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

Dena Kasraian
TU Delft, Faculteit Bouwkunde
d.kasraianmoghaddam@tudelft.nl

Kees Maat
TU Delft, Faculteit Bouwkunde en TBM
c.maat@tudelft.nl

1. Introduction

Infrastructure development, urbanisation and travel behaviour interact with one another. 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). While empirical research on the relationship between the built environment (also referred to as 'land use', or 'urban form') and travel behaviour is abundant, the interaction between the built environment and infrastructure development is investigated to a lesser extent. When this interaction is investigated, the focus is usually placed on the impact of the built environment, as the embodiment of spatial division of human activities, on transport, rather than the reverse impact (Dieleman and Wegener, 2004), or their interaction. Moreover usually the effect of single infrastructure projects are investigated in before-after studies rather than the development consequences of a large-scale infrastructure network. Only a few studies focus on long-term empirical data analysing the development of infrastructure network and the built environment simultaneously. This study adds to the latter category.

A key question in urban studies is the interaction between the growth of infrastructure networks and the growth of the urban area. When it comes to the long-term empirical analysis of this interaction, certain dependent variables are investigated, usually treated as the outcome of infrastructure development. These variables include regional-economic development, land/property values, accessibility, population density and the redistribution of urban functions such as jobs and housing at a variety of spatio-temporal scales. First, a large part of the existing literature is dedicated to the relation between the transport infrastructure and regional-economic development. Here from the viewpoint of economic geography, the impact of mainly large scale transport infrastructure such as highways or high-speed rails are investigated on economic changes at a regional scale, usually in form of before-after analyses of aggregated data (Rietveld and Bruinsma, 1998, Banister and Berechman, 2000). Second, there is another strand of literature looking at how infrastructure affects nearby residential or commercial real-estate (land/property) values (Huang, 1994). Third, a group of researchers have measured the changes in accessibility as a result of changes in the infrastructure's network and its consequence for accessible population or population density within buffers of the infrastructure (Erath et al., 2009, Axhausen et al., 2011, Koopmans et al., 2012). Looking at the composition of population in detail, some researchers have distinguished between working and residential populations and investigated the redistribution of urban functions such as job-housing in time, linked to the growth of transport infrastructure (Cervero and Landis, 1997, Baum-Snow and Kahn, 2005, Levinson, 2008).This article belongs to the last strand of research. Here, most studies investigate association between infrastructure development and population change (Koopmans et al., 2012, Levinson, 2008). This explains the dispersion of people, which can be seen as a proxy for land use. The present study, however, aims to explain the interaction with urban land use (Built-Up Area, BUA), itself. Thus we analyse the change in accessible BUA in relation to the change in infrastructure. In order to do so, we use multiple cross-section data on the BUA's footprint (as a proxy for urbanisation) and transport network development, namely the rail network.

As in many other cases, in the Netherlands, a main reason for the lack of long-term studies on the interaction of the built environment and infrastructure 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 2010 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. We follow the changes in the railway and urbanisation until the turn of the century where the urbanisation growth relatively slows down and returns to the vicinity of rail stations (1990-2010).
The paper demonstrates that the railway network first adjusted itself to the existing built-up area. Afterward it was associated with further urbanisation, starting with the impact of railways on a relatively concentrated urbanisation, but later was surpassed by tendencies of urban sprawl, initiated by the car and the motorway system. At the turn of the century however the total trend of urbanisation slowed down and returned to the vicinity of the rail once again.
The rest of this paper is structured as follows. In section 2, we describe the developments on the basis of the historical literature. Section 3 briefly discusses the used data. The fourth section encompasses our GIS-based analyses. In the final section we discuss the conclusions of our analyses which are explained with the help of theory and historical background.

2. History

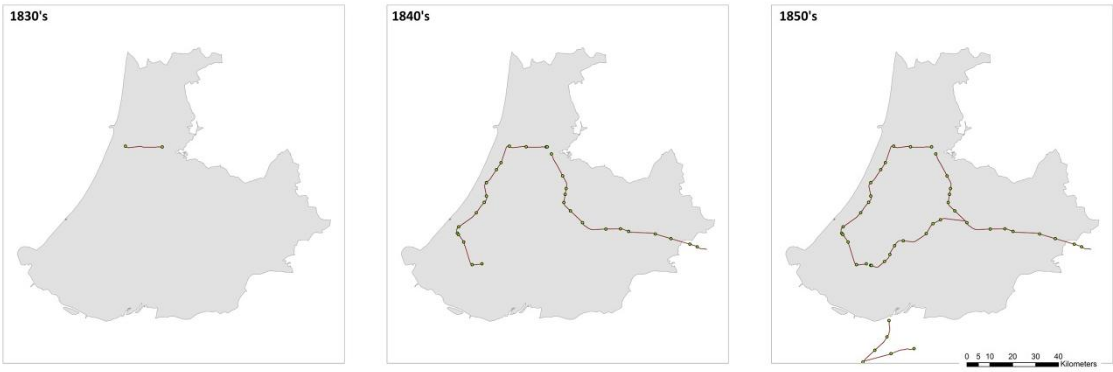
The development of railway infrastructure and urbanisation are discussed within four time frames in this article: 1850-1900, 1900-1940, 1940-1980 and 1980-2010. We describe the development of the railway network in the context of that era and add some words of the development of the urban area.

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

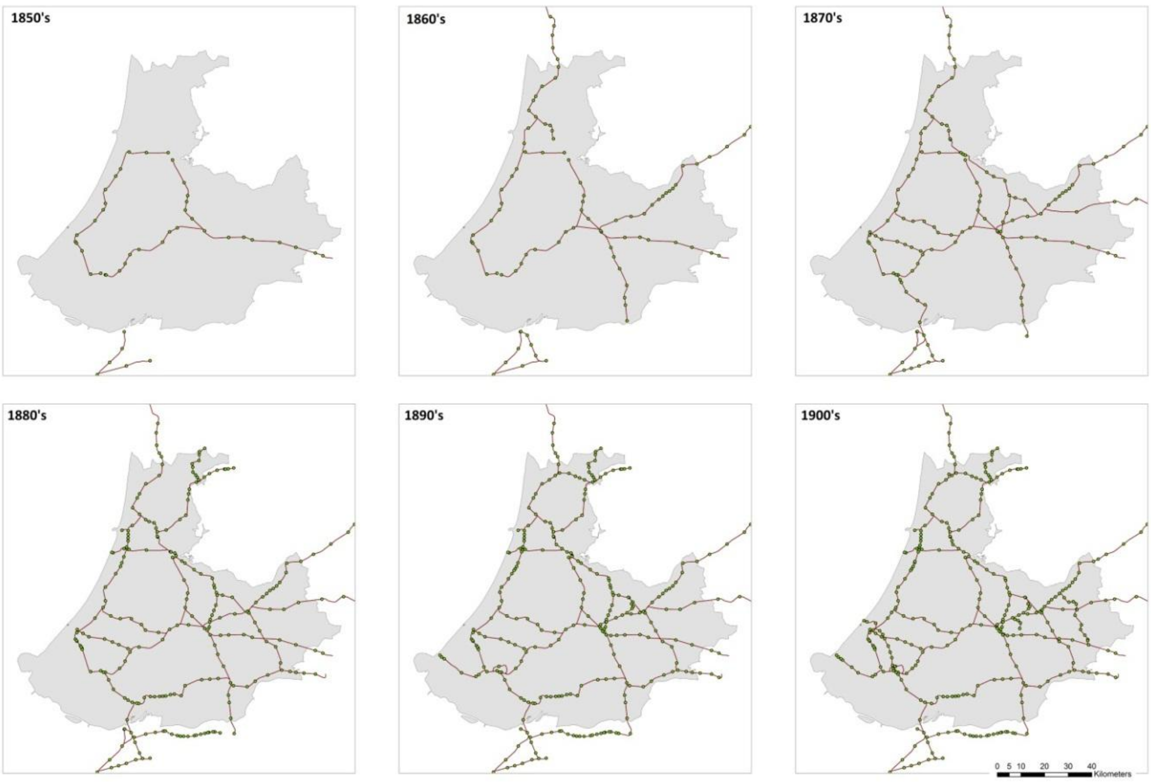
The industrial revolution started rather late in the Netherlands, between 1850 and 1890, resulting in demographic and economic growth in the second half of the 19th century, accompanied by migrations to cities where most of the industrialisation was happening (Schmal, 2002). There is not a consensus on the booming 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 frequency of service 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).

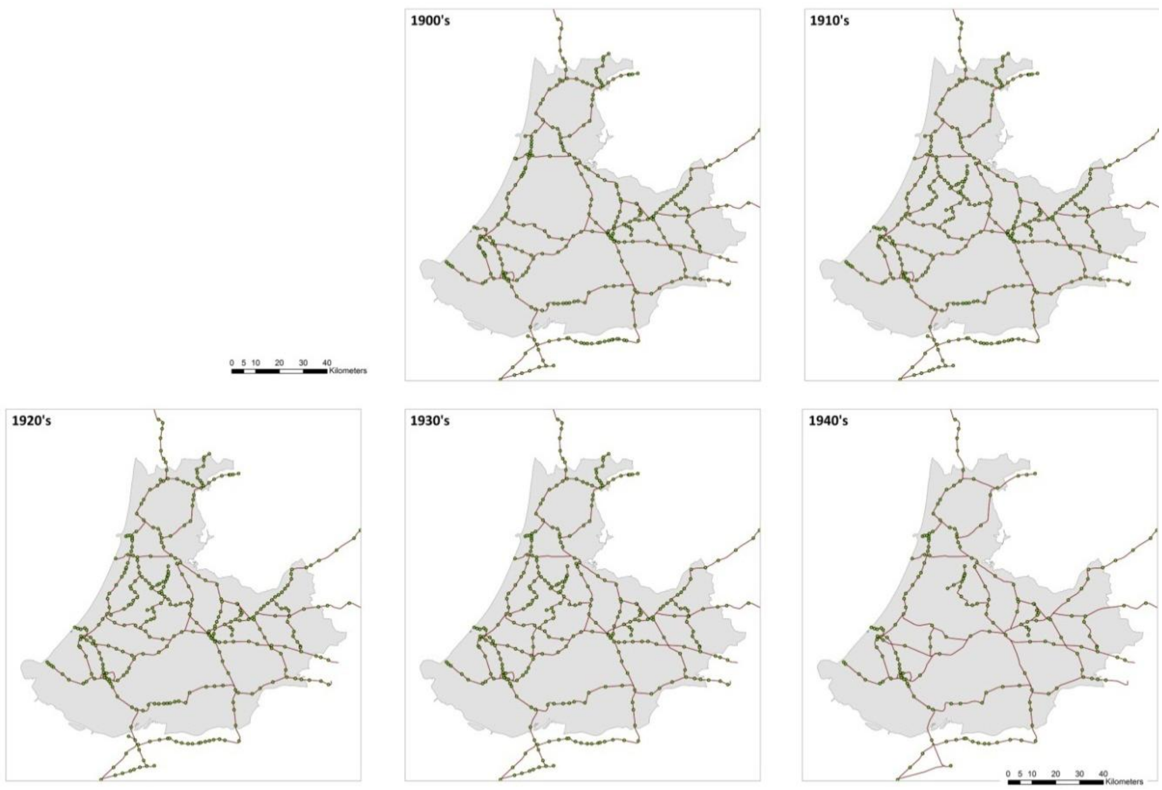
Commuting: for workers and for the wealthy

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 suburbanisation. 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

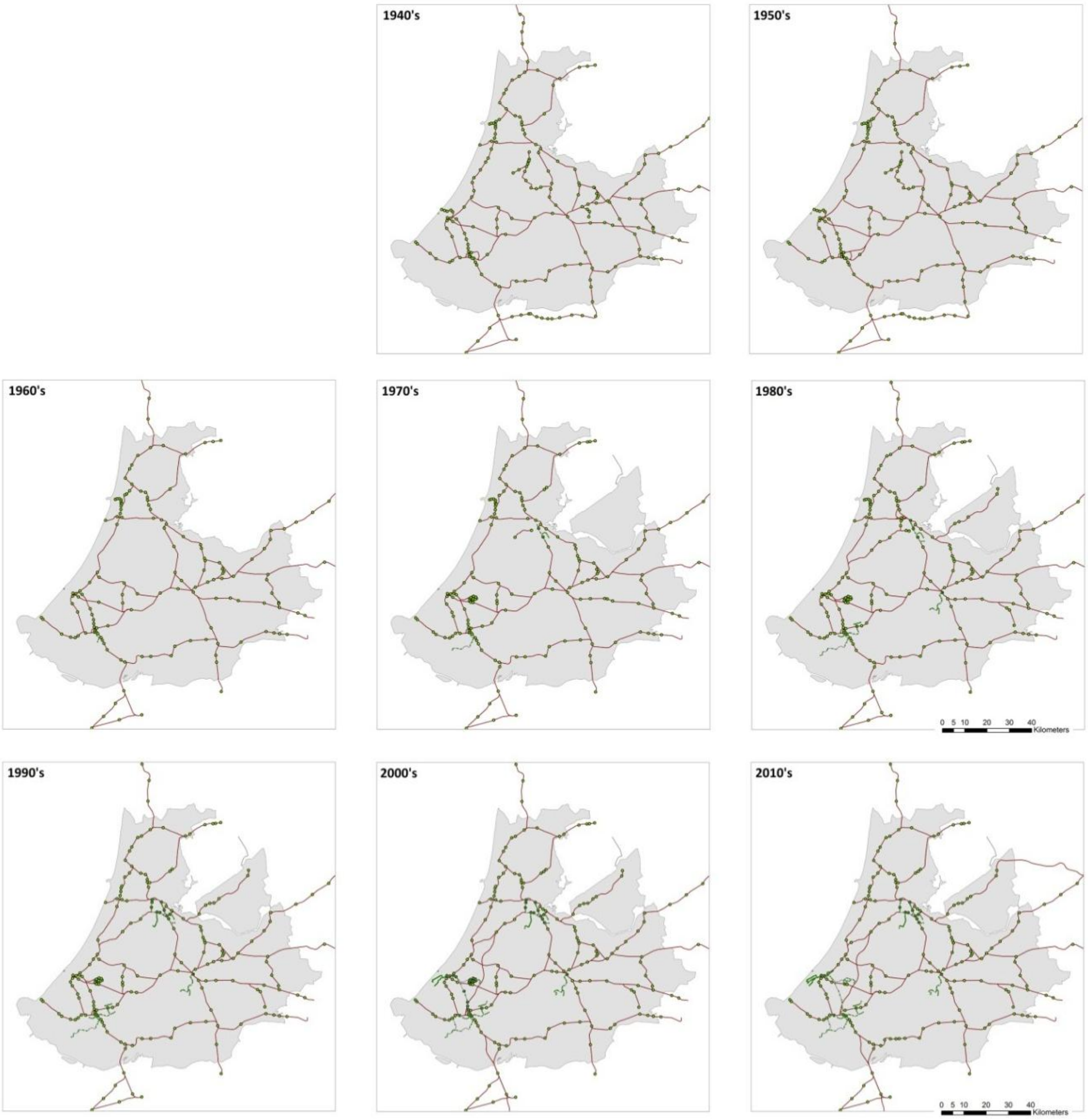


Railways versus motorways: 1940-1980

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 urbanisation 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 suburbanisation 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 suburbanisation. 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.

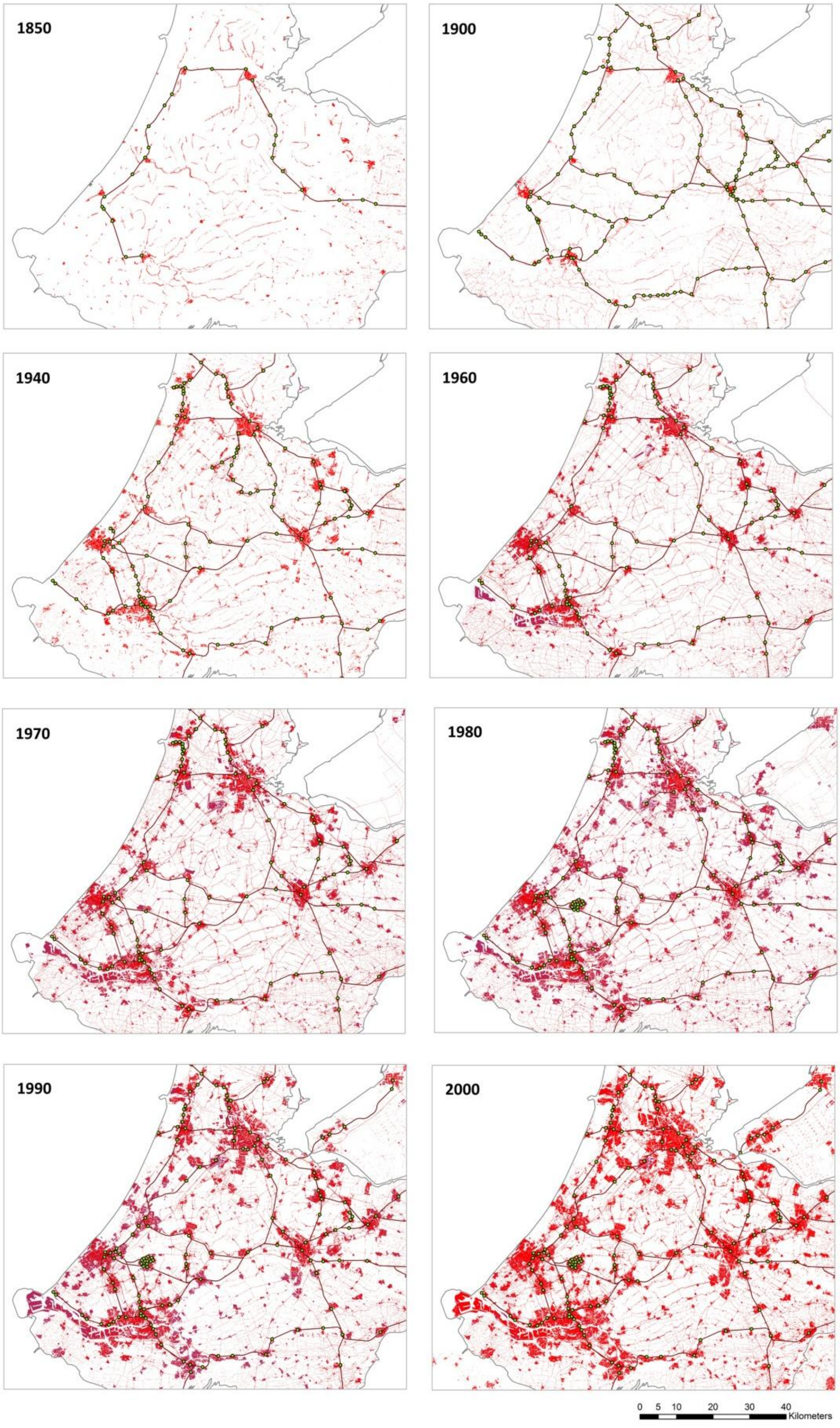
An era of planned development: 1980-2010

This time period is outside our focus on the historical background, as the developments during this time period are covered by many studies (e.g. Dieleman & Wegener, 2004, Geurs & van Wee, 2006, Maat, 2012).

3. Data

For the empirical study of the evolution of the railway network and the built-up area, 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



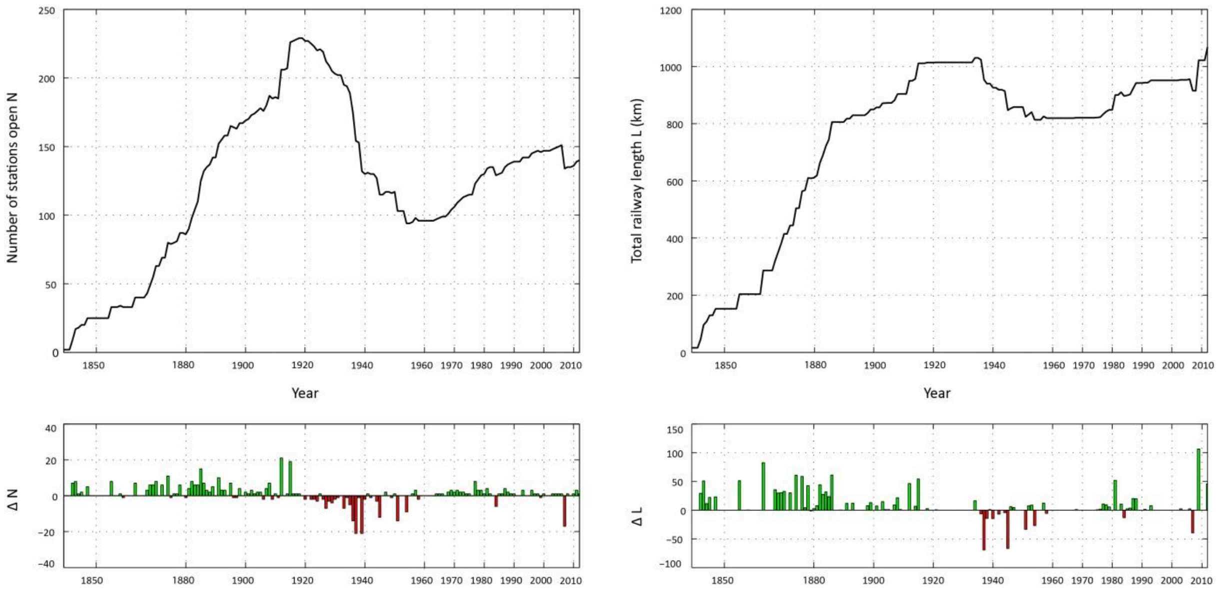
4. ANALYSES

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 2010

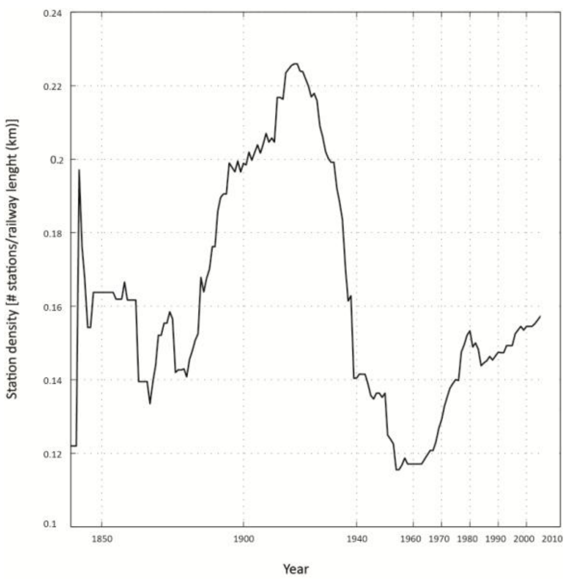


In the beginning we observe a rapid growth of the *railway lines* especially during 1860-1890, the so-called railway boom period. This growth continued with a slower pace and stabilised by 1920. After more than a decade of no change, the closure of the lines started in mid-1930s with a number of lines earlier built in the 'green heart'. The shrinkage of the total railway length continued during and after the WWII until it reached a stable state in around mid-Fifties. After that for nearly two decades the railway length stabilised. It is only in the mid-Seventies when we observe a new impetus in railway development once more with the addition of new railway lines since 1930s. In the decades that followed mainly lines for linking and reinforcing new developments such as the Zoetermeer Stadslijn, the Schiphol line and the Flevoland line were added. In the 2000s, the main changes were the shift of the so called 'Hofpleinlijn' from a railway to a lightrail track and the construction of the high-speed railway, linking the four large Randstad cities to Belgium and Germany in the South and the East. Not included is the Betuwelijn, which is limited to freight transport. We also left out the lightrail tracks, which are somewhere in between ordinary tramways and heavy rail.
Similar to the growth of the railway lines, the number of *railway stations* grew quickly in the early days. This growth was faster than that of the railway lines in the last decades of the 19th century and the beginning of the 20th century, resulting in a drastic increase in the station density (ratio of stations to lines).The rise in the number of stations during

the two first decades of the 20th century was due to the addition of many smaller, mainly local stations. The number of stations finally peaked around 1920. After this point in time we witness a decline which gained a fast pace during the 1930s (and WWII). The stations’ decline stopped and entered a stable phase in the Mid-Fifties before their numbers rose again in mid-Sixties. This rise continues relatively slowly till the present day with two exceptions: the addition of Zoetermeer Stadslijn stations and the switching of the aforementioned stations plus Hofpleinlijn stations in 2000s to lightrail stations.

Not surprisingly, the development of railway lines and stations both follow the same trend more or less: 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. A more detailed comparison nevertheless reveals that the number of stations is quite volatile and experiences more variation than the line lengths, probably because it is easier to start, close down or move a station than a railway line. This instability results in changing station densities (ratio of stations to lines) throughout time (see Figure 6b).

Fig 6b. Changes in the station density (ratio of stations to lines)

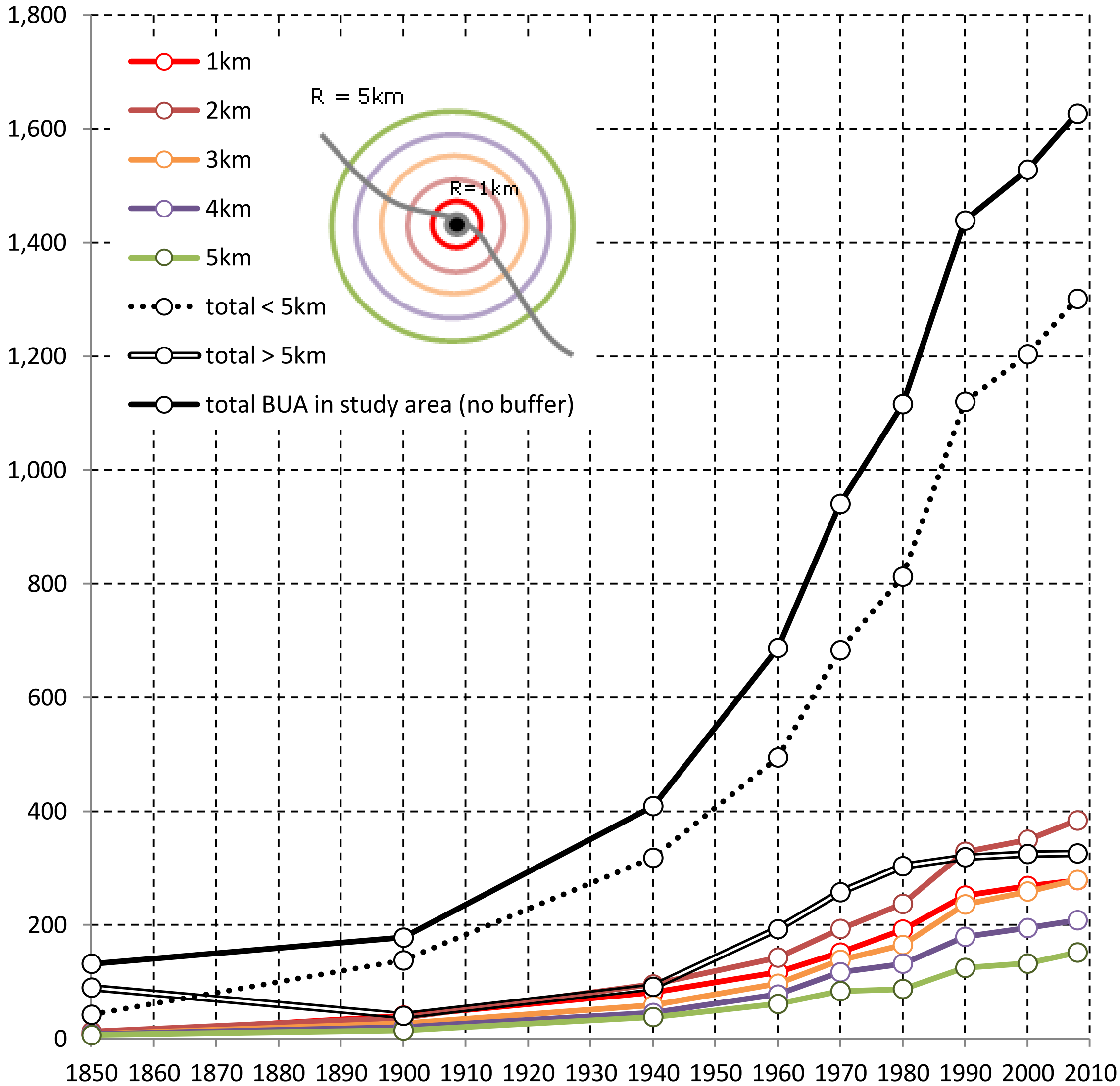


This ratio experienced a rapid increase at the turn of the century and even a more rapid decline from 1920 to 1950 before it started its relatively steady growth once again from 1960s to now. A conclusion can be that, after periods of drastic change, the railway network is becoming more homogenous regarding the distance between its stations, a distance which is becoming less and less with further network growth.

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 it 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 at nine points in time. Thus for years 1850, 1900, 1940, 1960, 1970, 1980, 1990, 2000 and 2010 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.

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

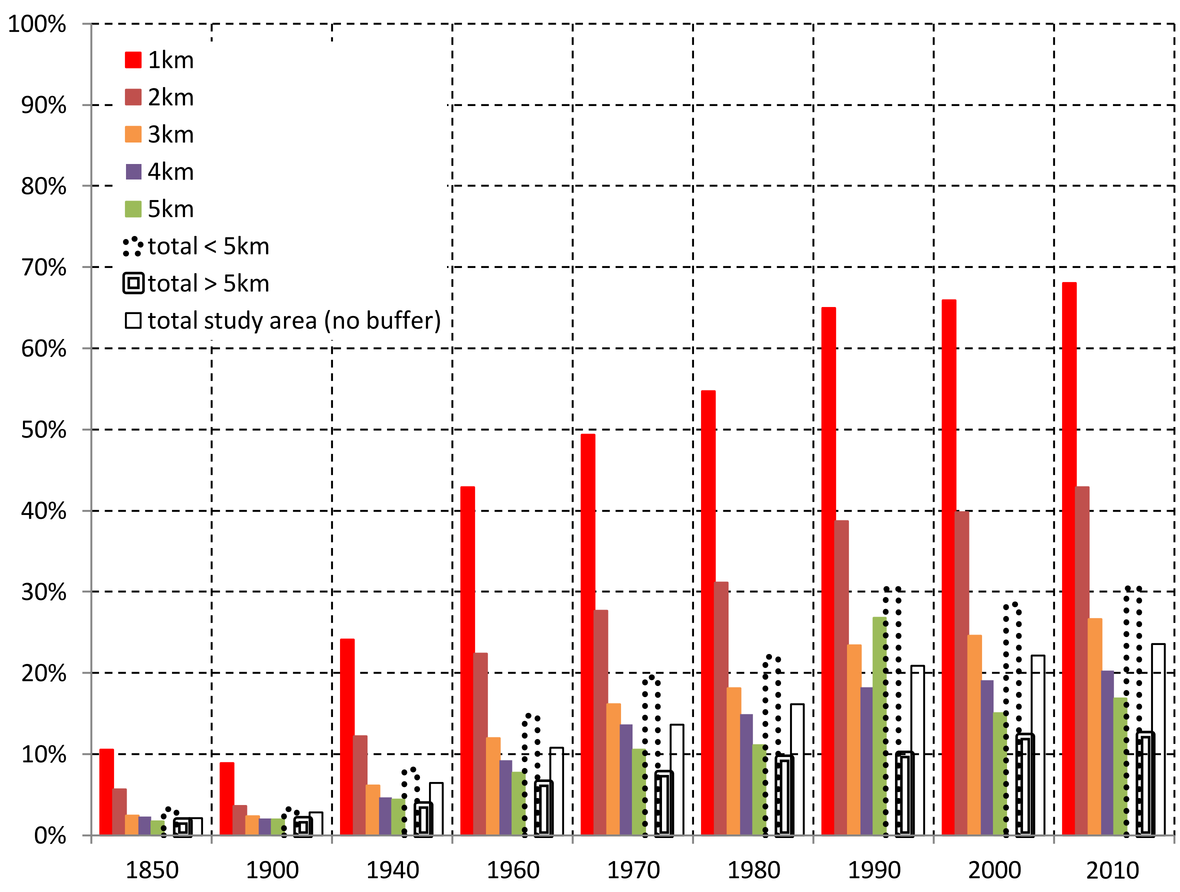


From Figure 7 we can see that there is an increase in the total BUA within each time period as expected. The BUA grew each decade faster than the previous one until 1990 when the urbanisation slowed down. Among other factors perhaps this can be attributed to the effectiveness of policies to curb suburbanisation before the 90s.
It is important to note that in our analysis the urbanisation is measured mainly based on two separate databases (the *Historische Grondgebruik Nederland, HGN* and the *Bestand Bodemgebruik, BBG*). We suspect that the actual extent of urbanisation change around 1980, when we shift from one dataset to another, might be overrepresented due to differences in measurement of the built up area. Further investigation into the comparability and consistency of the two datasets is needed before we can draw precise conclusions on the degree of this change. Nevertheless we use the existing outcome at this stage to explain the general trend of increasing urbanisation in the past century.

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 suburbanisation 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 suburbanisation. Since 1980s we observe once again an increase in the BUA growth within the 5 km buffer form the stations which makes it comparable to the total BUA growth. Not surprisingly the urban growth in the >5 km area stops increasing and stabilises during this period.
Between 1850 and 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 figures present an overview of the BUA within various station buffers in relation to the total area of the buffers (Figure 8) and the total BUA in the study area (Figure 9) at nine points in time. Figure 8 shows to what extent rings are covered with the built-up area. For example, in 1990, on average, 65% of the first ring around stations and 30% of the area within 5 km is covered by built-up area. The zone outside the 5km ring was only urbanised for 10%. In that year, 21% of the entire study area was covered by BUA.

Fig 8. Share of BUA per buffer



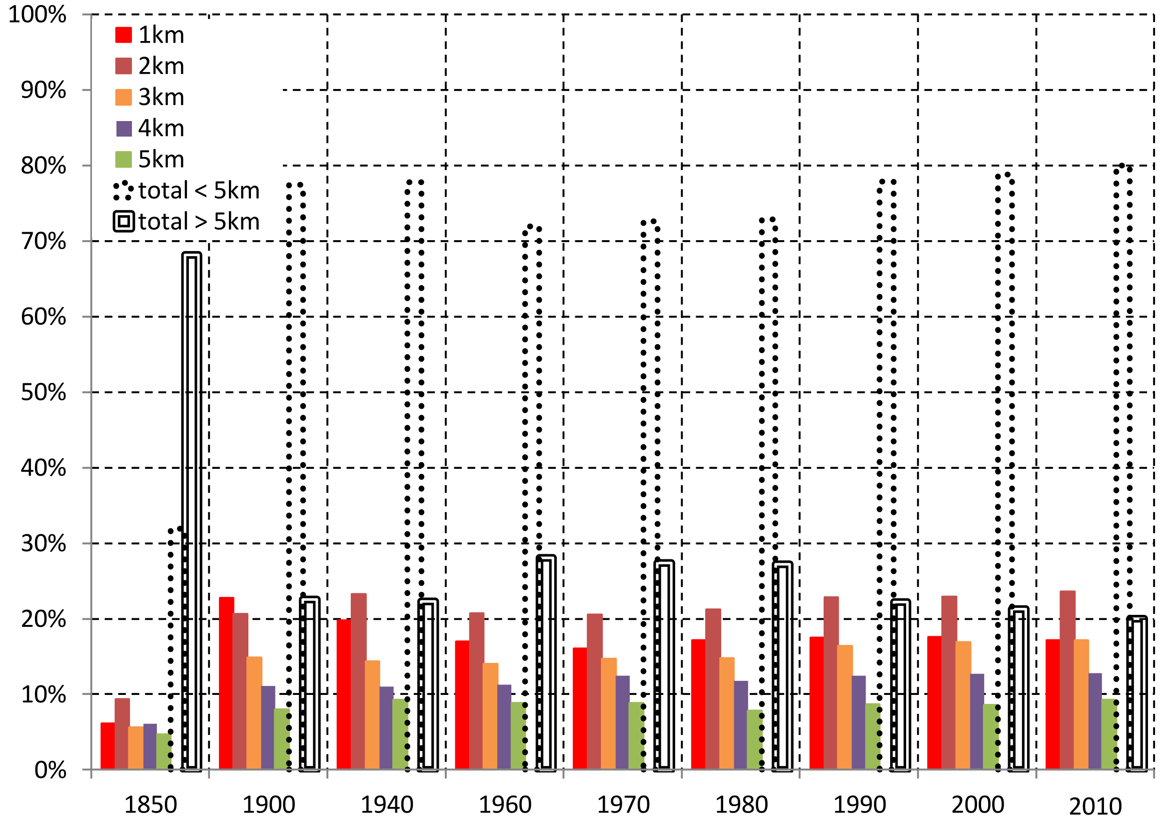
In Figure 8 we notice that while the total amount of BUA was higher in the second ring (Figure 7), a lower percentage of this ring was covered with BUA compared to the first one. This is because the area of the first buffer is a circle with just п = 3.1 sqkm, while the second buffer which is a ring has 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 1990. An exception is the share of the BUA in the 5 km ring which shows a drastic increase in the 1990s.

Figure 9 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.

Fig 9. Share of BUA within buffers in total BUA of the study area



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 is 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 the urbanised 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. After 1990, the 'old' situation is restored and the growth of BUA>5 stabilises.

5. Conclusions and discussion

Dieleman and Wegener (2004) distinguish three main theories explaining the two-way interaction between the transport and land-use: i) Technical theories (urban mobility systems), ii) economic theories (cities as markets), and iii) social theories (society and urban space). According to Technical theories, it is the technical conditions (transport technology) which guide the form and organization of urban developments. Economic theories include location costs (e.g. for firms or households) as well while social theories focus on the role of 'individual or collective appropriation of space' in shaping the cities. Here we try to briefly explain the relation of urban and transport infrastructure development based on the first two theory types.
In the very beginning urbanisation followed the main transport routes (waterways, ancient roads/pathways) obviously as it is not possible for a place to exist without a connection or link to access it. As Levinson (2008, p. 61) explains: "Transport can lead or follow land use, but land use must follow some (however primitive) transport network." The emergence of faster transport modes (train, trams, etc.) resulted in higher accessibilities and availability of land which was previously out of reach. The change form a city purely based on walking distances coupled with the removal of fortifications meant more spreading of urban development. The inhabitants were enabled to move to the periphery seeking a trade-off between the size/quality of their dwellings (which were larger and cheaper than the city centre) and the cost/time of commute to work (which became cheaper and shorter thanks to ever improving transport modes).
As new transport modes and infrastructures became available, they replaced older transport modes in existing markets. Being more efficient, they further generated additional travel. When the existing markets were exhausted they sought and moved on to new markets, which resulted in more urbanisation (Levinson, 2008).
Thus urban development is related to the transport modes and their consequent change in accessibility (Rodrigue et al., 2009) and the interplay of the demand and supply between infrastructure and urbanisation.
In this paper we distinguished four phases of infrastructure and urban development since the introduction of rail in mid 19th century. In order to link the urbanisation to infrastructure development we calculated the share of BUA per ring buffer from the railway stations at nine points in time and made comparisons between different rings and other locations in the study area (within station reach i.e. BUA<5, outside station reach i.e. BUA>5 and total BUA). It is hard to find out the exact interaction between the built environment and the rail in the past century at this stage and with the applied method. However we try to explain this interaction based on theory, the historical information presented in section 2 and the results of our preliminary GIS analysis:

1850-1900: As described in the history section, after the introduction of the rail (in 1839) train stations adjusted themselves to the existing settlements. Thus the transport followed the (existing) BUA at this stage. As the number of stations was limited at the time we see that the share of BUA within station buffers (BUA<5) is much lower than the area outside the buffer (BUA>5).
As new railway lines were added and the number of stations grew rapidly, more and more of the BUA existing in previous phase (1850) was covered by station buffers. Furthermore as the railway network grew in the absence of a competing (more improved) mode of transport, the new urbanisation happened within railway access as well. Put together, we witness a large decrease in BUA>5 in comparison to 1850. In other words, we observe a higher share of BUA<5 in 1900 than 1850. Looking at this drastic change, we can hypothesize that, the urbanisation followed transport during this period.
At this stage, we expect the BUA growth to be most within the walking distance of the station as accessibility and complementary modes are still limited. Confirming this expectation, the share of BUA decreased with further distance from the station. However, we see that second ring has a higher share of BUA in comparison to the first (with the exception of 1900 where the number of stations is highest). This is probably due to the restrictions of building in the direct vicinity of the rail station.

1900-1940: This was a period of train-led suburbanisation. During 1900-1940, BUA growth continued following the railway, still more dominant than other transport modes, and intensified around the stations built in this area. However this was partly cancelled out as the number of stations rapidly decreased in the 1930s. So the growth in the BUA within reach of stations, though more than the previous period, was less than the total BUA.

1940-1980: This was the period of post-war growth. Faster modes of transport (car) with a more flexible and widespread network (highway and road network) increased the overall accessibility. Bicycles, fast trams and metros added to the growth of accessibility. People were not solely dependent on rail anymore. On the other hand the number of stations didn't grow for a while (till at the end of this period when they slowly rose again). Consequently there was a significant BUA growth in the areas outside train station impact (BUA>5).
With the overall growth of accessibility during this period we expect more and more BUA growth in the outer rings. This total growth in the three outer rings is observable though it does not surpass that of the first two rings.

1980-2010: This period is an era of planned development which also witnessed the outcome of earlier restricting planning policies on urban development in the 60s and 70s. The urbanisation outside reach of stations (BUA>5) slowed down and stabilised in the last two decades while the development around stations increased more than before. Since the number of stations grew once again and with compact cities policy on the agenda, we observe the most growth within the reach of stations by the end of 2010.

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.

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 railways followed the existing urbanisation pattern in the very beginning, later the urbanisation developed and intensified very close to the stations. With the introduction of the car and other modes of transport, development increased farther away from the stations, before it returned to their vicinity at the turn of the 21st century.
This study was only a very preliminary one. Further investigations will include the role of the competition or complementarity with the auto network, 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 viewpoints including the role of network integration degrees, the role of multimodality and frequency. Finally, we aim to give attention to the role of planning policies for urban growth in the outcome of the interaction between infrastructure and urbanisation in the last decades.

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