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Understanding urban networks: Comparing a node-, a density- and an accessibility-based view

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ABSTRACT

The question investigated in this paper is how to understand urban networks, taking both place-bound activities and (quality of) transport networks into account. The description should help formulate planning questions about the development of urban networks. This paper proposes three different views: node-, density- and accessibility-based.

Urban networks can morphologically be described as major nodes or concentrations of activities and physical and/or functional connections between nodes in a geographical area. Beyond this morphological description, places within an area can also be characterised by the amount and diversity of activities to be accessed by means of a transport network. This paper will compare these different views of the urban network for the northern part of the Randstad Holland conurbation (the greater Amsterdam area) by means of different spatial representations. The comparisons between the patterns of these representations can help explore the changing urban network, giving rise to planning questions, which can help formulate a planning research agenda for urban networks.

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Introduction

The theme of urban networks is receiving more and more attention in geographical studies and planning practices. The debate on urban development has shifted from the city to the city-region as the primary unit of analysis (Burger, de Goei, van der Laan, & Huisman, 2011). The transition from the industrial to the information society compels cities to develop new spatial horizons, as the implementation of successful regional and urban development policies appears increasingly dependent on the ability to cope with a complex web of both horizontal and vertical economic and social interactions, both within and between cities (Arndt, Gawron, & Jähnke, 2000; van Houtum & Lagendijk, 2001). In urban planning, thinking based on the concept of the 'network city' or 'urban networks' has become central and embodies the search for new concepts to fit this changing reality (Albrechts & Mandelbaum, 2005). Bertolini and Dijst (2003) summarised three emerging perspectives on the network city and urban networks: *morphologic-descriptive*, *normative-strategic*, and *analytic*. Following the morphologic-descriptive perspective the terms are equivalent to 'polycentric/multi-nodal urban regions', and identify one of two situations: (i) functionally integrating, both competing and complementary

constellations of mostly mid-sized cities (these are "urban networks", see, e.g. (Ascher, 1995; Dieleman & Faludi, 1998), or (ii) the emergence of sub centres next to historic urban centres in metropolitan areas (these are "network cities", e.g. Batten, 1995). Those adopting a normative-strategic perspective (e.g. the concept of the Flemish Diamond Albrechts & Lievois, 2004) see the polycentric urban region as the most socially and/or economically and/or environmentally sustainable urban form, a belief increasingly popular among urban planners and designers (e.g. Batten, 1995; Hall & Ward, 1998; Rogers, 1997). The analytic perspective on urban networks and network cities rather sees cities as overlapping sets of physically connected (by transportation systems) and virtually connected (by telecommunication systems) activity places (e.g. Alexande, 1965; Castells, 1989; Castells, 1996; Dijst, 1995; Dupuy, 1991; Webber, 1964).

From a methodological perspective, most works that describe urban networks and network cities are qualitative and highly heterogeneous. As such, they are hardly comparable and do not allow us to fully appreciate the advantages and disadvantages of the different views in the face of the current planning tasks. However, more rigorous, comparable analyses are becoming possible. The advances in GIS (geographic information systems) have greatly improved the spatial data infrastructure in many cities and regions, making more quantitative analysis feasible and providing an exploratory environment for supporting planning practices. Therefore, there is an opportunity to integrate spatial analysis into the

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understanding of urban networks and network cities in a more quantitative and more clearly interpretable way.

In this paper, in order to explore these possibilities, we propose three views to help understand and compare network cities and urban networks (in the following just referred to as “urban networks”): a node-based, density-based and an accessibility-based view, the former two being more morphology oriented and the latter more function oriented. Their differences will be discussed using the case study of the Amsterdam urban region. In the conclusions, implications of the analysis for integrated land use and transport planning, particularly at the urban regional level, will be highlighted.

A conceptual model of three views and quantifications

Mathematically, a network can be abstracted as a graph including nodes and links connecting nodes. The varied meaning and interpretation of nodes and links in reality and practice form the rich applications of network theory in many disciplines.

The principal meaning of the network concept is twofold: the first one (physical) concerns infrastructure systems (highway and railway networks, drainage networks, etc.); the second one (functional) relates to the spatial interaction among urban places, economic activities and people (Camagni & Salone, 1993). The functional view based on interaction is able to interpret many new network concepts such as spatial synergy, coherence, competition and complementarity of urban areas in urban networks, as interaction is a concept for functionally linking different systems. For instance, the terms ‘missing links’ and ‘accessibility’ have become key elements in stressing the necessity of the filling of the ‘structural holes’ in the European urban network (van Houtum & Lagendijk, 2001). In another example, many of the non-metropolitan, but still large, cities that are close to each other can increasingly be seen as interdependent, and tied together in functional regions. The increased competitiveness between cities in the modern economy validates the necessity of such functional interdependence, since these cities by themselves are not large enough to compete with the larger metropolitan areas (van Houtum & Lagendijk, 2001).

The network concept is not only used in urban geography and urban economics, where it mostly has an analytical function, it is also utilised in urban planning, where it often has a normative function (e.g. in relation to the idea of the polycentric urban region as the most socially, economic, and/or environmentally sustainable urban form; see Bertolini & Dijst, 2003). In particular, land use planning and transport planning have both employed the network concept, albeit in different ways, following their different roles and perspectives and separated land use and transport planning processes. They perceive and represent the functions of urban networks in different languages and use different tools. For example, land use planners tend to employ direct distance to measure spatial interaction, and density to measure spatial concentration of social and economic activities. Transportation planners prefer instead to utilise travel time and the elements of transport networks for the same purposes. In contrast, actual users perceive urban networks as spatially dispersed places of activity and connections between them. Integrated transport and land use planning – a widely recognised condition of successful urban network development – should aim to understand these differences in interpretation. These differences can be represented as three views (Fig. 1). In the following section, we will briefly describe each. Later on, we will apply them to a real-world case. For the sake of simplicity, we will limit the analysis to places of residence, places of work, and their spatial interaction.

Fig. 1. A scheme of three views (respectively node-, density- and accessibility-based).

Node-based view

The public's perceived image of a city or region is usually concentrated on the major transport nodes (e.g. railway stations, metro stations, motorway outlets) and the physical networks connecting them as illustrated in Fig. 1. The spatial pattern of social and economic activities around the nodes is the simple description of a physical urban network. This view can be expressed in terms of the level of employment, and the diversity of employment around each transport node denoted as $E_a(r)$ and $E_d(r)$.

$$E_a(r) = \text{the number of jobs within } C(r). \quad (1)$$

$C(r)$ is the circle with a radius r (e.g. 1 km) buffering from a major transport node (e.g. a railway station).

$$E_d(r) = -\frac{\sum_j Q_{ji} \times \ln(Q_{ji})}{\ln(n)}, \quad Q_{ji} = \frac{E_{ji}}{E_i} \quad (2)$$

here $E_d(r)$, based on the concept of entropy, aims to quantify the job diversity within the circle defined by the buffering distance r to any node i : the higher E_d is, the greater the job diversity. E_{ji} is the number of job type j (e.g. industry, retail) in the circle i and E_i the total number of all job types in the circle i . Moreover, n is the number of job types. For instance, when a railway station is located within a fully residential area, the $E_d(r)$ is 0. By contrast, when a railway station is surrounded by high-rise buildings, in which all types of employment are mixed with equal proportion of magnitude, then $E_d(r)$ is 1.

Density-based view

The idea of a polycentric urban region (PUR) (Meijers, 2005) is clearly an application of the urban network concept with its explicit focus on the horizontal linkages between adjacent cities as a way to label and position the larger urban area with a notion of a wider (competitive) space. To represent this geographically, the relative differences between a centre and its surrounding areas are detected by the measure of spatial concentration, which defines the major nodes of a morphological (partially functional) urban network.

This view can be represented by the density of employment or inhabitants, and functional mixture of employment and inhabitants, at each locational site as $E_i(s)$ and $E_m(s)$.

$$E_i(s) = \text{the number of jobs (or inhabitants)}/A(s) \quad (3)$$

$A(s)$ is the area (ha) of a pixel in the defined grid (e.g. $500 \text{ m} \times 500 \text{ m}$).

$E_m(s)$ = the number of jobs/the number of inhabitants (4)

Furthermore, ‘focal points’ of employment (and inhabitants) can be identified in order to show the spatial concentrations and their spatial distribution in reference to major transport nodes, which can be measured as direct distance between transport nodes and focal points (see Fig. 1).

Accessibility-based view

The concept of accessibility, as an interface between the transport and land use interactions, provides a useful framework for the integration of transport and land use planning (Bertolini, Le Clercq, & Kapoen, 2005) at the urban regional level. Improving accessibility has recently re-emerged as a central aim of urban planners and aligned disciplines (Lacono, Krizek, & El-Geneidy, 2010). Within the scope of this paper, job accessibility can help us to understand the function of urban networks based on complex and dynamic interactions.

One can start by measuring accessibility to jobs from a residential location by calculating the number of jobs within reach of, say, half an hour travel time. This method has several terms including contour measure (Geurs & van Wee, 2004) or isochrone measure (Bertolini et al., 2005), which are considered straightforward for implementation and interpretation. However, this common measure suffers from a major methodological limitation – as it is a very incomplete assessment of accessibility components (Geurs & van Wee, 2004). One can, and should, go further by incorporating travel distance decay effects (or the idea that more distant jobs are – all else being equal – valued less). The difference between both results will indicate whether it is necessary to include travel distance as a discriminating planning element in thinking about urban networks or, if no major differences occur, if it is sufficient to use only the locational pattern of jobs to inhabitants ratio (the density-based view). The example can be extended to the incorporation of other accessibility components that might affect job opportunity, such as competition for the same jobs by other workers (competition on demand), or competition for workers by other employers (competition on supply). In addition, one could consider the impact of the diversity of available jobs on the level of accessibility (following the idea that a greater variety of job types increases the chance of finding a suitable one).

The measurement of job accessibility (Shen, 1998) with incorporating competition on the demand side only (competitions for jobs between workers) has been extensively applied in many case studies (e.g. Sanchez, Shen, & Peng, 2004). Geurs and van Wee (2004) and Horner (2004) suggested that both job demand and supply aspects of competition should be incorporated through the use of inverse balancing factors. They argued that the balancing factors of the well-known doubly constrained spatial interaction model could be interpreted as an inverse accessibility measure that incorporates the interdependent competition effects on origin and destination locations. However, this method is better suited for analysing spatial balancing or matching between residential and employment locations (e.g. Geurs, 2006) than for assessing job opportunities, since it primarily aims to distribute spatially the jobs based on spatial gravity at national level, within a spatially closed system.

Opportunity is the simplified representation of accessibility, as it is easy to understand and links well with reality. It is often expressed in terms of an absolute value such as the number of jobs, or number of people within reach. This method is particularly welcome to urban or transportation planners or policy makers as it is easy to interpret and can help users play with various scenarios. For example, Straatemeier (2008) favoured an application of

opportunity-oriented job accessibility measurement using an isochrone method as a planning framework for looking at strategic planning issues at a regional level. Another interesting example can be seen in the work by Bertolini et al. (2005). In this paper, we adopt a probabilistic method similar to Huff’s model (Huff, 1969) to incorporate competition on both demand and supply sides into the measurement.

Job accessibility is not only influenced by the interactions between land-use structure and transportation (e.g. availability of vehicles, existing road network, and congestion in high-density areas), but also by the functional and structural aspects of jobs and worker systems (e.g. employment type, gender, age, education, household roles, and income) (see an example by Wang, 2005). In this light, diversity of employment should be considered in the measurement.

The measurement of job accessibility represented as an absolute value (i.e. job opportunity) is described in the following formulas by incorporating different components (job opportunities within reach, the competition for those opportunities, and the impact of distance to and diversity of jobs on the value attributed to opportunities):

$$D_j = \frac{\sum_l Q_{lj} \times \ln(Q_{lj})}{\ln(n)}, \quad Q_{lj} = \frac{E_{lj}}{E_j} \quad (5)$$

$$f(t_{kj}) = e^{-\beta \times t_{kj}} \quad (6)$$

$$P_{jk} = \frac{E_j^{D_j} \times f(t_{kj})}{\sum_s E_s^{D_s} \times f(t_{ks})} \quad (7)$$

$$O_i = \frac{\sum_j E_j \times P_{ji} \times W_i \times f(t_{ij})}{\sum_k P_{jk} \times W_k \times f(t_{kj})} \quad (8)$$

Eq. (5), similar to Eq. (2), aims to compute the diversity of jobs at a job location j , where a total of l types of jobs are available and E_{lj} is the number of type l jobs and E_j the total number of jobs at location j . Eq. (6) is a negative exponential function chosen for quantifying the distance decay effect into the measurement as this function is more suitable for ‘analysing short distance interaction’ at an urban or regional level (Fotheringham & O’Kelly, 1989, pp. 12–13). t_{kj} is the travel time from residential location k (origin) to employment location j (destination).

Eq. (7) represents the competition of employers for workers or competition on the supply side between location j and s . The impact of diversity on job attraction is quantified by the power function $E_j^{D_j}$, which means that opportunity should be equal to E_j when $D_j = 1$, and will be 1 when $D_j = 0$. In econometric terms, D_j works as an elasticity with regard to the availability of jobs, directly stemming from the diversity of jobs available. The elasticity is between one (each additional type of job will affect the probability that a worker from i will be attracted by j) and zero (no additional type of jobs will affect the probability of a worker from i to be assigned to j).

Eq. (8) represents the final job opportunity O_i allocated to residential location i , after taking distance decay, competitions on both demand and supply sides and job diversity into account. W_i and W_k are the number of workers at location i and k , respectively, competing for jobs at location j . P_{ji} implies the attraction of jobs at location j to workers at location i , resulting from the competition for employees with other locations which can be reached by i within the travel time or cost threshold T (e.g. 30 min). P_{ji} represents the job-desire probability at any location i to seek for jobs (at location j), or rather, the relative attraction of employment j to residential location i . Fig. 2 is an example showing the competition on both the demand and supply sides.

Table 1Major differences between three views. *Source:* based on discussion in this section.

View	Form	Type	Spatial concept	Information source	Planning
Node-based	Morphology	Physical network	Node-place	Perceived, static	Transportation
Density-based	Morphology	Functional nodes and physical network	Spatial concentration	Quasi-analytical, Quasi-dynamic	Land use
Accessibility-based	Functional	Functional network	Spatial interaction	Analytical, Dynamic, Virtual	Transport-Land use

Fig. 3. Amsterdam urban region, with main infrastructure and (sub)centres.

'nodes' have emerged which typically combine excellent accessibility by public and by private transport. The most important of these new nodes is the international airport of Schiphol, which provides a unique combination of intercontinental air links and direct connection to the regional and national motorway and railway networks. The airport area has become the focus of a rich and diverse concentration of activities (including office, conference, hotel, retail, and logistics). Other older and newer nodes are also increasingly the focus of specific concentrations. Large-scale office complexes, and financial and business services in particular, have been clustering around the railway stations of Sloterdijk (for example, Teleport), Lelylaan (World Fashion Centre), Amstel (Philips, Worldcom), and Zuid (World Trade Centre, the ABN-AMRO and ING banks). The area between Bijlmer station and the A2 motorway appears to be a preferred location for combined warehouse and office complexes, including a dynamic information and communication technology (ICT) sector (with, among others, the European headquarters of Cisco). In these locations, firms enjoy the availability of space, as well as excellent access both to the regional labour market and to metropolitan facilities including the airport. Urban centres elsewhere in the region, such as Almere to the West or Zaanstad to the North, are also experiencing growth as business locations, particularly with back offices. Many specialised small-scale professional services have, on the other hand, remained faithful to Amsterdam's historic city centre, which is also proving an ideal breeding ground for up and coming Internet and multimedia businesses.

A similar differentiation may be also observed in the distribution of urban facilities; most noticeably: new hospitals along the

A10 motorway ring; the RAI congress and exhibition centre, the Insurance Exchange, the District Tribunal and the Free University around Zuid station; and a giant retail and leisure complex at Bijlmer station. At the same time, more finely grained shopping, entertainment, and cultural activities have continued to thrive in the old city. Reinforcing this trend, after an unfortunate attempt at downtown-style office development between the 1980s and 1990s, a number of large cultural facilities have recently been or will shortly be opened along the southern IJ-river banks, east and west of Central Station. Shopping and leisure centres with a marked urban regional orientation are also being developed in Zaanstad and Almere.

The important question for the future of the city, then, is how these increasingly scattered areas of urbanity can remain connected within the networks of urban interaction, the focus of which is partly outside the traditional municipal boundaries. This gives rise to a new situation, where Amsterdam will have to exchange its traditional 'inside-out' policy (planning its expansion) for an 'outside-in' approach, where the focus shifts to positioning itself in the networks of multiple centres in a broader spatial field (Bertolini & Salet, 2003).

In this project, a desktop GIS package ArcGIS 10.0 with the extension of Network Analyst was selected as a platform for all the spatial analysis tasks described above. The information requirement here was related to the transport network and locational activities (working and housing) on an urban regional scale. The car network – to which we limited the analysis – is classified into 11 categories based on the attributes of speed, direction and exits.

Fig. 4. The amount of jobs within the 1 km radius at each major transport node (railway stations).

The 11 categories mainly include motorway, expressway, freeway, main roads, national roads, etc. each of which is defined by a speed limit for car driving. For instance, the speed limit on motorways is set as 110 km/h, the highest among 11 classes.

Employment (with job structure) was registered using a 6-digit postcode level, represented as point data, classified into nine major types as offices, education, health, industry, transport, retail1 (daily goods), retail2 (non-daily goods), restaurants and agriculture.

Both inhabitants and jobs can be approximately aggregated/disaggregated to a user-defined spatial unit. The traditional spatial (analysis) unit in the Amsterdam region is the administrative district or neighbourhood, with an average size of 14.4 and 3.2 km², respectively throughout the whole of the Netherlands. This unit is too large to produce accurate results. Apparicio, Abdelmajid, Riva, and Shearmur (2008) examined the effects of spatial units used to calculate distance on the aggregation errors of accessibility measurements by taking residents' accessibility to healthcare services as an example. They concluded that smaller spatial units should be used to avoid a low level of accuracy.

Consequently, we first selected a 500 * 500 m² grid as a basic spatial unit, to which both employment and inhabitant data can be aggregated and disaggregated. As employment data are registered at postcode level, which is represented as points denoting the centroid of each postcode area, each type of job can be summarised or aggregated from the postcode level to the grid level using the spatial join tool in ArcGIS. The dasymetric mapping method (e.g. Holt, Lo, & Hodler, 2004) was chosen to disaggregate population data from the census unit level to the grid level. There are several steps of GIS data analysis designed to achieve this. Firstly, ETM satellite imagery was collected for the study area and then residential land use was classified using the maximum likelihood algorithm of supervised classification. The overall classification accuracy is 89% and kappa co-efficient is 0.8. It should be noted that the accuracy of land use classification, particularly the residential land use, is crucial for the measurement of job accessibility. Secondly, the population value was allocated to each residential land use cell (15 * 15 m²) based on the assumption that residential

density is homogeneously distributed across the neighbourhood. Thirdly, the allocated population value at the residential cell level was aggregated to the grid level (500 * 500 m²). Obviously, this method is subject to limited accuracy of population estimation but this is not the focus of this paper.

A Node-based view

While interesting, the picture of the Amsterdam urban network sketched at the beginning of this section and captured by Fig. 3 is still highly qualitative and dependent on users' perceptions. The description provides a conceptual understanding of the evolving morphology of the network and a language for planners to discuss its change. However, it does not explain its components nor the factors that are behind such evolution, and is thus of limited value for understanding the functioning of the network. A node-based view can help us make a first step in addressing this problem.

Figs. 4 and 5 show the density and diversity (according to Eqs. (1) and (2)) of employment within the 1-km buffering distance of each transport node (in this case, railway stations). The combination of density and diversity (Figs. 4 and 5) can offer some quantitative information for the classification and ranking of the different nodes. Fig. 6 is an example of classification based on job opportunity and diversity. The mean value of job opportunity and diversity is 7148 (jobs) and 0.75, respectively, based on which of the four categories (high-high, high-low, low-high and low-low) can be distinguished, with high indicating greater than the mean value and low indicating lower than the mean value. For example, the nodes with areas of high density and diversity (dark blue² in Fig. 6) can be considered the most important ones in the urban network (e.g. Central Station, Zaanstad, Lelystad, Zuid, Haarlem, Hilversum, and Almere). The nodes with high density and low diversity such as Schiphol airport, Sloterdijk, Amstel, Bijlmer and

² For interpretation of color in Figs. 4–13, the reader is referred to the web version of this article.

Fig. 5. The diversity of employment within the 1 km radius at each major transport node (railway stations).

Fig. 6. Classification of station areas in terms of job amount and diversity.

Hoofddorp are markedly mono-functional and are thus relatively more dependent on a regional transportation system. Among them, Schiphol airport and Bijlmer are extremely low in job diversity as shown in Fig. 5. Finally, the nodes with low density and diversity (red colour in Fig. 6) can be seen as the least important ones in the urban network, most of which are located in the urban fringe with low population density. These simple views can help pinpoint the specific position of each node in the urban network. They do not,

however, say much about the relationships *between* them. In order to appreciate this, we need to move to a density-based view.

A Density-based view

Cities can be seen as places of concentration of social and economic activities connected by transport networks. Fig. 7, derived from Eq. (3), reveals the spatial concentration of jobs based on

Fig. 7. Pattern of employment density.

Fig. 8. 3D pattern of employment density.

job density (number of jobs per ha). Together with Fig. 8 (a 3D illustration), Fig. 7 demonstrates that the areas with high employment density are located in Amsterdam city centre and other smaller (town) centres. Fig. 9, derived from Eq. (4), shows the functional mixture of employment and inhabitants as a ratio of jobs to workers (on average 40% of inhabitants in the Netherlands). The majority of cells exhibit a low functional mixture, less than 3.12. Fig. 10 illustrates the spatial concentration of employment by focal points and their relationship to major transport nodes (in this case railway stations). Focal points are defined here as the cluster of jobs with continuous areas and much higher density than the neighbouring areas. Technically, the focal points were explored from the contour lines (Fig. 10) created from the employment density surface and the density surface was created using kernel density estimation and the point data of employment. Kernel density estimation is a popular GIS tool widely employed for exploring spatial concentration of point data which takes distance decay into account. For example, Schiphol airport is a typical focal point of employment since it has a much higher density of jobs than the

surrounding areas. Fig. 10 also shows that a majority of focal points are located at or near transport nodes and Amsterdam city centre except for one at the northwest corner (which is located in the port and industrial area).

Compared with Figs. 3–6, Figs. 7–10 provide more accurate and detailed information for identifying centres and their spatial connections within the transport network, thus providing a more objective support for the morphological description in the previous section. However, they still do not capture the functioning of the urban network as such, because the actual interaction between places of activity is not considered. Furthermore and related to this, density-based representations of networks are not sensitive to changes in human activity and transport and land use planning strategies, that is, they are of a static nature and as such not able to reflect the dynamic changes in social and spatial interactions.

To illustrate both the potentials and the limits of a density-based representation of the urban network, let us consider the example of the relationship between the demand and supply of jobs. The ratio of employment to workers as depicted in Fig. 9 can help us understand the spatial mismatch between inhabitants and employment from a locational point of view, since it reflects the functional mixture at any fixed residential location. However, this information does not take into account the role of the transport network in determining access to jobs and workers, or the interaction between transport and land use. As a consequence, on the basis of such representation, it is impossible to assess how good a residential location is in terms of access to jobs, or a business location in terms of access to workers. For this, we have to examine an accessibility-based view.

An accessibility-based view

The proposed measure of job accessibility (Eqs. (5–9)) can therefore estimate the job opportunities accessible for any residential location by systematically considering the impacts of competition, distance decay and job diversity. From the point of view of planning, its advantage lies in the fact that job accessibility can be

Fig. 9. Functional mixture of employment and inhabitants (geometric interval classification).

Fig. 10. The focal points of employment in relation to transport nodes (railway stations).

linked with relevant transport and land use policy since its value will be impacted by, for example, densification (workers and jobs), job diversification, and transport improvement.

Figs. 11 and 12 show the difference in spatial patterns of job opportunity after application of this measure, respectively without and with the different accessibility components. Fig. 12 exhibits a more dispersed pattern than Fig. 11 and there are substantial differences in the calculated accessibility between some adjacent

cells. This results from the heterogeneous distribution of workers – intensity of workers in each cell. When the competition on the supply side (amount of workers) is taken into account, the cell with more workers has stronger competition than its neighbouring cell with fewer workers. By considering both supply and demand side competitions, the integrated accessibility measurement can model the impacts of residential changes (location and magnitude), not just job changes (location, amount and diversity), on the network.

Fig. 11. Opportunity without any component (jobs within reach).

Fig. 12. Opportunity with all components (jobs within reach, taking account of distance decay, competition, and job diversity).

This is one of the strengths of the measurement – modelling the complex interaction between the transport and land use systems. These figures demonstrate, for example, that job access in the city of Almere (right hand side in Figs. 11 and 12) is comparatively enhanced after incorporating all the components of job accessibility. The same is also true for the cities of Hoofddorp and Zaanstad. By contrast, job access in the northern part of Amsterdam city; and the peripheral areas of other smaller cities is reduced. This is be-

cause the former perform better when the impact of competitions, distance decay and diversity is taken into consideration.

Linking Figs. 11 and 12 and Eqs. (5)–(8), we can summarise that most notably land use densification, functional mixture and job diversification, rather than simply transport improvement, can affect the level of job opportunity in locations of the network, and thus the functioning of the network as a whole. This is because change in any of these domains affects the different components

Fig. 13. Ratio of job opportunity to number of workers.

of job opportunity in a distinctive way. Consequently, they can be utilised as policy instruments within the framework of a network planning strategy.

In general, in contrast to node-based and density-based views, an accessibility-based view can better address the issue of the spatial relationship between job demand and supply in the network. In order to illustrate this, the ratio of job opportunity (taking account of all the accessibility components) to the number of workers was calculated (see Fig. 13). This accessibility-based ratio shows a remarkably different pattern to that of the density-based ratio in Fig. 9. In Fig. 13, the accessibility-based ratio implies a much stronger spatial match between job opportunity and workers, which are expanded to the peripheral areas. This is mainly because of the fact that the job accessibility measure considered the interaction of transport and land use (location of employment and workers, and quality of the transport network).

Concluding remarks

There is increasing awareness that a city is a complex, networked system, which is characterised by multiple actors, dynamic social interactions and emergent spatial patterns. Any effective policy-making must be based on some understanding of this.

The case described above, by taking job accessibility as an example, shows the importance of understanding urban networks from the functional rather than just the morphological perspective. The latter is able to reflect the dynamics of the network better.

The morphological approach assesses the balance in the distribution of size, or of absolute importance of centres, but the functional approach typically looks at the balance in the distribution of functional linkages between centres (Burger et al., 2011). The proposed accessibility-based view can explore how a change (for example) in jobs at one location affects the level of opportunity at another location; a change that is normally hard to perceive. This new insight is possible because a focus on the functional inter-

actions within the network has replaced the traditional one based on direct physical proximity.

From the point of view of the implications for planning, there are two observations. The first, more general observation, is that to some extent the three methods, i.e. node-based, density-based and accessibility-based, may represent the different languages or perspectives of urban development participants, i.e. users, urban planners, and transport planners. In this sense, all the views have a role to play in a planning process, inevitably characterised by a variety of actors and issues. At the same time, the different views could be combined in order to enhance a common perception and thus support a policy-making process. For instance, the discussion above shows that density-based views can be utilised to explain the reasons for network change. The change itself can however be better represented and understood by an accessibility-based analysis.

A second, a more specific observation, is that a functional, accessibility-based perspective on urban networks (and network cities) points to a series of interesting, but yet not sufficiently addressed, questions for planning practice, such as:

- What should be the planning aim for urban networks: making the accessibility of places more homogenous, more diverse or rather making it subject to (controlled) competitive developments?
- Improvements in the transport system may have more or less exogenous impacts on the accessibility and thus the competitive position of places. How should these impacts be acknowledged in planning?
- Are comprehensively planned (and controlled) interventions thinkable in urban networks, or are urban networks rather the outcome of adaptively evolving, and necessarily partial planning interventions, such as those responding to traffic congestion, the need for urban expansion, and changes in location preferences?

A discussion of these questions could help develop a planning research agenda for urban networks. Central to the challenge is a need for finding planning methods to continuously assess the potential implications of changes in accessibility and its appreciation by individuals and organizations, and to identify ways of dealing with the ensuing development opportunities and threats. Furthermore, land use and transport planning tools will need to be integrated if any progress towards successful planning practice, based on the understanding of the functioning of urban networks, is to be made. The accessibility-based perspective on the functioning of urban networks introduced in this paper could provide a platform for such integration. However, to achieve successful planning support, participatory methods should be extensively applied to bridge the gap between academic research as described in this paper and planning practice.

In particular, a structured dialogue between modellers and planners such as that proposed by [Te Bommelstroeet and Schrijnen \(2010\)](#) and applied in the case of accessibility indicators by [Straatemeier and Bertolini \(2008\)](#) seems a precondition for the effective employment of GIS applications to support planning practice.

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