Interaction of rail infrastructure and urbanisation in the Netherlands; a preliminairy analysis

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Samenvatting

Samenhang tussen rail infrastructuur en verstedelijking; een eerste analyse

Het is al vaak betoogd dat verstedelijking van invloed is op de ontwikkeling van infrastructuur en vice versa. Toch zijn er weinig studies die de relatie tussen de groei van netwerken en de groei van het stedelijk oppervlak bestudeerd hebben. De oorzaak daarvan houdt zonder twijfel verband met het ontbreken van data over een lange periode. Recent worden steeds meer historische kaarten met behulp van GIS op gelijke wijze gedigitaliseerd en verder bewerkt tot een consistente dataset. Het doel ons onderzoek is om met behulp van deze bronnen de ontwikkeling van verstedelijking en infrastructuur netwerken te analyseren. In dit paper focussen we op de samenhang met het spoornetwerk. We beperken ons tot de Randstad voor de periode van 1850 tot 1990 (de periode tot heden is nog niet gereed). In de analyses concentreren we ons op enkele belangrijke momenten (deels door databeschikbaarheid ingegeven). We starten met 1850, wanneer net de eerste spoorlijnen zijn aangelegd. De periode tot 1900 wordt gekenmerkt door het grotendeels aanleggen van het netwerk zoals we dat nu ook nog kennen. In de periode tot 1940 wordt het verder voltooid, hoewel het aantal stations weer afneemt. Tot die tijd draagt het spoornetwerk sterk bij aan de verstedelijking. Vanaf de jaren zestig krijgt het spoornetwerk te maken met hevige concurrentie van het snelwegnetwerk, hetgeen resulteerde in forse ruimtelijke spreiding. Opvallend was dat het netwerk vooral langzame groei kende, soms wat afname, maar het aantal stations veel meer variatie liet zien. Het paper laat met name zien hoe de verstedelijking toenam. In de eerste decennia vooral in een zone van een kilometer rond de stations, later vooral in de volgende zone van een kilometer. Naarmate de tijd voortschreed, groeide het bebouwde oppervlak op steeds grotere afstand van de stations. In dit paper komen we slechts tot een gedeeltelijke verklaring, die we graag verder willen onderzoeken: de beschikbaarheid van grond direct bij het station, de toenemende mogelijkheden om het station van grotere afstanden af te bereiken, en natuurlijk de invloed van de auto. Bovendien worden in het vervolg van het onderzoek ook de laatste decennia meegenomen.

1. Introduction

It has repeatedly been argued that both urbanisation and infrastructure development interact with travel behaviour. A rise in urbanisation induces travel demand and requires infrastructure, while every piece of new infrastructure also creates demand (Maat, 2001). There are now many studies, analysing the relationship between travel behaviour and the development of the built environment (see for overviews TRB, 2009 for the US, and van Wee and Maat, 2003, for the Netherlands). Some Dutch studies have explicitly related urbanisation and travel demand to spatial policies (Faludi and van der Valk, 1994, Dieleman et al., 1999). However, so far, studies analysing the development of infrastructure and the built environment simultaneously, hardly exist. In the Netherlands, a main reason for this gap was the unavailability of consistent data over a longer period. Nonetheless, recently, such land use and infrastructure data became available, partly as GIS data, and was processed by us to a consistent dataset.
The aim of this paper is to analyse to what extent dynamics in the development of the built-up area and the expansion of railway infrastructure are associated. The case study area is the Randstad, the economic and population core of the Netherlands. We analyse the developments between 1850 and 1990 (the next two decades are in progress) by describing the expansion and in particular the interaction of the built-up area with the railway lines and railway stations. The analyses concentrate on some significant moments: we start with 1850, just after the introduction of the first railway which develops into a large railway network by the end of 1900. We continue with the 1940s. Since the 1960s, the railway network was heavily competed by the motorway system, which resulted in increasing urban sprawl and later attempts to keep the sprawl within limits. In Section 2, we describe the developments on the basis of the literature. Section 3, briefly describes our data. The fourth section encompasses our GIS-based analyses. The paper demonstrates that the railway network was associated with further urbanisation, starting with the impact of railways on a relatively concentrated urbanisation, but later surpassed by tendencies of urban sprawl, initiated by the car and the motorway system.

2. History

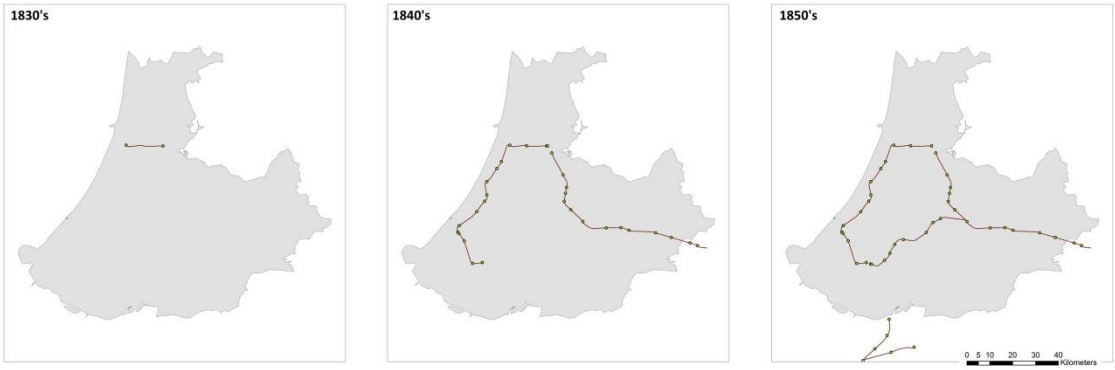
The development of railway infrastructure and urbanisation are discussed within four time frames in this article: 1850-1900, 1900-1940, 1940-1980 and 1980-2010. We describe the development of the railway network in the context of that era and add some words of the development of the urban area.

Pre 1850, the advent of railways

The Dutch predecessor of the train was the 'Trekschuit', a barge towed by horses along the canals. Thus it is not surprising to find the first railway lines built along to the existing canals. In 1839, the first Dutch railway between Amsterdam and Haarlem was built. The competition of trains and railways with barges and canals went on for several decades till the end of 19th century after which the barges finally conceded.
The introduction of the rail transport system shows some interesting characteristics. Initially, it was a complementary transport mode along the waterways (van der Knaap, 1978). Furthermore, even then, in the 19th century, the government was planning the

network to maintain and to reinforce the position of Amsterdam and Rotterdam as an important port and the centre of international transit (de Jong, 1992). In that time, the urban structure consisted of many small towns, a small number of medium sized and a few large ones (Deurloo and Hoekveld, 1980), but a according to Dijksterhuis (1984) the demand factors for the design of the Dutch railway network included not only the connection of those cities, but also the connection of the seaports with industrial hinterlands, and the Netherlands with its neighbouring countries. Figure 1 shows this early backbone structure of the railway network.

Fig 1.The development of the railway network till 1850's



The railway boom: 1850-1900

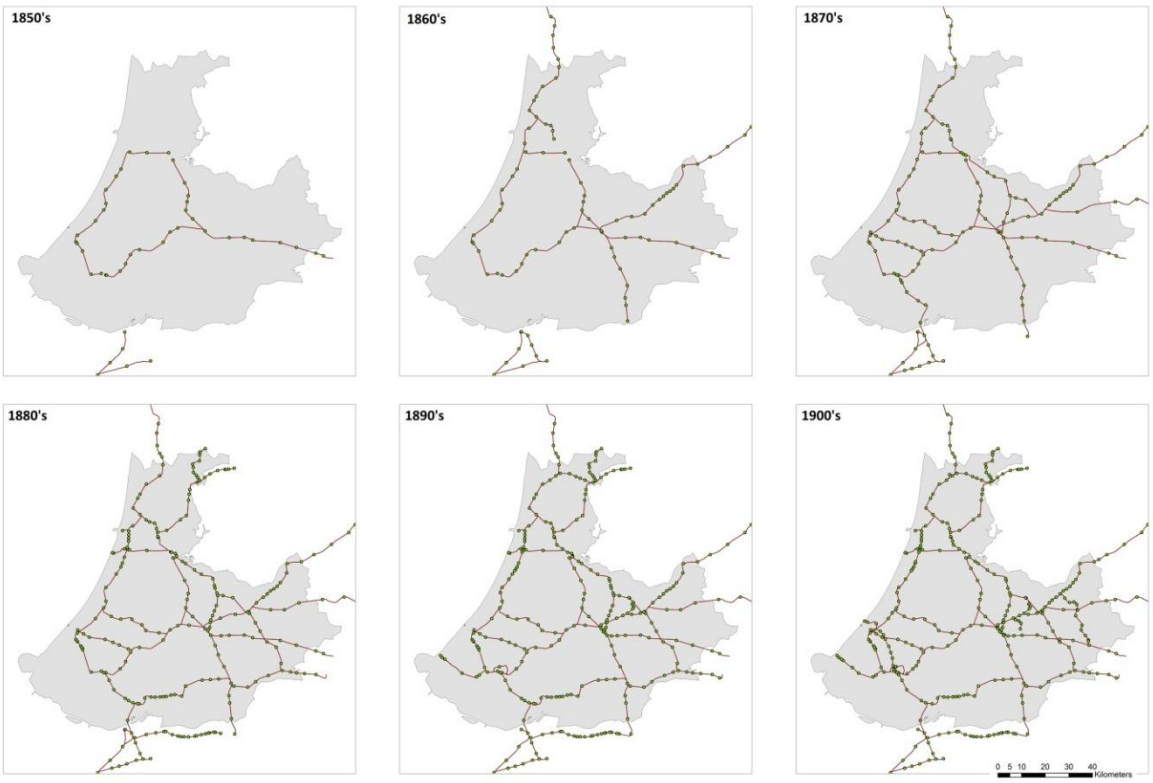
The industrial revolution started rather late in the Netherlands, between 1850 and 1890, resulting in demographic and economic growth in the second half of the 19th century, accompanied by migrations to cities where most of the industrialisation was happening (Schmal, 2002). There is not a consensus on the "take-off" period of the Dutch economy, according to some economic historians this period was between 1850 and 1870 while others consider the period at the turn of the century (1895 to 1914) to be critical (van der Knaap, 1978). The relatively late and limited Dutch industrialisation and the competition with barges plus an unfavourable soil condition are thought to be the main reasons behind the late development of the railway network in the Netherlands (Schmal, 2003, Dijksterhuis, 1989).

Coinciding with the starting point of modern Dutch economic growth, the period from 1860-1890 is considered the railway boom. Starting from dispersed lines around the country which opened in the 1860s and 1870s (Schmal, 2003), the railway network developed to be an integrated transport mode capable of competing with others by the end of 1890s (de Jong, 1992). During this time, the travel speed and number of through-trains increased as well (Annema and van Wee, 2009). It is also important to know that the first Dutch railway branches did not consider goods' transportation. They were constructed to answer the demand for passenger transport. Around 1870s, the railways had already monopolized the transportation of passengers between cities (de Jong, 1992). Figure 2 shows the fast development of the network in the second half of the 19th century, resulting in a railway network that does not differ so much from our actual network. In mid 1870s, the government allowed removal of fortifications (1874) which resulted in extensions beyond the city walls, so the Dutch cities expanded for the first time since the 17th century in the decades that followed (1870-1920) and opportunities for new railways appeared.

Need for local railways

In the meantime the railway construction technology was developing as well. In the beginning, the primary railway lines which connected the main population cores were built heavily and in long curves, as a precaution, taking into account high speeds. After 1870 however, the need to connect less populated regions and smaller cities and villages was felt. Moreover, population and industrial production growth were rising. New means of transport were needed within cities to respond to this growth and to cover the increasing distance between work and living. There was a strong demand to replace horse-drawn trams and omnibuses for faster modes, so local railways were developed at this stage (Dijksterhuis, 1984). Thus in the last decade of the 19th century local railways and tramways (as an alternative for the rail) were constructed with the help of the government's financial support in less dense and rural areas (Annema and van Wee, 2009). Moreover, during this period, secondary stations were built on the present railway lines which later on supported the development of suburban areas (Cavallo, 2007). All in all, during this period the length of the railway network, as well as accessibility, grew tremendously. Although the network continued to expand in the coming decades, its pace slowed down considerably (Koopmans et al., 2012). See Figure 6 for the growth and later decline of the number of railway stations.

Fig 2.The development of the railway network from 1850s to 1900s



The reinforcement of the existing urban infrastructure

In the beginning of this period the new railway lines only linked the existing economic and political centres and acted as a replacement of an older means of transport. As the railway did not link new urban areas at this stage, it did not bring along fundamental economic changes (de Jong, 1992).

The building of railway lines had indeed a regional effect on the existing urban structure. Their location parallel to canals for passenger transport and their role in connecting the existing rows of settlements around transport connections, be it land or water, led to strengthening of the existing structure (Dijksterhuis, 1984).
This pattern is already evident in 1848 when the network-in-the-making connects the urban centres of Amsterdam, The Hague, Rotterdam and Utrecht. This curve completed in 1855 into a ring which already corresponded to what we now consider the Randstad. As the western part of this circle was built first, it confirms the aim to re-enforce the existing urban structure. The early placement of these urban cores on the railway network gave them 'an additional advantage' for further development in comparison to others (van der Knaap, 1978).

The era of the large cities: paving the way for suburbanisation

It is also meaningful to take a look at what was happening at the national level at this stage.
According to Kooij (1988) the period between 1850/60 to 1910/1914 is critical for a nation-wide urbanisation which witnessed the formation of an integrated Dutch urban system. The emergence of an integrated transport system (railways and tramways, canals and roads) constructed during the second half of the 19th century played an important role in this respect. This network connected and integrated the large peripheral cities in the north and south of the country with the concentrated and more developed cities in what we now call the Randstad. Along with the growth of accessibility, the urban population increased, though the direction of causation is not clear. The three largest Dutch cities, Amsterdam, Rotterdam and Den Haag which had gained much concentration of people and jobs during this period, acted as 'regional gateways' with the hinterland of peripheral cities.
Suburbanisation, however, was at its infancy during this period. Schmal (2003, p.43) believes that at this stage "the most significant role of the railway was not in the internal reorganisation of city functions as such, but rather in hastening the process of suburban extension and segregation." The gradual construction and expansion of the railway routes had a major influence on stimulating and strengthening the trend towards further suburbanisation. As we see in the following section, with new opportunities brought along with the rail, the paradigm of living close to working place will finally change.

Railways and early suburbanisation: 1900-1940

Continuing growth until the WWI

Economic growth increased considerably in the beginning of the 20th century. The government's plan for a spatially integrated railway network continued and was accomplished by 1915. Though the length of the network peaked by 1940, there was no major change in the basic structure since 1915, as could be expected on the basis of the investments made in this period (van der Knaap, 1978).
Following the trend starting in the late 19th century, mainly smaller local railways were realized during this period. Such railways were also constructed in what we call now the Green Heart, during 1910s which did not flourish and were closed later on. So, a substantial development of the railway network took place until the first world war. On top of that, a shift from steam to electricity and diesel power took place. During the first

decade of 20th century the first electric tram (1900) and electric rail (1908) started operation. The first world war necessitated the electrification of most railways and strengthened the role of the government in railroad matters (Cavallo, 2007).

Development of modern industrialisation outside the cities,

Around the turn of the century the local railways particularly provided access to the factories which, thanks to the new connections (direct or via tramlines), expanded rapidly. However, the structuring role of the railway in the location of the industry was problematic from a spatial point of view as it promoted the spreading of the industry (Dijksterhuis, 1984).
Thus industry concentrated in factories located mainly in or near bigger cities. These modern industries were not dependent on the traditional set of locational factors. Previously, companies mainly looked for waterways to locate themselves, but now they could benefit from the access to both waterways and railways. Furthermore, they used electricity and later on trucks which made them more flexible in their choice of location (Dijksterhuis, 1984, Smidt, 1987).

Commuting: for workers and for the wealthy

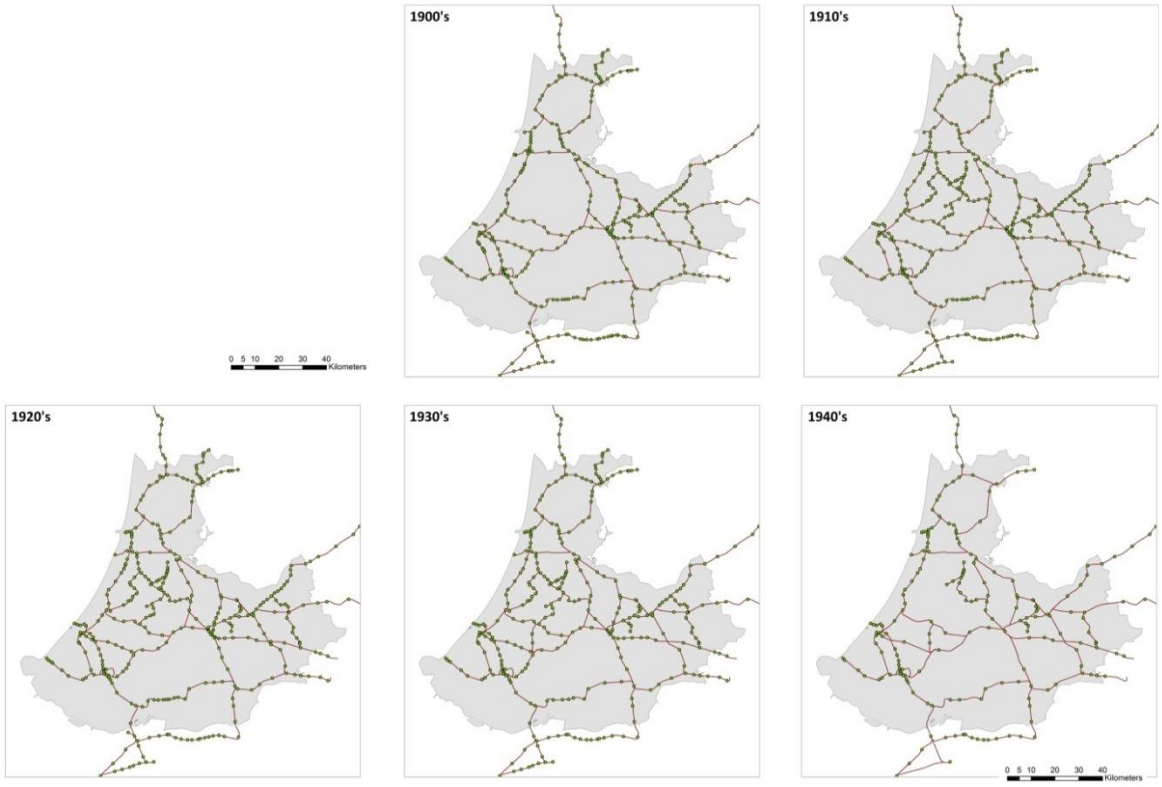
Following the dispersal of the industry in and around bigger cities, many people moved to the cities where they had found work in commerce or industry. Employees lived sometimes in residential areas built by the industry owners. In the meantime, authorities in the villages attempted to keep the factory workers in the village community and thus slowed down the migration towards the cities. The railway companies contributed to this by establishing stations on the railway lines towards the city. The factories also promoted this working commute by compensating travel costs (Dijksterhuis, 1984). Later on, the local railways with their many stops strengthened the opportunity for commuting of workers towards regional centres.
Thus the centuries-old paradigm of living close and within walking distance of one's working location changed. Undoubtedly along many other factors, the easy travel opportunity which was provided by the railways contributed to this early suburbanisation. Later on, the road transport, i.e. the bus as well as the private car, entailed a much more diffused commuting pattern. However till 1925 or around that time, commuting was entirely a matter of rail transport (Dijksterhuis, 1984).
The railway brought along another sort of commute with a much different nature: the commute of the well-to-do between their work in the city and their houses outside in the countryside. When made accessible by rail, people started to leave the big cities to green residential areas located in the sandy grounds. The train had the monopoly in (public) passenger transport outside the cities from around 1875 till 1925 (Dijksterhuis, 1989), and brought along early commuting and suburbanization. This situation however was soon to be changed with the rising power of the road transport.

Between the wars, increased competition with vehicular road traffic

In 1937, the existing railway companies were merged into the national railway company, NS. In the two decades between the World War I & II, the train's competition with road traffic increased. The need to compete with the ever-increasing road traffic (cars and buses), plus the war and the economic crises were reasons for the railway companies

and later the NS to encounter heavy financial losses during this time (mainly after 1917 and 1933) with the exception a few financially good years (Annema and van Wee, 2009). The already weak local rural tram disappeared and NS was forced to revise the service concentrating on long-distance travel. In order to counter the financial loss, NS opted to reduce the frequency of service on regional lines. A reduction which caused the closure of many (around 150) stations (Cavallo, 2007). In the meantime roads improved and bus services became available, sometimes as a replacement of trams, but also as a completely new link between villages and their service centres. These buses became rivals for local railways, which were often no match for them. In 1939 hundred kilometres of railways were already closed for passenger transport, and it seemed that this trend was to be continued. Under such conditions eventually there were no more plans for the development and expansion of the railway network (Dijksterhuis, 1989). This downturn is depicted clearly in Figures 3 and 6.

Fig 3.The development of the railway network from 1900s to 1940s



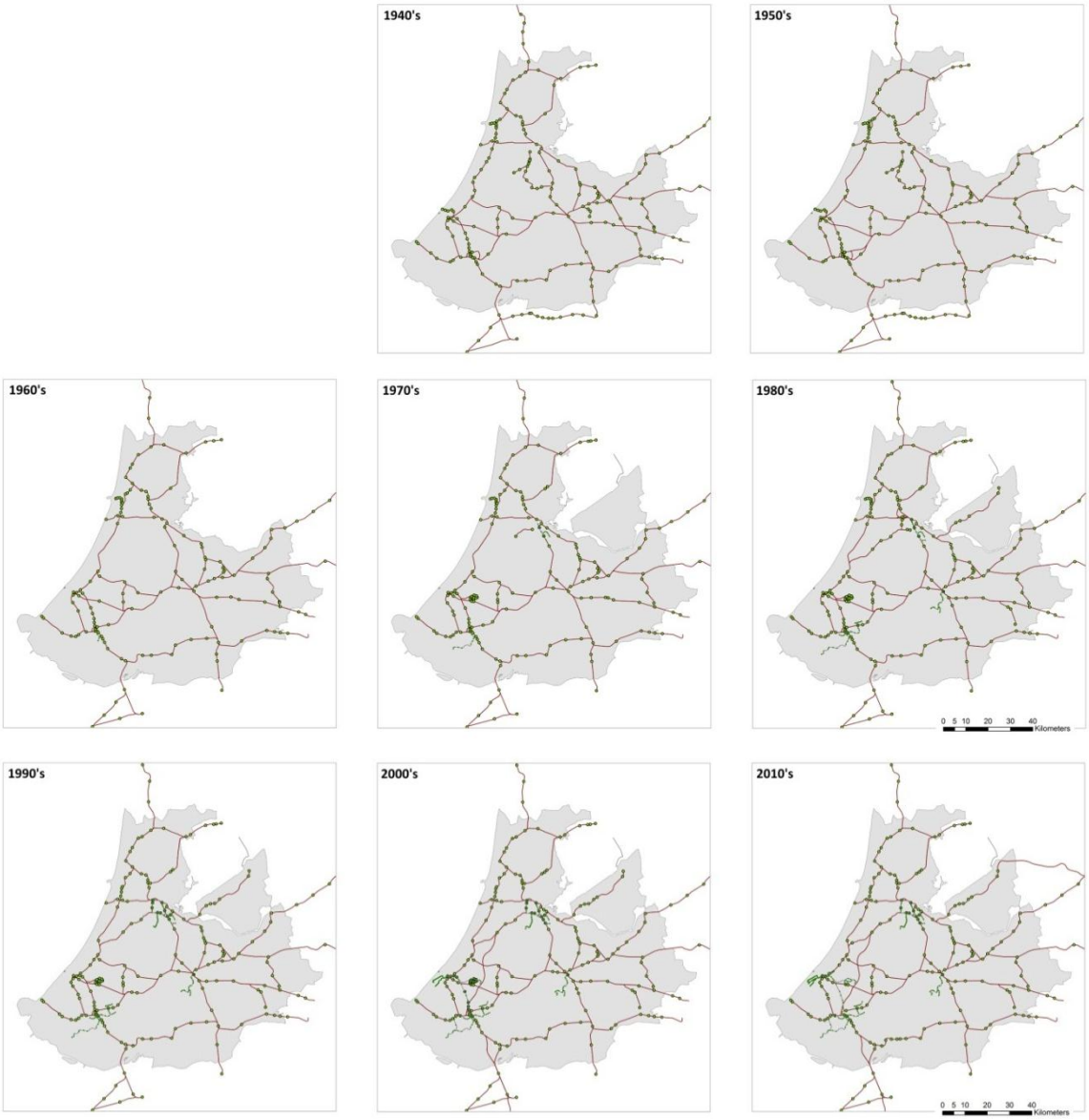
Railways versus motorways: 1940-1980

1950s and 60s, the post-war boom

The era starting after the WWII was characterised by sharp economic and demographic growth. The population explosion that took place increased drastically the need for new housing and consequently city expansions. A shift from employment in industry to employment in business and personal services was taking place which led to the fast growth of the service sector. Dual incomes were increasing as well. Though battered from the WWII, the railway network became completely operational by the end of the 50s. A considerable renovation of stations took place between 1945 and 1960 (Cavallo,

2007). Yet the railway network shrank in length and number of stations till 1960 (see Figure 6).

Fig 4.The development of the railway network from 1940s to 2010s



At the same time the road network was improving fast. Driven by economic and population growth, a new round of industrialization and an increasing welfare, the ownership and use of private vehicles (first mopeds and shortly afterwards cars) surpassed the use of train and other means of public transport (Dijksterhuis, 1989, Annema and van Wee, 2009). New roads and parking places increasingly attracted new road transport. The growing demand for the car use was further supported by the government who constructed and improved the trunk roads. Within cities and villages changes were made to fit larger roads and around large cities peripheral roads were built (Annema and van Wee, 2009).
Contrary to this overall growth, the NS closed down some less profitable lines and focused on applying higher frequencies, improving comfort, connections and rapid

electrification of the main lines. Furthermore, station squares turned more into multi-modal nodes, weaving pedestrian, bicycle and road traffic together. Till the end of Fifties obviously there was no intention to expand the size of the rail network (Dijksterhuis, 1989).
During this period the urbanization continued in form of large urban expansions in order to house the population growth. From the spatial as well as socio-economic perspective, everything was to the benefit of the car use: the increased distance between residential and work location, the sprawling suburbanization at the higher scale and the composition of the living areas influenced by 'modern' town-planning (C.I.A.M. modern movement) at the lower scale. Contrary to the railway, the car caused a much more diffused pattern of commuting, which led to massive suburbanization. This new type of commuting differed from the earlier one in the sense that it was not confined to public transport nodes anymore (Dijksterhuis, 1989).
Moving away from its passive role in the 40s and 50s, NS finally became actively involved in planning during the 60s. It shifted its policy from prioritizing the connection of larger cities to linking suburbs and growth centres to the existing railway network when possible (Dijksterhuis, 1989). Furthermore, by the end of 60s large cities invested in reinforcing and development of their internal public (rail) transit. Rotterdam metro started its operation by the end of 1960s. Amsterdam's metro and later on Utrecht's fast tram followed in the 1970s and 1980s.

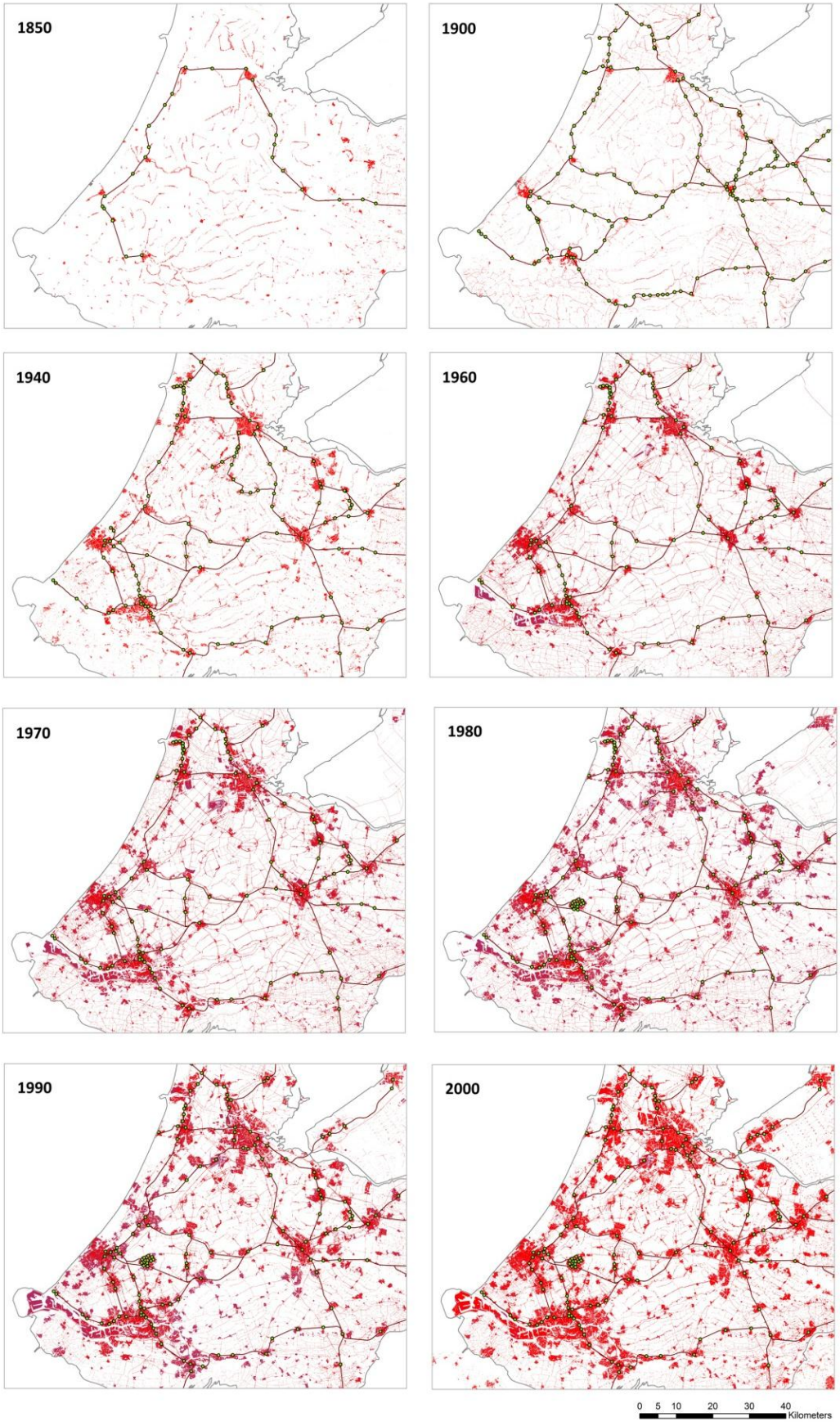
1970s and 80s

Due to the lack of space, we do not discuss the developments since the 1970s as there are loads of literature on these decades (e.g. Maat, 2012).

3. Data

For the empirical study of the evolution of the railway network and the built up areas, a unique database was constructed in a GIS environment, bringing together various sources for both topics throughout time (Figure 6). Sources for the built up area include maps from the series OverHolland, Architectonische studies voor de Hollandse stad, made available to us by the Mapping Randstad Holland group of the Delft University of Technology. They illustrate the existing built up areas (excluding the transport network) in the years 1850 and 1940. Furthermore, we use Historical Land Use Maps of the Netherlands (Historische Grondgebruik Nederland, HGN). These raster-based maps were provided by the University of Wageningen for the years 1900, 1960, 1970, 1980 and 1990. The database also includes the Existing Land Use dataset (Bestand Bodemgebruik, BBG), produced by the Dutch Central Bureau of Statistics (Centraal Bureau voor Statistiek, CBS) and The Netherlands' Cadastre, Land Registry and Mapping Agency (Kadaster). These vector-based maps include a series of digital geometry of the Dutch land use starting from 1989 issued every three to four years. While in the database, these maps were not yet used for the analysis at this stage.
We used various data sources for the development of the railway network and stations. Most of them are open source, but merged and operationalized by us.

Fig 5.The development of the railway network and the built-up area in the Randstad from 1850 to 2000



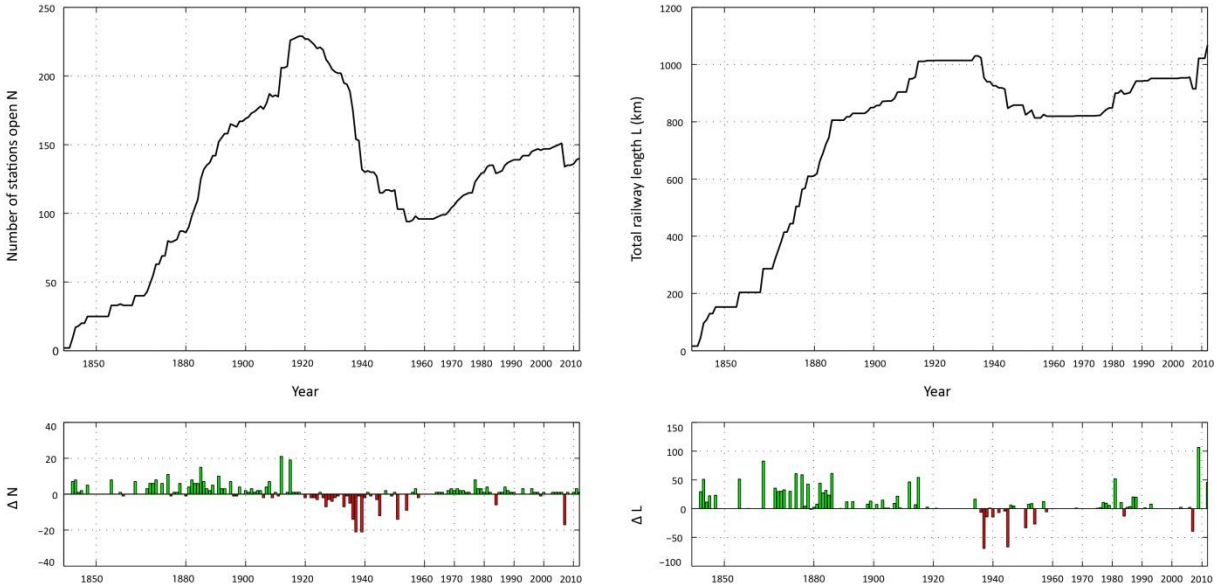
4. ANALYSES

The preliminary analyses in this section provide an overview of the development of the railway network, including railway line lengths and station numbers, and an overview of the development of the built-up area, measured as its footprint in square kilometres, in relation to the railway stations.

4.1 development of the network & stations

Figure 6 shows the development and change of the railway line lengths and station numbers in the Randstad from 1850 till present, as described in Section 2.

Fig 6. Development of the railway network (lines and stations) in the Randstad from 1850 to 1990



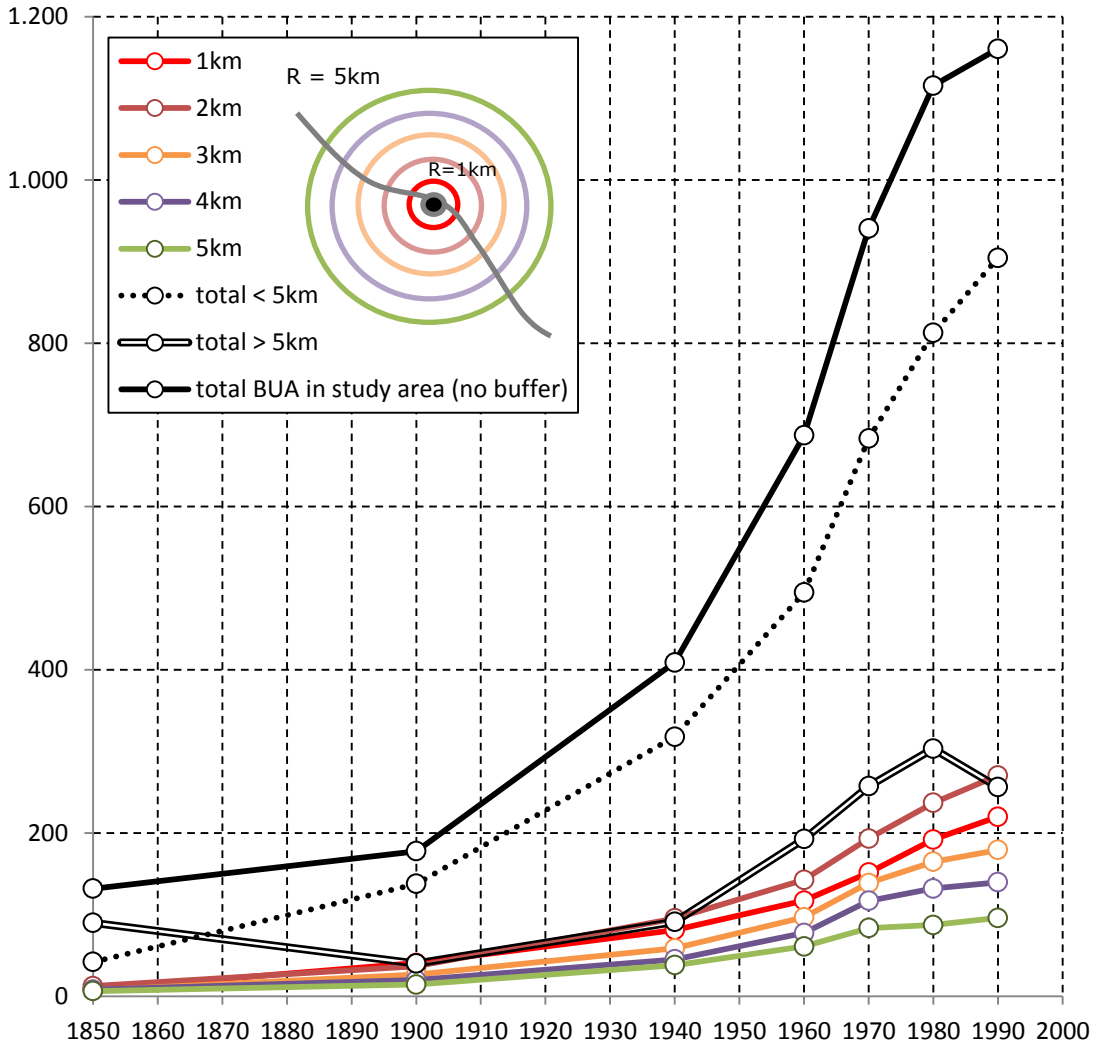
4.2 development of built-up area related to railway stations and overall built-up area

The borders of the Randstad area in this study are defined by the extent of the available historical data. This area remains the same until 1970 after which grows by 8% with the reclamation of the Flevoland province. We disregard relatively smaller changes such as the reclamation of Haarlemmermeer polder at the very beginning of our study period or the gradual development of the Rotterdam harbour in the course of the 20th century. In order to compare the amount of built-up area (BUA) with respect to the distance to railway stations, ring-buffers with intervals of 1 km are generated for the existing stations in seven points in time. Thus for years 1850, 1900, 1940, 1960, 1970, 1980 and 1990 the share of the BUA within and outside certain buffers of the existing stations are calculated. The result of these calculations is presented in Figure 7.

From Figure 7 we can see that there is an increase in the total built-up area (BUA) within each time period as expected. The BUA increase shows an s-curve, as the BUA grew each decade faster than the previous one until 1970 when the urbanization slowed down. Among other factors perhaps this can be attributed to the effectiveness of policies to curb suburbanization in 60s and 70s.

Until 1900, the growth of BUA within 5 kilometers of the railway stations is slightly higher than the overall growth of the BUA. This difference is possibly due to the rapid growth of the number of stations and the fact that the suburbanization was still railway-oriented at the time. After 1900 however, the growth within that zone slows down, compared to the total BUA growth. This is because of the increasing development far away (> 5 km) from the railway stations brought along with the car-oriented suburbanization. In the last decade of the study (1980-1990), we observe once again a higher growth within the 5 km buffer form the stations than the total BUA. Not surprisingly this growth is accompanied with the decline of the urban growth in the >5 km area at the same time.

Fig 7. Development of the built-up area in total and within different station buffers



During the era between 1850-1900, most urban development was in the first ring around the railway stations. After 1900, the greatest development was in the 1 to 2 km ring, suggesting that most of the space around the railway stations was already in use by urban uses. On the other hand, it is clear that development occurred close to railway stations, as development occurred less on longer distances from the stations.

The following tables present an overview of the BUA within the various station buffers in relation to the total area of the buffers (Table 1) and the total BUA in the study area (Table 2) at seven points in time. Table 1 shows to what extent rings are covered with the built-up area. For example, in 1990, on average, 57% of the first ring around stations and 25% of the area within 5 km is covered by built-up area. The zone outside the 5km ring was only urbanized for 8%. In that year, 17% of the entire study area was covered by BUA.

Table 1. Share of BUA per buffer

Share of BUA in per buffer	1850	1900	1940	1960	1970	1980	1990
1km	11%	9%	24%	43%	49%	55%	57%
2km	6%	4%	12%	22%	28%	31%	32%
3km	2%	2%	6%	12%	16%	18%	18%
4km	2%	2%	5%	9%	14%	15%	14%
5km	2%	2%	4%	8%	11%	11%	21%
total < 5km	3%	3%	8%	15%	19%	22%	25%
total > 5km	2%	2%	4%	6%	8%	9%	8%
total study area (no buffer)	2%	3%	6%	11%	14%	16%	17%

In Table 1 we notice that while the total amount of BUA was higher in the second ring (Figure 7), a lower percentage of this ring was covered with BUA compared to the first one. This is because the area of the first buffer is a circle with just π = 3.1 sqkm, while the second buffer which is a ring has an area of three times more, 9.3 sqkm. So the ratio of the BUA to the buffer area is less.
In all the buffers the share of the BUA increases with time. The exception is the 1900 when this share is lower in the first two rings and stays the same in the others. The cause is probably the higher number of stations in this period which means a larger buffer area and thus a decreasing share of the BUA.
The growth in the share of BUA per buffer and in total BUA continues with a slower pace after 1960. An exception is the share of the BUA in the 5 km ring which almost doubles in the last decade of the study.

Table 2 presents the share of BUA within station buffers in the total BUA of the entire study area in each year. Herewith we can compare the growth in the different station buffers to the overall growth in the Randstad.

Table 2. Share of BUA within buffers in total BUA of the study area

Share in total BUA entire study area	1850	1900	1940	1960	1970	1980	1990
1km	6%	23%	20%	17%	16%	17%	19%
2km	9%	21%	23%	21%	21%	21%	23%
3km	6%	15%	14%	14%	15%	15%	15%
4km	6%	11%	11%	11%	12%	12%	12%
5km	5%	8%	9%	9%	9%	8%	8%
total < 5km	32%	77%	78%	72%	73%	73%	78%
total > 5km	68%	23%	22%	28%	27%	27%	22%
total study area (no buffer)	100%	100%	100%	100%	100%	100%	100%

Comparing the growth of the BUA in different buffers to the overall BUA of the study area we can see that in 1850, the share of BUA within station buffers in total BUA is rather low in all rings. This is because the rail network is just established and the number of stations are still limited. Later on with the development of the rail network and the increase in number of stations, the share of BUA within station buffers in overall BUA increases. Rings 3, 4 and 5 are rather stable since 1900. The BUA outside the 5km buffer has a high share in total BUA in 1850. This is because many cities do not have a railway station at this stage. In the next two periods however, only near one fifth (23% and 22% in 1900 and 1940) of urbanized area is outside the reach of a station. Later on the contrary, the share of BUA increases outside 5 kilometres from the railway station (28% , 27% and 27% in 1960, 1970 and 1980) at the expense of the BUA within the 5 kilometer range. Here we witness the rise in developments within suburbs. In 1990, although in the pre-VINEX era, the 'old' situation is restored.

When observing the relationship between the development of BUA and railway stations throughout time, it is important to keep in mind the changes which happen in the stations' accessibility. For instance, in 1850, it was not easy to bridge distances more than 1km from the station, as there were no bicycles and other public transport was poor. This accessibility improved over the course of time.

At the turn of the century the local and regional trams complemented the railway network and increased access to its stations. Later on bus, metro and light rails sought their stations at railway nodes, increasing their accessibility further. Thus certain railway stations became multi-modal nodes with higher accessibility and catchment areas than their previous counterparts. Furthermore changes in the direct station environment such as provision of parking places for cars and bicycles added to the ease of access. Another issue is the rise in service frequencies which also made the stations more accessible. The difference of growth between intercity and other stations with this respect is interesting.

While the transport network structures the built-up area, it is in turn closely influenced by its development. Within this interrelation, the structure of the urban cores in terms of mono- or polycentricity plays a role. For instance in 1950s and 1960s, urban public transport connected neighbourhoods and railway stations quite well, partly because of the many public transport services and partly thanks to the relatively mono-centric urban structure at the time. This deteriorated after the 1960s, as many services were terminated, and the urban structure became more polycentric.

5. Conclusions

This paper set off to analyse the extent of the relationship between the development of the built-up area and the expansion of the railway infrastructure in the Randstad during the period 1850 to 1980. The development of railway network (railway lengths and station numbers) more or less followed the same trend: growth and climaxing by 1920, deterioration in 1930s to 1950s, and a period of stabilization around 1960s before redevelopment, though at a slower pace, from 1970s to present. Nevertheless the station numbers experienced more variation than the railway length. The growth of the railway network was highly associated with the growth of the built-up area. As could be expected, the development started very close near the stations, but during the course of time, development increased farther away from the stations.

This study was only a very preliminary one. Further investigations will include the two decades beyond 1990. Moreover the role of the competition and complementarity with the auto network will be analyzed, as well as the influence of lightrail and tramways. Attention will be given to effects of changes in accessibility to and from the railway network on the growth and structure of the built-up area. This accessibility will be investigated from various view points including the role of network integration degrees, the role of multimodality and frequency. Finally, we aim to give attention to the population density of the built area.

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