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MEASURING SUSTAINABLE ACCESSIBILITY POTENTIAL USING THE MOBILITY INFRASTRUCTURE'S NETWORK CONFIGURATION

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Abstract

This paper is an exploration into the analysis of public transport networks using space syntax approaches combined with concepts of sustainable accessibility. Present urban development policy aims to achieve sustainable mobility patterns, shifting mobility to soft transportation modes such as walking and cycling, supported by a more integrated multi-modal public transport system, and understanding how different urban areas can support this objective is an important urban policy and design task. We propose that the description of urban areas in terms of 'modal environments' is useful to understand the mobility patterns of their populations. We explore this hypothesis by characterising the neighbourhoods in the Randstad region of the Netherlands in terms of public transport 'modal environments' by measuring the centrality of the public transport infrastructure of the city-region, and compare their centrality to the mobility patterns of the population.

The multi-modal network model of the Randstad includes the three main public transport networks, namely rail, tram and metro/light rail, and it is a simple topological undirected network where the stations or stops represent nodes in the graph and the mobility infrastructure defines the links. In order to create a multimodal network we introduce a fourth set of links representing modal interfaces that make the connection between the nodes of the different public transport modes. We then measure the degree, closeness and betweenness centrality of this network and correlate the results with the data of the 2008 Mobility Survey of the Netherlands, aggregated at neighbourhood level.

Although the centrality of the multi-modal network does not fully explain the patterns of public transport use in the different neighbourhoods, it seems to offer a possibility of characterising those neighbourhoods in terms of their public transport use potential, i.e. to what extent they can be public transport 'modal environments'. The realisation of this potential is dependent on other factors, and further work is required to understand what makes a walking and cycling or a car environment in terms of multi-modal mobility networks.

Furthermore, it was found that topological centrality measures show a hierarchy in the multi-modal network infrastructure, and that one should use different methods to analyse the different modes because they play *different roles. Finally, it was found that, despite these differences, it is important to consider the network as an integrated multi-layered system. How these layers are modelled and articulated should be subject of further research.*

1. INTRODUCTION

This paper represents the early stages of a research project and is an exploration into combining the analysis of public transport networks using space syntax approaches with concepts of sustainable accessibility, hoping to raise questions to further the research more than providing answers.

Present urban development policy aims to achieve sustainable mobility patterns, shifting mobility to soft transportation modes such as walking and cycling, supported by a more integrated multi-modal public transport system built around quality neighbourhoods and vibrant city centres (Banister, 2005). Understanding how different urban areas can support this objective is an important urban policy and design task.

In this context, the mobility network is normally used for utility-based measurement of accessibility to land use, population and employment (Bertolini et al. 2005; Cheng et al. 2007; Silva & Pinho, 2008). However, the notion that the mobility infrastructure in itself already impacts on mobility patterns is present when different neighbourhoods are characterised in terms of 'transit versus automobile' (Cervero, 1995).

We propose that the description of urban areas in terms of 'modal environments' – whole environments incorporating land uses, places and practical equipment to sustain 'movement cultures' (Read, 2009) – is useful to understand the mobility patterns of their populations and the sustainability potential of their accessibility. To explore this hypothesis we characterise the different neighbourhoods in the Randstad region of the Netherlands in terms of public transport 'modal environments' by measuring the centrality of the public transport infrastructure of the city-region, and compare their centrality to the mobility patterns of the population from the Netherlands Mobility Survey (2008).

2. THE CASE STUDY

The Randstad is a region in the Netherlands comprising its four biggest cities (Amsterdam, Rotterdam, The Hague and Utrecht) and is one of the largest polycentric regions in Europe. It does not correspond to an official administrative region with official boundaries and specific governance. However, its urban areas form a unit of movement and exchange that is acknowledged in many studies (Hall and Pain, 2006; van Eck and Snellen, 2006) and it is addressed by policy at government level, namely the 'Spatial Vision Randstad 2040' by the Ministry of Housing, Spatial Planning and the Environment (VROM). For our study, we adopt the definition of the Randstad based in the work of van Eck and Snellen (fig. 1), where the municipalities of the Netherlands are classified as belonging to particular areas of the Randstad. These areas correspond to the main urban centres that are at the core of daily urban systems (DUS), their surrounding areas as suburbs of DUS, the 'Green Heart' as the central rural and natural area, and an outer ring that defines a buffer where municipalities start having stronger connections outside the Randstad.

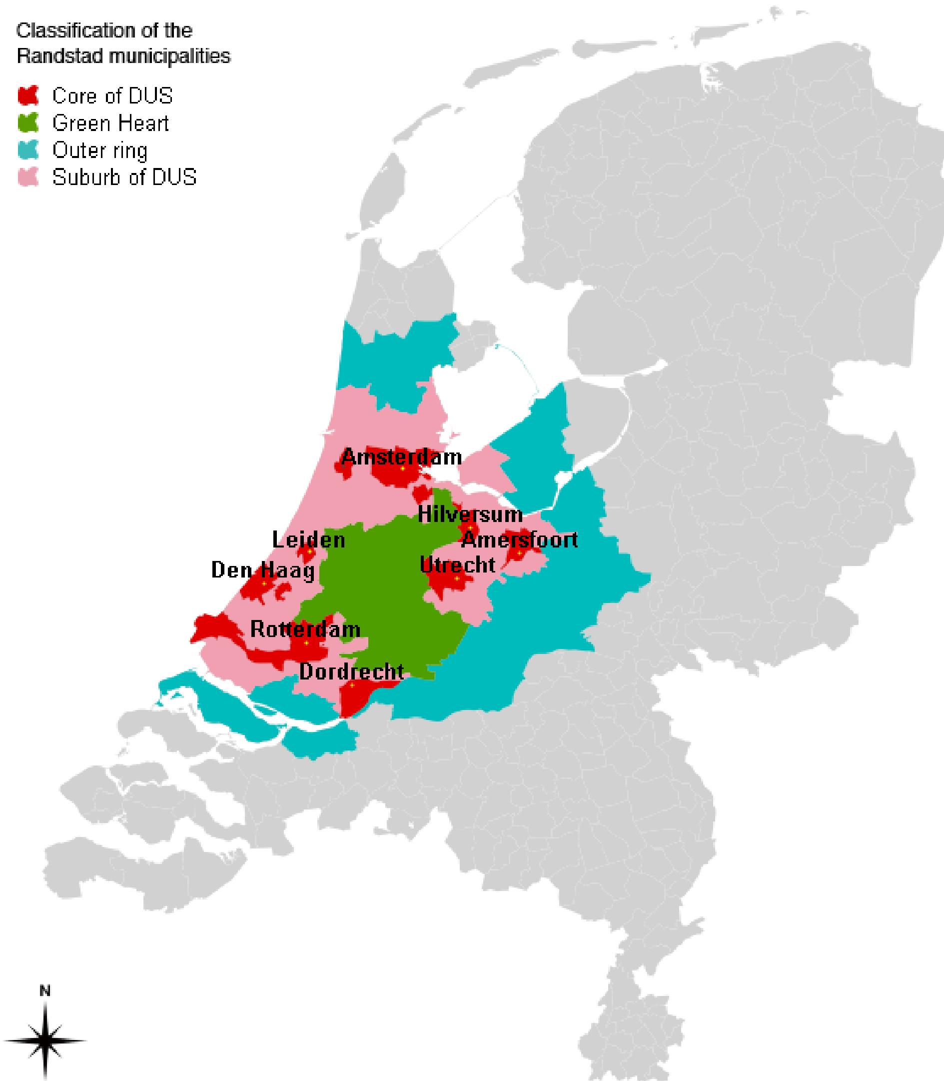

Figure 1 – Map of the Netherlands with a classification of the municipalities of the Randstad, based on van Eck and Snellen, 2006

Regarding mobility and the study of sustainable accessibility, the Randstad is significant because in addition to its road and motorway network it is served by a comprehensive public transport infrastructure, comprising a rail network connecting the main urban centres, local tram, metro and light rail networks in these centres and bus networks providing local service in suburban areas (fig. 2).

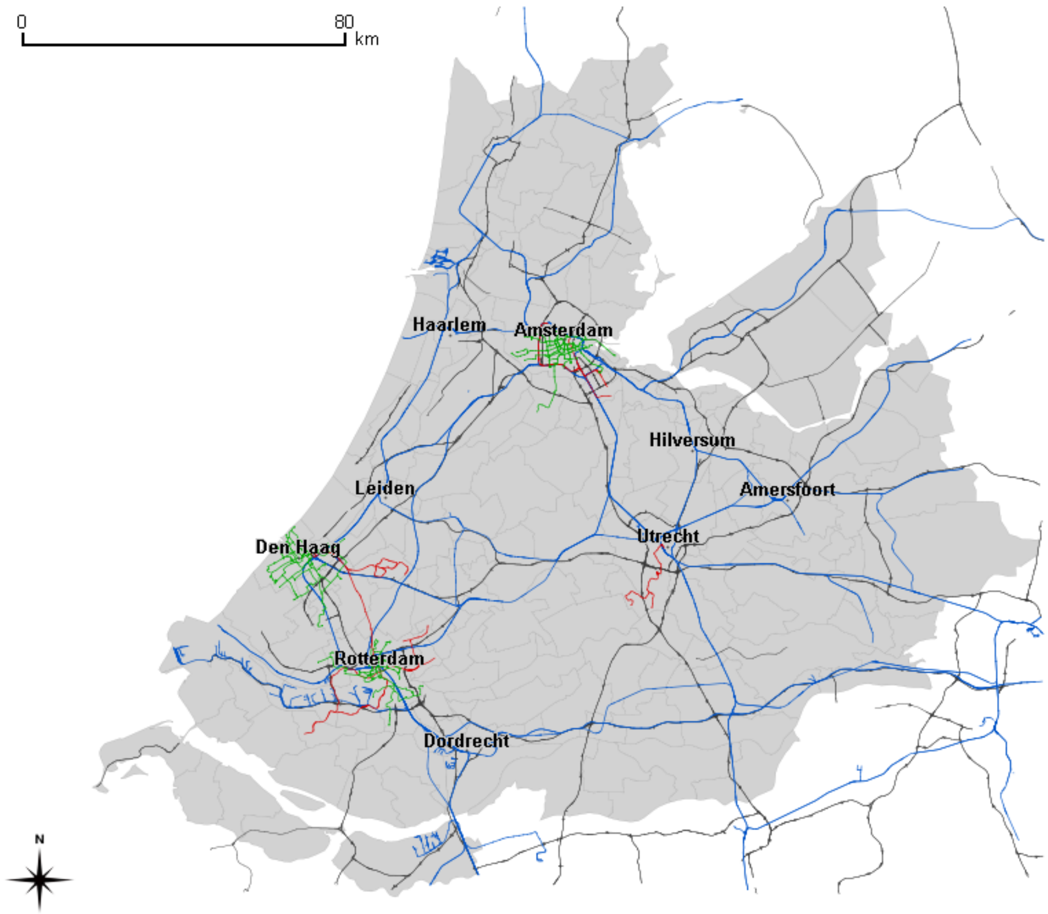

Figure 2 - The map of the Randstad city-region showing the mobility infrastructure networks: motorways (black), rail (blue), metro and light rail (red) and tram (green). The network data was retrieved from OpenStreetMap.

2.1 Mobility survey of the Netherlands

The Ministry of Transport and Waterways has been conducting since 2004 a yearly survey of the mobility of the population in the Netherlands called Mobiliteitsonderzoek Nederland (MON) (between 1978 and 2003 an equivalent survey has been conducted by the Central Bureau of Statistics (CBS)). In the present study, we use the data from the 2008 survey. This is based on a random sample of 20,589 addresses in the Netherlands with 30,121 individual respondents, in the form of a travel diary registering the daily journeys of these individuals, including a variety of information relating to origin, destination, purpose, mode of travel, distance, duration, and details of individual legs on multi-leg journeys. From the full data set we extract and georeference all the journeys that have origin and destination in one of the municipalities of the Randstad region, resulting in a data set of 44,538 individual journeys (fig. 3).

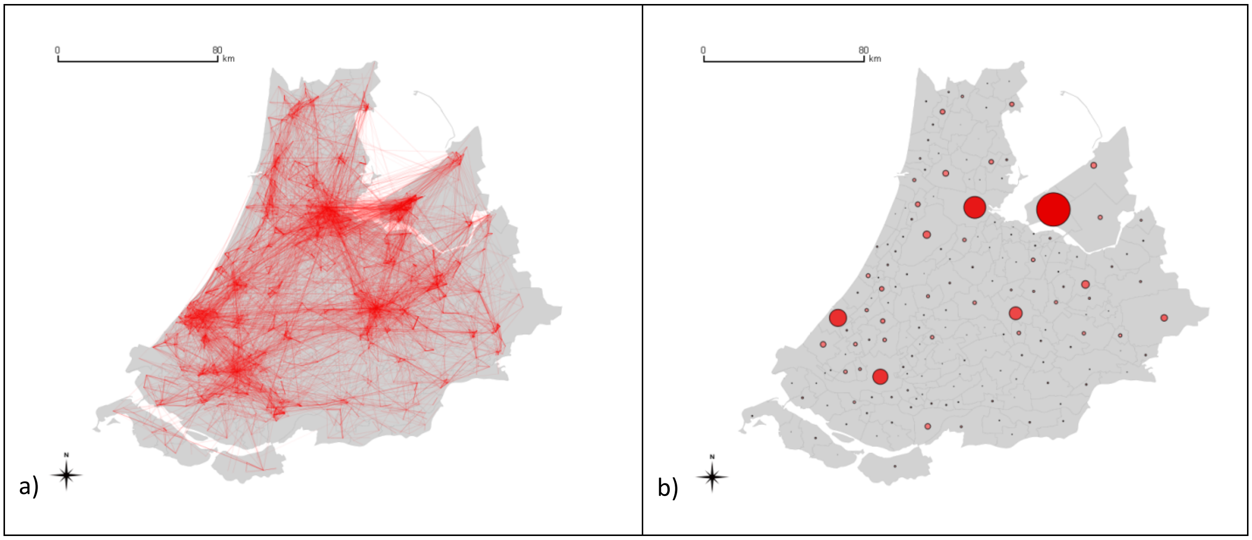

Figure 3 – Maps of all the journeys in the MON 2008 data set, showing a) journeys with origin and destination in different neighbourhoods, b) journeys within the same municipality.

2.2 Mobility patterns in the Randstad

The conventional way of presenting the MON data set is to analyse it statistically and produce 'Table books' of numerous tables with aggregate figures on the travel behaviour of the population in the country or its regions according to each statistic gathered. In a similar fashion, and taking the data specific to the Randstad region, we start by analysing the mobility behaviour of the Randstad population in respect to transport mode choice that has a direct impact on sustainable mobility patterns.

From all journeys, those using the car as the main transport mode account for 46.1% of journeys, using the bicycle are 25.94%, walking 20% and using public transport only 5.64%. The multimodal journeys, those that involve more than one transport mode, represent 5.45% of all journeys made. Since 85% of those use public transport as the main mode, we can conclude that the majority of public transport journeys are multimodal (82%). In contrast, only 8.3% of journeys with the car as main mode will start or end with some other mode. The modal share of the first leg of multimodal journeys is quite different, with the preferred mode for starting the journey being walking (52%), followed by public transport (22%), cycling (14%) and the car (10%). We can conclude that in the Randstad, walking goes hand in hand with the use of public transport in multimodal journeys.

With regards to the relation that might exist between the mobility behaviour of the population and the urban form of the city-region, the statistics don't say much. A previous study by Snellen and Hilbers (2005) has looked to identify spatial factors that might explain modal choice in the Netherlands and has concluded that the socio-economic profile of the population is a prevailing factor. Although they identify that some spatial factors have influence, the spatial factors are aggregate descriptions and classifications of urban form, such as distance to nearest town centre or jobs to residents ratio. Furthermore, in this series of studies the authors fail to present any maps of the phenomenon.

A first step is to visualise the spatial distribution of modal share in the Ransdtad, to see if the mobility patterns correspond to some kind of spatial pattern. Our 'spatial spectacles' might show any striking patterns that quantitative statistics might miss.

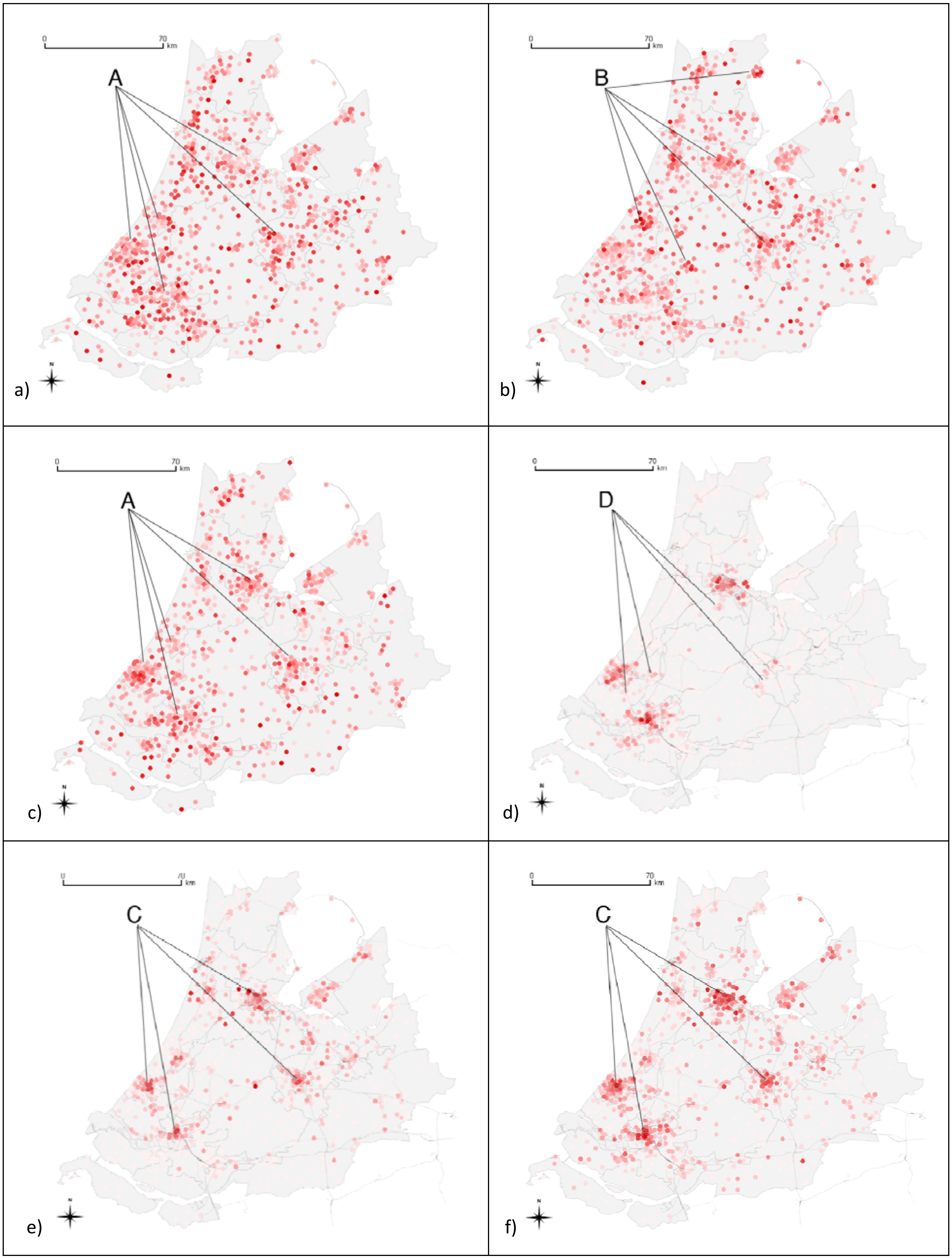

Figure 4 – Series of maps of the modal share in the Randstad, with journeys aggregated at the start and end neighbourhood. The maps correspond to the following modes: a) car, b) bike, c) walk, d) tram/metro, e) rail, and f) multi-modal.

The modal share distribution maps (fig. 4) show two very different groups of patterns, one for private transport (a, b, c) and another for public transport modes (d, e, f). The private transport modes don't show an obvious spatial distribution pattern at the regional level. Only if we look closer can we see that there is indeed less use of the car (4a) in the neighbourhoods of the major urban centres (A). It is also in these areas that more walking takes place (4c), as well as in some more isolated rural neighbourhoods, although this could be an effect of the data collection on the outer ring of the Randstad. Regarding bike journeys (4b), the pattern shows symmetry to car journeys where the higher the bike share the lower is the car share, and vice versa (B). This suggests a certain degree of substitution of car travel on some types of journeys. In order to explore the local spatial patterns of private transport modes we would have to analyse this data set also in terms of journey purpose and distance.

The pattern of public transport modal share at the regional level is clearly 'infrastructure-bound' to the public transport system. The rail mode (4e) and multi-modal (4f) share patterns give a clear indication of zones of accessibility to public transport, with hotspots around urban areas where there is more quantity and variety of public transport services, in particular the central railway station (C). The higher tram/metro modal share (4d) only occurs in the urban areas that have those transport systems. Nevertheless, there are clear differences within those areas and some neighbourhoods have a very low share of tram/metro use despite the presence of the service (D).

This suggests that when it comes to investigating the potential for sustainable accessibility in relation to the use of public transport modes, it is important to take into account the affordance of the public transport infrastructure, not only its presence in a given neighbourhood, but also the affordances of that presence in terms of access to the daily needs. For this reason we propose to represent the public transport mobility infrastructure of the Randstad as a network model and analyse its structure in terms of network centrality measures.

3. METHOD

In this study, we create a multi-modal network model of the public transport infrastructure and analyse the network in terms of centrality measures. We take the traditional space syntax approach of measuring the structure and configuration of the network itself, which has shown to be indicative of the level of use of public transport nodes (Schwander, 2009; Chiaradia et al., 2005). Then, we aggregate the results at the level of the neighbourhood using the official neighbourhood boundary geometry (CBS and Kadaster, 2010), and we correlate the result with the data from the MON 2008 mobility survey at the level of the neighbourhood.

3.1 A multi-modal mobility infrastructure network model

The multi-modal network model of the Randstad includes the three main public transport networks, namely rail, tram and metro/light rail. It is a simple topological undirected network where the stations or stops represent nodes in the graph and the mobility infrastructure defines the links. Where there is more than one stop of the same transport mode with the same name within a close location, either representing different platforms in a station, or different tram stops on either side of a road or around a crossing, we only consider one node. The links connect the nodes directly to each adjacent node irrespective of the geometry of the infrastructure, as long as it belongs to the same mode of transport. This way we obtain three different independent networks for rail, tram and metro (fig. 5).

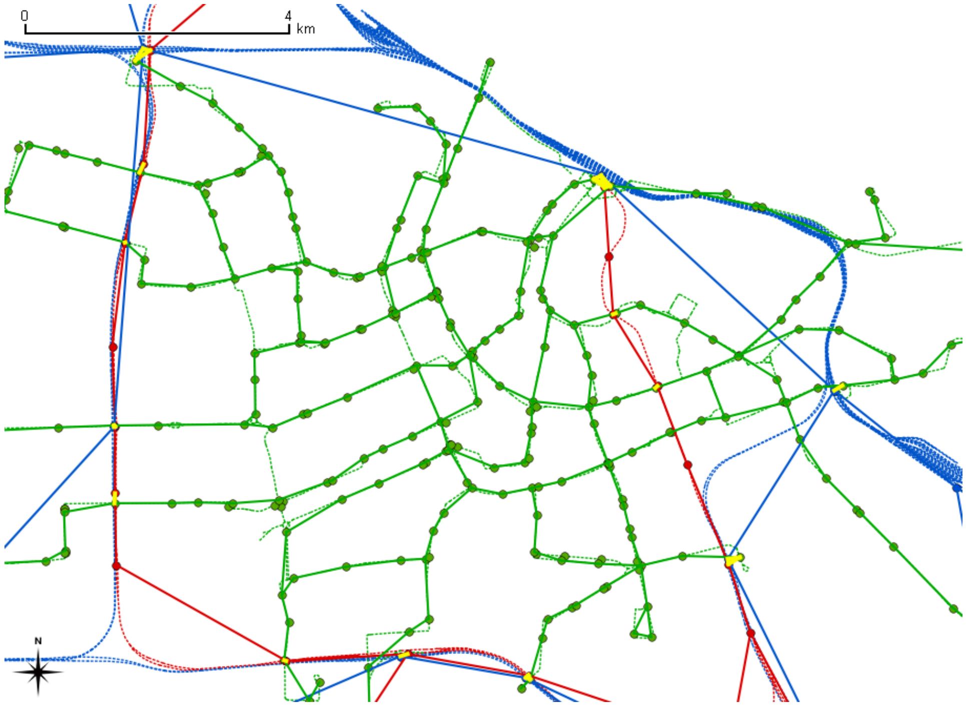

Figure 5 – Detail of the multi-modal network model around central Amsterdam, showing the three networks: rail (blue), metro (red) and tram (green). The dotted line represents the original infrastructure and the continuous line represents the network links. The circles represent the stations and stops. In this model, a single node is used in a group of stops of the tram network around a crossing (A) or on both sides of the road (B). The links connect the nodes directly, irrespective of the geometry of the infrastructure (C).

In order to create a multimodal network we introduce a fourth set of links representing modal interfaces that make the connection between the nodes of the different public transport modes. They occur where the nodes from a network link directly to those of another network in the same platform, in the same physical space, but also where the link is notional and the name of the stations/stops are the same. Often a tram stop is named after the metro stop nearby, or the tram and metro stops are named after the main railway station. This naming convention defines a transfer opportunity between nodes.

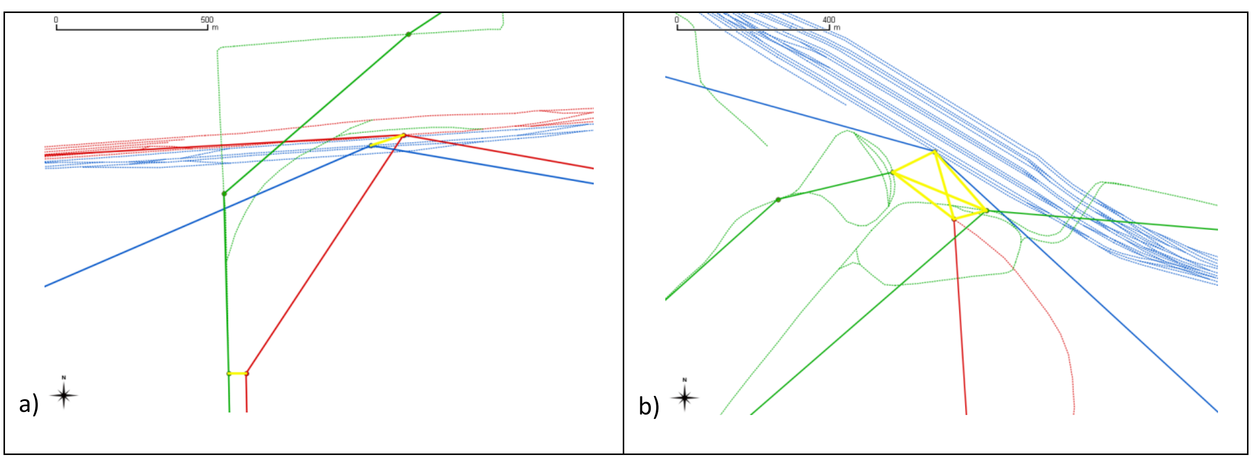

Figure 6 – Two details of the multi-modal network showing examples of interface links (yellow). Image b) shows a particular case where two nodes of the same mode (tram, in green) are connected with an interface link (yellow), because they belong to separate branches of the network and have different names, but meet in the same space facilitating the transfer.

The model was produced in a PostgreSQL/PostGIS database containing the other data sets for the study. It was largely based on GIS data extracted from the OpenStreetMap (OSM) data set for the Netherlands, which contained the public transport network tracks and most stop locations. It was however necessary to complete this information with further stops and stations, and to correct the name, location and transport mode of some stops. The extra stops and all network links were drawn manually using Quantum GIS (QGIS), connected directly to the data base. Initially we tried to link the stops using the topology information contained in the OSM data. However this proved to be too incomplete and incorrect, and we used more conventional public transport network maps and Google Maps to assist in the modelling of the network. Once the multi-modal model was completed, we were able to perform the network analysis.

3.2 Analysis methods

The analysis of the multi-modal network model was performed in NetworkX (Hagberg et al. 2008) using its centrality algorithms to calculate degree centrality, closeness centrality and betweenness centrality. These approximate the space syntax measures of connectivity, integration radius N and choice radius N, respectively. We could not use standard space syntax analysis software because these only accept as input an axial map and create the graph for analysis internally and automatically from this input.

In order to correlate the network analysis results with the MON 2008 survey data we have aggregated the values from the nodes into the neighbourhood areas. The spatial aggregation was performed in PostgreSQL/PostGIS. We preformed different levels of spatial aggregation, merging the nodes with the official boundary as is but also with wider neighbourhoods using 400m, 800m and 1500m buffers. We have also used different methods for quantitative aggregation, namely the sum, the maximum and the mean of the values of the nodes within each neighbourhood area.

As for the mobility data, we have calculated the modal share in each neighbourhood because the survey sample is random and the raw total number of journeys is not representative of the population nor their behaviour. Furthermore, we have eliminated the bottom quartile of survey areas in terms of number of journeys (less than 24) because the modal share number would not be reliable.

4. MOBILITY INFRASTRUCTURE NETWORK ANALYSIS

We have calculated the network centrality measures for the complete multi-modal network, as well as for the rail network on its own and the tram and metro networks combined (the MON 2008 survey presents combined results for both modes). The results are presented in the maps in figure 7.

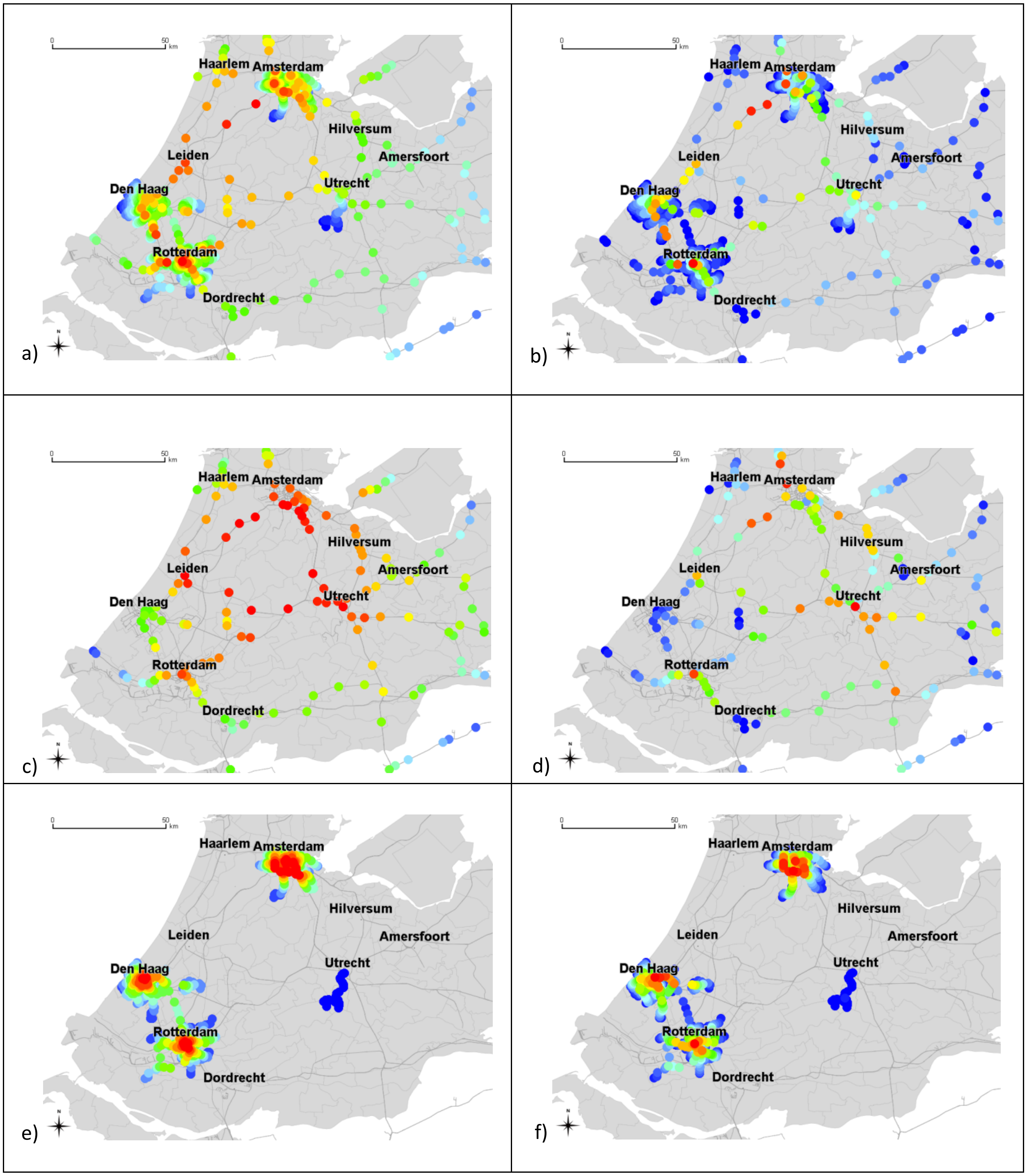

Figure 7 – Maps of the multi-modal network (top), rail network (middle) and tram/metro network (bottom) analysis results showing a), c), e) closeness centrality and b), d), f) betweenness centrality. The colour range is the 'classic' space syntax range with red for high centrality values. The values of the tram/metro network have been normalised for each individual local sub-network.

The centrality maps of the Randstad's multi-modal network (7a and b) provide a picture of the hierarchy of nodes that reveals a strong West wing linking Amsterdam, The Hague and Rotterdam via Leiden, which also reflects the more strongly connected and urbanised area of the Randstad (figure 3a). When compared to the multi-modal share map of figure 4f, there is a clear visual correlation between the highest closeness centrality nodes (7a) and the hotspots of high multi-modal share. The stations of Hooddorp and Schiphol, South of Amsterdam, stand out particularly in the betweenness centrality analysis (7b). These stations correspond to the new main area of business development in Amsterdam and also to the location of the main international airport of the Netherlands.

In the case of the individual networks (7c, d, e and f), the analysis gives very different results. The rail network closeness (7c) shifts to a central part of the network as the influence of local public transport networks is removed. The Utrecht region, Leiden and their links to Amsterdam and Rotterdam are more integrated and have higher betweenness (7d). Only Rotterdam, to some extent, maintains its importance and The Hague appears quite marginal, while Hoofddorp and Schiphol, south of Amsterdam, reveal their strategic importance in the rail network. These results reflect a more regional and even national role of the rail network, with a structure that is sparse and distributed, and are to some extent influenced by the cropping of the network at the limits of the Randstad. The tram/metro network analysis shows the main closeness centrality (7d) in the urban centres but more specifically in the nodes of highest interchange with the rail network (7e), despite these nodes not being present.

Finally, for an initial analysis of the results we have produced a table ranking the public transport nodes based on their combined closeness and betweenness centrality, by summing each rank (tab. 1). We do this analysis for the multi-modal network, including a ‘Mode’ column to indicate the transport mode of each node, and for the rail network on its own.

Table 1 – List of the top 20 ranking nodes in the analysis of the multi-modal network and of the rail network on its own.

Rank	Multi-modal network nodes	Mode	Rank	Rail network node
1	Hoofddorp	rail	1	Woerden
2	Rotterdam CS	rail	2	Schiphol
3	Schiphol	rail	3	Utrecht CS
4	Schiedam Centrum	rail	4	Hoofddorp
5	Amsterdam Lelylaan	rail	5	Vleuten
6	Leiden Centraal	rail	6	Leiden Centraal
7	Delft Zuid	rail	7	Rotterdam CS
8	Amsterdam Zuid	rail	8	Utrecht Terwijde
9	Rotterdam Blaak	rail	9	Amsterdam Sloterdijk
10	Nieuw Vennep	rail	10	Bunnik
11	Amsterdam Sloterdijk	rail	11	Utrecht Lunetten
12	Delft	rail	12	Weesp
13	De Vink	rail	13	Breukelen
14	Amsterdam RAI	rail	14	Duivendrecht
15	Rijswijk	rail	15	Amsterdam Lelylaan
16	Amsterdam Centraal	rail	16	Amsterdam RAI
17	Rotterdam Noord	rail	17	Bijlmer ArenA
18	Voorschoten	rail	18	Alphen aan den Rijn
19	Rotterdam Centraal	tram	19	Amsterdam Muiderpoort
20	Station Zuid	metro	20	Amsterdam Zuid

The list of top ranking nodes in the multi-modal network matches the western ‘wing’ of the Randstad linking Amsterdam, The Hague and Rotterdam. One would expect that the central stations connected to the large urban centres with tram and metro networks would score highest, as in the case of Rotterdam CS, but Utrecht CS, Den Haag CS and Den Haag HS are notably absent from the top. The two stations of Hoofddorp and Schiphol have a high ranking indicating a strategic location in terms of public transport network. While in the case of Schiphol it links to one of the large airports in Europe and is indeed a busy station, in the case of Hoofddorp it is mainly an interchange station and the area it serves is a car oriented business centre South of Amsterdam. It is interesting to note that only one tram and one metro stops make it into the top 20 list.

The list of top ranking nodes in the rail network alone reflects the shift in centrality to the geographic centre of the network around Utrecht, reinforcing the eastern ‘wing’ between Utrecht and Amsterdam, and around the ‘Green Heart’.

4.1 Aggregation methods

These results have been aggregated at the level of the neighbourhood to enable the correlation with the MON 2008 survey data. From the various methods tested, we decided to sum the results of the nodes within an area, as the maximum was leaving out a large part of the information where several nodes fall in an area. The mean value did not give meaningful results, as had been previously shown by Turner (2009), even when here we are looking at mobility related data instead of socio economic data. The best neighbourhood area was the one including a 400m buffer, which is in line with what residents of an area perceive to be their neighbourhood within walking distance (Jenks and Dempsey, 2007). This ranged proved positive in terms of tram/metro mobility, but did not affect the rail network in the same way. Although other studies suggest that the range to a railway station should be 1500 m, this buffer did not produce better results in relation to rail travel.

4.2 Correlation with mobility patterns

The statistical correlation of multi-modal network centrality measures against mobility patterns in terms of modal share is generally low, but shows some patterns that indicate that the configuration of the network can be an indication of the potential use of public transport in an area (tab. 2).

Overall, the correlation coefficient between the multi-modal network centrality measures and rail mode share in the various neighbourhoods was not found to be strong, although there was a very slight improvement with the betweenness measure (R^2=0.17).

On the other hand, the correlation between the multi-modal network centrality measures and the tram/metro mode share give positive results when considering the 400m neighbourhood (R^2=0.37) indicating that the presence of this network infrastructure has a positive effect on modal choice. It is not simply an effect of having more nodes in the neighbourhood because the correlation does not increase if we extend the buffer to 800m and 1500m

Table 2 - Table with R^2 values for public transport modal share against structural characteristics of the multimodal mobility network, aggregated at the neighbourhood boundary level, or at a neighbourhood boundary with a 400 meters buffer. (P value is < 0.0001 in all correlations.)

Mobility	**Closeness**	**Betweenness**	**Degree**	**Node Count**
Neighbourhood boundary				
Rail share	0.07	**0.17**	0.08	0.04
Tram/metro share	**0.20**	0.08	**0.21**	**0.20**
Multi-modal share	**0.20**	0.18	**0.21**	0.15
400m buffer neighbourhood				
Rail share	0.07	**0.13**	0.08	0.05
Tram/metro share	**0.37**	0.17	**0.35**	**0.35**
Multi-modal share	**0.30**	0.23	**0.30**	0.25

5. FINDINGS AND DISCUSSION

From the results of this analysis we can start drawing some ideas about the structure and role of public transport infrastructure network in potentiating more sustainable mobility patterns.

5.1 Hierarchy in multi-modal networks

There is a hierarchy in the structure of multi-modal networks, where the rail operates at a larger scale and more centrally topologically than the tram/metro, and has a more global impact. On analysis of the network's centrality at radius N we see that the top nodes of the multi-modal network are firstly and mostly from the rail network, then come the tram/metro nodes, and the share of rail nodes quickly drops (fig. 8).

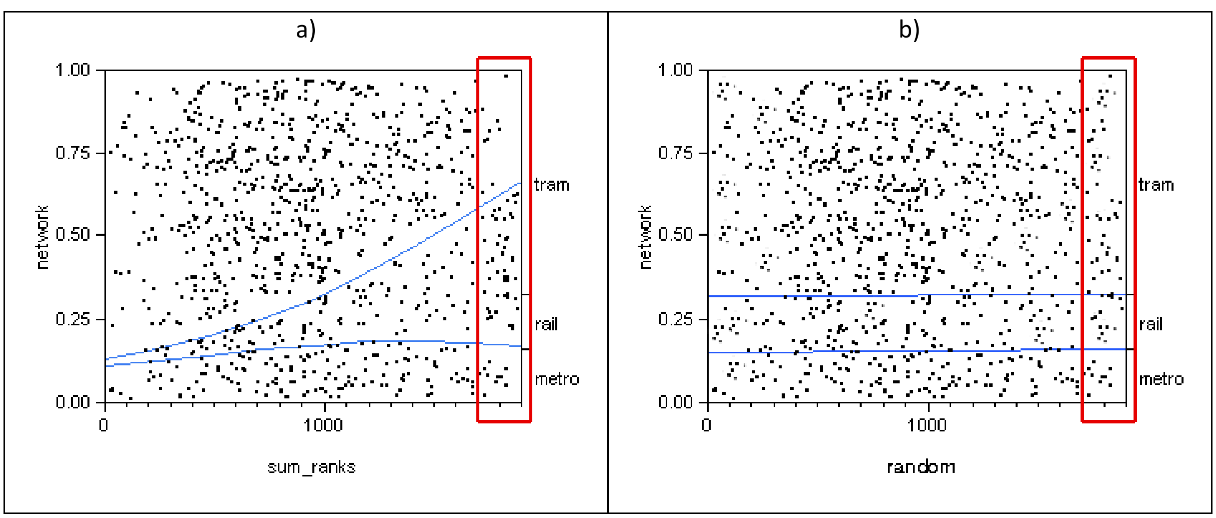

Figure 8 – Plot a) shows the nodes of the three public transport networks ranked in terms of centrality and grouped by network. The red box highlights the top 10% nodes, where we find the biggest proportion of rail nodes and only a small representation of metro and tram nodes. All things being equal (plot b), one would have more tram nodes in the top 10% because there are more of them.

Since rail is a long distance travel mode, the decision to use it seems to be less related to the characteristics of the multi-modal network at neighbourhood level. This is reflected in the low correlation in the analysis against neighbourhood level mode share patterns and in the type of centrality measure that has a slightly more positive result, i.e. betweenness centrality. Tram mobility, on the other hand, seems to be affected by local properties of the network such as node count and degree, more than the global structural relations. The tram/metro network has a strong spatial dependency on the local structure of the city and only exists in cities of a considerable size.

The structure of these networks is indeed different, with different distance between stops and reach of the network. A parallel can eventually be established with the road network's hierarchy, where there is a motorway system serving a different purpose to the local distributive system in the urban centres.

5.2 Multi-modal versus single mode network models

Because each network works differently and operates at different hierarchical levels, one might consider analysing them separately to better understand their impact on the modal choice of the population. However, they are still part of the same multi-modal mobility system. If we correlate the results of the centrality analysis of the tram/metro network on its own against tram/metro mode share in a neighbourhood we see a considerable drop in the correlation coefficient (tab. 3). The multi-modal network model usually gives better correlations than modelling the single mode networks independently, even in terms of local centrality measures such as node count and degree. It is in fact curious that the centrality measure that improves in the single network analysis is betweenness, maybe indicating a structuring role of the tram/metro network in relation to a lower level network such as walking. This hypothesis remains to be tested and will require the integration of the street network in the multi-modal network model.

Table 3 - Table with R^2 values for tram/metro mode share against the centrality measures on a multi-modal integrated network and on the tram/metro network alone.

Tram/metro share	**Closeness**	**Betweenness**	**Degree**	**Node Count**
Neighbourhood boundary				
Multi-modal network	0.20	**0.08**	0.21	0.20
Tram network	0.11	**0.12**	0.10	0.07
400m buffer neighbourhood				
Multi-modal network	0.37	**0.17**	0.35	0.35
Tram network	0.21	**0.17**	0.21	0.18

This result confirms that the existence and importance of specific nodes in a public transport network is dependent on their relation to other levels of mobility. These mobility and centrality patterns are historic ones, with many layers, as systems have started building up, connecting and making sense together over time. The everyday use of these apparently independent systems is already influenced by their relations. As Schwander (2009) has shown in his model of the rail network of the South East of England, a schematic representation of the Underground was required to provide links connecting the main railway stations together.

In relation to a sustainable mobility strategy, we should not forget that the large majority of public transport journeys is multi-modal and involves the transfer between different modes, including individual transport, mainly walking and cycling. Hence, we need to consider them in an integrated model to better represent the structure of the sustainable mobility infrastructure. How to best build this model should be subject of further work.

5.3 Potential for sustainable mobility

Indeed, the correlation between the centrality measures of the proposed multi-modal network model and the public transport mode share of the neighbourhoods is not enough to say that this is a key factor or indicator of modal choice. However, we can start understanding that the structure of the networks plays a role in defining the sustainable mobility potential of the environment, towards the qualification of 'modal environments' (fig. 9).

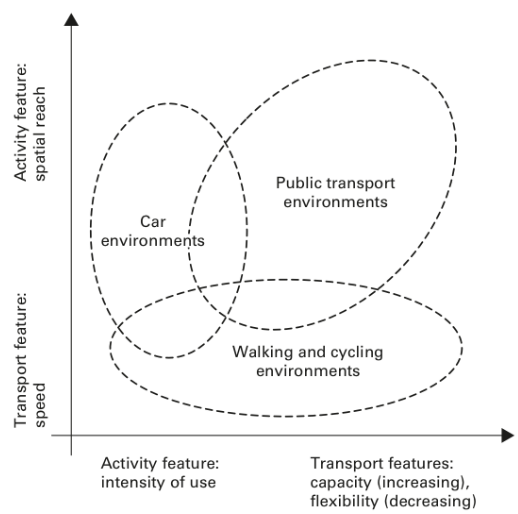

Figure 9 – Diagram of the qualification of the different environments in the multi-modal urban region, based on their main modal share and other local accessibility characteristics (Bertolini, 2005)

If we consider the scatter plots of public transport share against closeness centrality, we can identify an area of low public transport use that corresponds to the nodes with lower closeness centrality (fig. 10). From the structure of the multi-modal network we can infer the potential for a neighbourhood to achieve high levels of public transport journeys: where closeness is low the public transport share is low, where closeness is high there is a possibility for a higher public transport share. The vertical range at any point represents the range of possibility for a high public transport share.

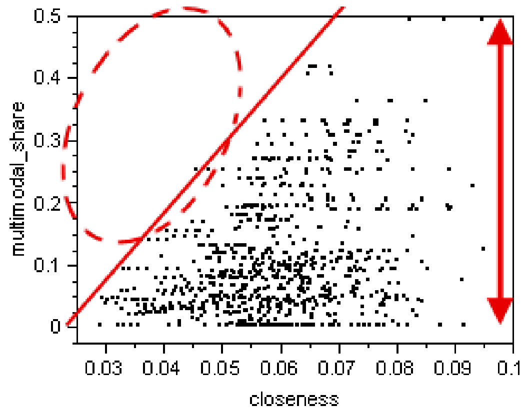

Figure 10 – The scatter plots show the distribution of public transport nodes in terms of the multi-modal share of the neighbourhood in relation to each node's closeness centrality value. The ellipse represents environments of none to very low public transport modal share. The arrow indicates the maximum public transport share potential.

Despite this potential, we can also conclude from the low correlations (tab. 2) and from the scatter plot (fig. 10) that most often this potential is not realised. What other characteristics lead urban areas to fulfil or not their sustainable mobility potential? Looking back at the mode share maps (fig. 4), we must identify the characteristics of those neighbourhoods with higher car and walking/cycling share that, once added to the vertical axis of our mode share plot, identifies the car environments as distinct from the walking and cycling environments.

6. FURTHER WORK

From the preceding discussion, we arrive at many questions and lines of further inquiry. To proceed with this research we can explore other aspects of the mobility patterns of the Randstad, other dimensions of urban form of the neighbourhoods, and other ways of making an integrated mobility network model.

Firstly, we must merge the various years of the MON survey to obtain a larger data set and be able to draw conclusions that are more reliable. We must also include all journeys that start or end in neighbourhoods of the Randstad, even those that originate outside it. We then need to study walking, cycling and car journeys as the first two modes are also part of a sustainable mobility strategy and are indeed complementary to the use of public transport. We could also analyse the relation between transport mode and the different types of journey in terms of purpose and distance, and we should characterise the different neighbourhoods in terms total or average travel distance by mode and per person. We can then maybe identify which types of journeys have a greater potential for modal shift, and in which urban areas this modal shift is actually a possibility and people are not 'locked' into using their cars.

With this aim, we should be considering other local urban form characteristics and accessibility measures. The characteristics of the neighbourhood at origin and destination of the journey can have an influence on the modal choice (Brons et al. 2009). Having a collection of measures we should consider profiling the various urban areas to identify particular neighbourhood types (Chiaradia 2009) and build a multivariate model to correlate with the mobility characteristics in terms of journey mode, distance and purpose.

One important task is to explore how to best to build the model multi-modal network model. On the one hand, we must consider adding other levels, such as the bus network, the airports, the motorways and the local streets. On the other hand, we must explore the best way of integrating them while retaining their structural and hierarchical differences. We should consider different methods of analysis for each mode, having weighted modal interface links (fig. 6) in the case of a single unified network, or use the modal interface links as weighting nodes on a multi-network model.

7. CONCLUSION

In this work, we investigate the potential for urban neighbourhoods to support sustainable mobility patterns in the city-region by presenting a high modal share of public transport journeys. We propose to measure this potential using a topological multi-modal network model that represents the main public transport networks of the Randstad city-region. We then take a space syntax based approach and analyse the network's structure in terms of centrality, instead of utility-based accessibility measurements using the network to link to population or land use.

Although the centrality of the multi-modal network does not fully explain the patterns of public transport use in the different neighbourhoods, especially in terms of rail mode share, it seems to offer a possibility of characterising those neighbourhoods in terms of their public transport use potential, i.e. to what extent they can be public transport environments. The realisation of this potential is dependent on other factors, and further work is required to understand what makes a walking and cycling or a car environment in terms of multi-modal mobility networks.

Furthermore, it was found that topological centrality measures show a hierarchy in the multi-modal network infrastructure, and that one should use different methods to analyse the different modes because they play different roles. Finally, it was found that, despite these differences, it is important to consider the network as an integrated multi-layered system. How these layers are modelled and articulated should be subject of further research.

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