link in the network 1: no hierarchical structure as every link in the network has equal intensity of flow	A network does not have a hierarchical structure when every node in the network associated with equal intensity of flow	A network does not have a hierarchical structure when every link in the network is equally strong	A network does not have a hierarchical structure when every node in the network is symmetrical in terms of its net flow or every node has NSI_{ij} = 0	A network does not have a hierarchical structure when every link has LSI_{ij} = 1 or every node in the network is completely connected to each other and every link in the network is symmetrical

Denotation

l	*= Link in the network (l=1,2,3,…,L)*
Z_l	*= Proportion of journeys on link l in relation to the total number of journeys in the network*
I_i,I_j	*= The number of inward journeys to node i and j*
T_i,T_{ij}	*= The total number of journeys associated with node i and j*
T_{ij}	*= The number of journeys from node i to j*
O_i	*= The number of outward journeys from node i*
f_{ij}	*= The proportion of journeys on the link from node i to node j in relation to the total number of journeys between node i and j*
f_{ji}	*= The proportion of journeys on the link from node j to node i in relation to the total number of journeys between node i and j*
X_i	*= The proportion of flow on link l in relation to the total flow on links connected to node i*
N	*= The total number of nodes in the network*
i, j	*= i = 1, 2, 3,…, I; j = 1, 2, 3, …, J; for i ≠ j*

With respect to the demarcation of urban areas, we follow the work by Vliegen (2004) who identifies twenty-two urban areas in the Netherlands on the basis of the size of the contiguous built-up area, population density, and the number of inhabitants. We added the urban area of Hilversum because this area plays an important role in the northern part in the Randstad. This yields twenty-three urban areas in total. On the basis of geographical proximity, four regions can be identified in the Dutch urban system, namely the Randstad, the Intermediate Zone, the north and the east region, and the south region (Figure 1) In fact, the Intermediate Zone consists of two sub-regions. One comprises Arnhem and Nijmegen, which are closely related and together they have formed The KAN region (Knooppunt Arnhem Nijmegen), which is a strategic location between the Randstad and the Rhine-Rhur area in Germany. Another is the Brabantse Stedenrij consisting of a group of urban areas in the southern part of the Intermediate Zone, which is the main area profiting from the decentralisation of economic functions from the Randstad. In the current study, we employ the most recent boundaries of urban areas and applied these also to the earlier years because the urban areas may have extended over time.

The current analysis focuses on commuting trips between urban areas. Each year, around 9-11% of the total trips recorded in the database are commuting, and the commutes undertaken between urban areas accounts for some 7-9% of the total commutes. Unweighted data on 582, 3811, 3551, and 2518 commute trips for 1992, 1995, 1999 and 2002, respectively are available for the empirical analysis.

5. Development in hierarchy on the basis of commuting flows

5.1 The strength of interaction between urban areas

On average, the strength of interaction has remained the same throughout the period concerned, as the mean, median, and standard deviation of the RSI_{ij} values for the four years considered indicated (Table 2). Some key results are presented in Figure 3, which shows all nodes in the network and a selection of the links between them. To keep the stylised maps readable, we have only depicted uni-directional links for which the RSI_{ij} values exceed a threshold of 0.5% of the total interaction in the network for a given year. The area of a node is proportional to the value of the dominance index: the larger it is, the more dominant is the node. From Figure 3, four sub-systems can be identified on the basis of the strength of interaction, namely the Randstad; urban areas in the south of the country; and two groups of urban areas in the southern and the northern part of the Intermediate Zone, or the Brabantse Stedenrij and the KAN region, respectively.

Table 2 Means, medians, and standard deviations of interaction indices for commuting network

	1992	1995	1999	2002		1992	1995	1999	2002
Dimension of strength									
RSI_i					DII_i				
Mean	0.20	0.20	0.20	0.20	Mean	1.05	1.06	1.06	1.05
Median	0.00	0.02	0.02	0.00	Median	0.74	0.58	0.57	0.61
Standard deviation	0.59	0.61	0.57	0.58	Standard d	1.13	1.26	1.27	1.19
Dimension of connectivity									
EI_i					EI	0.68	0.69	0.71	0.69
Mean	0.47	0.55	0.57	0.51					
Median	0.49	0.58	0.60	0.58					
Standard deviation	0.17	0.14	0.14	0.15					
Dimension of symmetry									
NSI_i					LSI_i				
Mean	-0.04	-0.06	-0.07	-0.06	Mean	0.44	0.59	0.61	0.54
Median	-0.10	-0.06	-0.08	-0.06	Median	0.00	0.88	0.88	0.78
Standard deviation	0.26	0.15	0.18	0.17	Standard d	0.46	0.45	0.44	0.45

We observe a dense web of interaction between urban areas within the Randstad. Urban areas other than the four major urban areas tend to interact with urban areas in close proximity, which indicates that the geographical distances still play an important role in determining the level of interaction between urban areas. Further, we find that the interaction between the four major urban areas is rather strong and in 2002 strong interactions between them are observed in all directions. This reflects an important characteristic of a polycentric urban area. However, among these major urban areas the interaction between Amsterdam and Utrecht is strongest for all the years considered. We also find that the interaction between urban areas in the north wing is more complex than its south wing counterpart. In addition, the interaction between Haarlem and Amsterdam; Rotterdam and The Hague, Rotterdam and Dordrecht; and Hilversum and Amsterdam are rather intense and they remain the backbone of this sub-system throughout the period concerned.

The results suggest that the urban areas of Geleen/Sittard, Maastricht, and Heerlen form a very stable sub-system in the south, because every urban area is fully connected to the other two and the interaction between them has steadied over the investigated period. However, we do not observe any strong interaction between urban areas in the southern region and other urban areas in the network. Two further sub-systems are located in the Intermediate Zone. Urban areas in the southern part of the Intermediate Zone interact closely with the Randstad in 1992, but the strength of relation has become less over the years, and the interaction between Breda and Rotterdam is the only strong interaction we observe between this sub-urban system and the Randstad from 1995 onwards. In addition, we also observe intense interaction within the KAN region, which has become stronger over the years. However, the interaction is still limited to only two nodes; they rarely interact with other urban areas. For urban areas that have not been discussed, it can be said that their role in the network is only small. They remain rather isolated on the basis of the dimension of strength, at least for the current data.

When examining the distribution of the dominance index values, we find that the changes in the dominance index values from 1992 to 2002 are not very large and the average value of dominant index has steadied over the years (Table 2). Although we find that the dominance index values vary in a slightly wider range, as suggested by an increase in the standard deviation from 1992, these findings do not suggest a clear reduction in the level of hierarchy in the urban system. Considering the dominance index value for individual nodes, we find that the urban system is dominated by the four major urban areas within the Randstad: Amsterdam, The Hague, Rotterdam, and Utrecht receive many commutes from other nodes in the network (Figure 3). The results show that the number of commutes received by Amsterdam is five times larger than the average received by other nodes in the network and the dominant position of Amsterdam has increased slightly throughout the period concerned. The same holds true for Utrecht. The stronger position of Amsterdam and Utrecht can be explained by the fact that they are specialised in financial and business services sector; and this sector has experienced a dramatic growth in the Netherlands over the last decade due to the changing composition of the economic structure from traditional capital intensive sectors towards more advanced knowledge-intensive sectors (Atzema and Lambooy, 1999). This contrasts with the position of The Hague and Rotterdam, where we do not observe the growth in their importance. The dominance position for The Hague has even declined. Rotterdam is still specialised in goods-related services, where the white-collar workers account for a smaller share of the total employment than in the service sector. Since it is worker with higher income and education that are more likely to commute over long distances relative to those with lower income and education (Limtanakool *et al.*, 2006), it can be said this economic structure tends to attract less commutes from distant urban areas. For The Hague, the decentralisation of government functions may reduce the externalisation of government activities, which has led to the decline of the advanced services firms. This finding is in line with the literature showing that the south wing of the Randstad lags behind the north wing in terms of new business formation (Kloosterman and Lambregts, 2001).

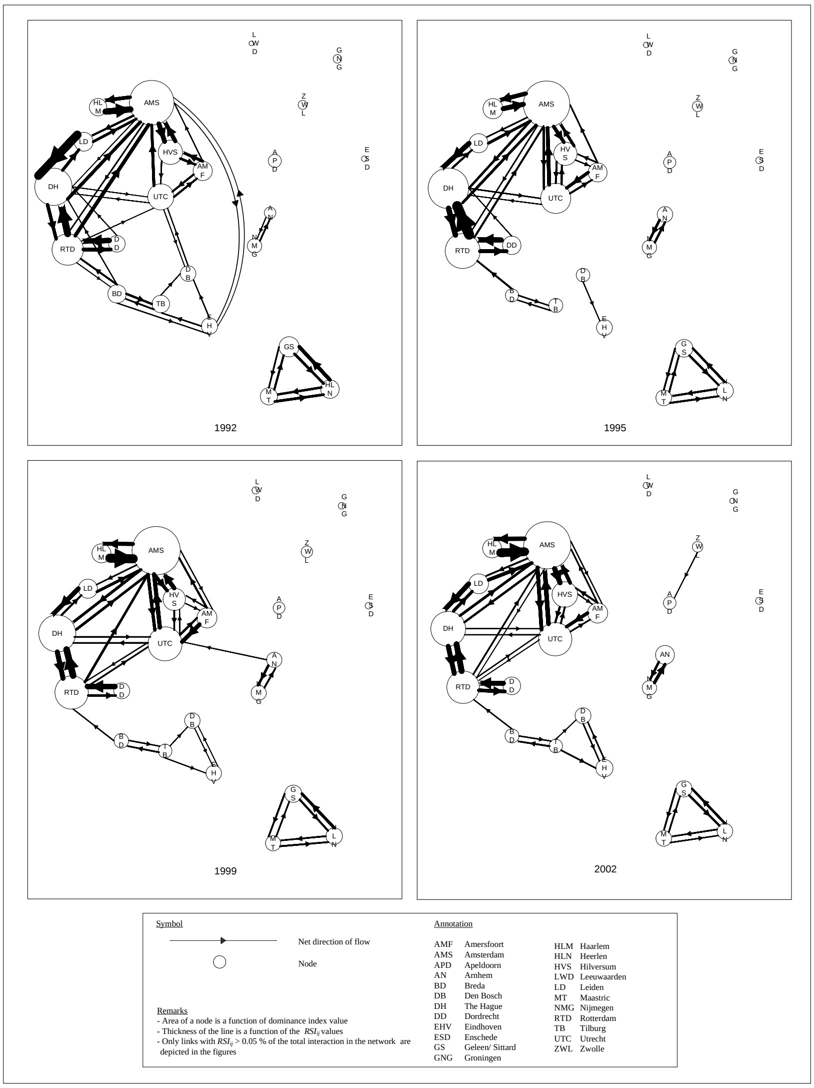

Figure 3 Commuting flows between urban areas in the Netherlands, 1992-2002

Nevertheless, the dominance of The Hague is still higher than that of the Rotterdam throughout the period considered. As a result, the position of Utrecht is comparable to The Hague and Rotterdam in 2002, and at the same time this results in a sizable gap between these three urban areas and Amsterdam in terms of the ability to attract workers from distant areas. In addition to the four major urban areas, Hilversum also plays an important role in attracting commutes from other urban areas, followed by Haarlem, Leiden and Amersfoort. Their dominant positions have also been strengthened over the years.

The role of Geleen/ Sittard, Heerlen, and Maastricht, three urban areas in the southern part of the country, in terms of attracting commute is moderate in 1995. However, they have experienced a large decline from 1995 onwards. In addition to the urban areas that have been discussed, the role of other urban areas is only small, particularly Groningen, Leeuwaarden, and Enschede.

On the basis of the dimension of strength, we can identify four sub-systems, but the results provide little evidence that urban areas have become integrated into one functional urban system. It can be said that this network is dominated by multiple nodes in the Randstad, but especially by Amsterdam. Based on the strength dimension, two major changes in the level of hierarchy are revealed. First, the level of urban hierarchy becomes stronger as the position of dominant nodes like Amsterdam has been strengthened over time. Second, the level of hierarchy among the major urban areas other than Amsterdam has been weaker as the gap in the degree of dominance between The Hague, Rotterdam and Utrecht has become smaller over the years due to the reasons discussed earlier.

5.2 The connectivity of urban areas in the network

When all urban areas are treated as one whole system, we find that the total interaction between urban areas is moderately distributed across all links in the network. The *EI* values have steadied over time as they only vary in a narrow range between 0.68 and 0.71 in the period considered. Concerning the EI_i, Table 2 shows that the average value of EI_i has increased until 1999, and has declined slightly afterwards. However, the results do not reveal a clear tendency of the reduction in the level of urban hierarchy in terms of the connectivity. Among the four major urban areas, the intensity of flows across links connected to Amsterdam and Utrecht has become less evenly distributed over the period of ten years. The EI_i values for Amsterdam and Utrecht in 1992 are 0.72 and 0.78 and have declined to 0.67 and 0.71 in 2002, respectively. Further investigation suggests that the integration within the north wing of the Randstad is the reason for this. The interaction among urban areas within the north wing has become more intense and balanced over the years. If only the interaction among urban areas in the north wing is considered, Amsterdam and Utrecht have very high EI_i values of 0.91 and 0.85, respectively, in 2002. The concentration of intense and balance interaction within the north wing has led the distribution of flows on links connected to Amsterdam and those connected to Utrecht to become less evenly distributed when all urban areas in the system is taken into account.

On the basis of our results, it can be said that the level of connectivity largely relates to the geographical location of urban areas. We find that nodes that are located centrally within the Netherlands, such as Utrecht and Den Bosch (i.e. their EI_i values are above 0.69), tend to have higher levels of connectivity, while nodes located further in the south such as Heerleen, Geleen/ Sittard, and Maastricht have a very low score for this index.

5.3 The symmetry of the interaction between urban areas

With respect to the symmetry dimension, the change in the values of standard deviation after 1992 suggests that the NSI_i values vary within a smaller range, and hence the inequality between nodes seems to decrease slightly. In this respect, the level of urban hierarchy has become less over the period considered. Further examination of the distribution of the NSI_i values illustrates that the proportion of nodes with a net surplus remains the same at about 30%. This suggests that this network can be characterised as a weakly centralised network, where six urban areas attract more flows than those they send out. However, the major change is the decline in the NSI_i values among nodes with a large surplus in net flow in 1995. The highest NSI_i value of 0.58 in 1995 has declined to about 0.25 in the subsequent years. This again suggests that the level of hierarchy in the network has been lessened in the course of time.

Among urban areas within the Randstad, we see a clear distinction between the four major urban areas and the rest in terms of the node symmetry. The Hague and Amsterdam function as major receivers in the network, as indicated by the positive NSI_i value of 0.24 and 0.26 in 1992, respectively, although the surplus in net interaction gained by these two urban areas has decreased over the years. The role of Utrecht as a receiver has become more apparent, and stands at the same level as Amsterdam and The Hague in terms of node symmetry in 2002. This finding suggests that the high-skilled employment for which commute tolerances tend to be higher (e.g. Van Ham *et al.*, 2001) that can attract commutes from other urban areas is more concentrated in the three major urban areas in the Randstad than in the other urban areas. In the Intermediate Zone, due to the fact that Eindhoven is the base of many high-technology firms as well as the technical university, Eindhoven is the only urban area in this region that functions as a receiver as indicated by the large surplus in net flow from 1995 onwards.

Further, the functions of the three urban areas in the south have changed over time, Geleen/ Sittard functions as a major receiver, while Heerlen has a moderate role as a sender and Maastricht is rather neutral in terms of its net flow. However, the differences among these nodes have converged over the years, and all are rather neutral in 2002. In fact, the characteristic of this sub-network is very close to the ideal polycentric network on the basis of the symmetry dimension. In sum, the examination of the NSI_i suggests the tendency that the complete urban system has become less hierarchical over the period from 1992 to 2002.

The result for link symmetry suggests that on average links in the network have become more symmetrical after 1992, although we see a moderate decline from 1999 to 2002. The variation of the LSI_{ij} values is very stable over the period considered, as indicated by the value of standard deviation (Table 2). The distribution of LSI_{ij} values shows that the proportion of uni-directional links observed in the network is as high as 50% in 1992; but declined to around 30% afterwards. An increase in the number of bi-directional links implies that the interaction between urban areas becomes more reciprocal, which suggests a decline in the level of hierarchy in the urban system.

The distribution of LSI_{ij} values further illustrates that in 1992 there is a large gap in the level of symmetry across all links in the network. We find a high proportion of links with uni-directional interaction and a high proportion of links that is both bi-directional and highly symmetrical. It appears that this is a combined characteristic of a polycentric and monocentric network. This is because the highly symmetrical interaction tends to be observed within a group of major urban areas including Amsterdam, The Hague, Rotterdam, and Utrecht where relationships can be characterised as reciprocal. At the same time, there are other urban areas that depend on the employment opportunities within the major urban areas, and results in the high-proportion of uni-directional interaction in the network such as that between Rotterdam and Breda. Further, the uni-directional interaction between the secondary urban areas also accounts for a large proportion of the uni-directional links in the network; however, the intensity of interaction on these links tends to be small. Over time, the gap between these two types of interaction has become narrower, particularly between 1995 and 1999. For individual links among the four major urban areas within the Randstad, we see a fair increase in the level of symmetry on every link from 1992 onwards. The biggest improvement is found on the links between Amsterdam and Utrecht and between Amsterdam and The Hague.

Although the results are not presented in Tables here, we find that the links between urban areas within the Randstad have become more symmetrical over the years. We find that the average level of link symmetry between them has increased from 0.62 in 1992 to 0.79 in 2002. The reduction in the number of the uni-directional links observed in the network (i.e. LSI_{ij} =0) is one explanation for this. It is also evidenced that the reciprocal relationship is still confined to the interaction within the same region. The average level of link symmetry within every region, namely the Randstad, the Intermediate Zone, and the southern region, is higher than 0.80, while the average level of link symmetry between regions is much lower. In sum, the level of link symmetry suggests that the interaction between urban areas becomes more symmetrical over the years but this improvement is mainly observed within the groups of urban areas which are close to one another in geographical space. This implies that there is a tendency for the decline in the level of urban hierarchy within these groups, while the same tendency is less obvious for the whole system.

5.4 Hierarchy of the urban system

With respect to commute flows, the results suggest that the hierarchy within the urban system has been slightly lessened over the period concerned. Amsterdam has continued to dominate the urban system and the gap between Amsterdam and the other three major urban areas within the Randstad, namely The Hague, Rotterdam, and Utrecht has become larger. However, the dominance positions of these three major urban areas are comparable in 2002. The results suggest that the position of the dominant node at the top of urban hierarchy has been reinforced, while the level of hierarchy has been weakened among The Hague, Rotterdam and Utrecht.

We observe more intense interaction between urban areas over the years; however, the intense interaction is often confined to urban areas that are geographically close to one another. The role of physical distances is even more apparent outside the Randstad, as the intense interaction is mainly observed between urban areas within the three regions, namely the Randstad, the Intermediate Zone, the south region. This suggests that physical distances still play an important role in the spatial integration process. The result provides little evidence that the Intermediate zone has become integrated with the Randstad.

Further, we find that relations between urban areas have become more symmetrical; their main function as a sender or a receiver has not changed within this period. One reason may be that the structural changes in the urban areas in terms of the distribution of employment and population often take a long time before we observe a significant adjustment. We also observe an increase in the level of connectivity in the network, particularly the urban areas located centrally in the Netherlands.

Considering all things, it can be said that urban areas within a region have become more integrated through an increase in the intensity of interaction and the level of symmetry, and hence we observe a lower level of hierarchy within the same region. Nevertheless, the result provides little evidence that the level of hierarchy in the Dutch urban system has been decreased because the interaction between regions is still limited. The three urban areas in the north and east region do not actively participate in the national urban system, and the same holds true for the three urban areas in the southern part of the Netherlands that form a stable system on their own. On the basis of these findings, this urban system can be described as having a polycentric structure with a weak degree of centralisation towards Amsterdam, Utrecht, The Hague, and Rotterdam. A slight decline in the level of hierarchy in the urban system over the period of ten years suggests that the spatial integration process has taken place among urban areas in the Netherlands, but very slowly. This is in line with the finding that the urban systems exhibit a degree of persistence and continuity which is increasingly difficult to break (Batty, 1998).

6. Conclusions

Using the 1992, 1995, 1999, and 2002 Netherlands National Travel Surveys, the current study has examined the level of hierarchy in the Dutch urban system on the basis of commute flows between twenty-three urban areas. Since spatial integration is a dynamic process, we have operationalised it via spatial interaction and monitored the changes over a ten-year period. With respect to commute flows, the results suggest that the hierarchy within the Dutch urban system has been weakened after 1992; however, the level of hierarchy in the urban system has slightly increased again after 1999. The interaction between urban areas has become more intense, more symmetrical, and urban areas have become more connected until 1999. However, spatial integration is a selective process, and it does not occur in all areas to the same degree. The spatial integration is most apparent between urban areas within the same region. In other words, urban areas have become more integrated at the sub-system level, particularly urban areas within the north wing and south wing of the Randstad, the KAN region, Brabantse Stedenrij, and the southern region (Figure 1). We observed that the dominance of The Hague and Rotterdam, major urban areas in the south wing of the Randstad, has grown at a lower rate than that of Amsterdam and Utrecht in the north wing. The result also provides little evidence that the Intermediate Zone has become integrated with the Randstad. However, the remaining urban areas of the Netherlands are functionally rather isolated from other urban areas.

The results of this empirical study also show that the complexities of spatial integration process can be simplified considerably by distinguishing the four important dimensions of spatial interaction. Since spatial integration is a multi-dimensional process and we have seen that changes do not occur at the same degree across all dimensions, we are convinced that using a set of interaction indices rather than a single indicator provides better insight into the change of urban hierarchy and hence the spatial integration process. These dimensions should be therefore addressed in future studies of spatial integration.

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