Node Survivability and Dynamics of the Dutch Municipality Network

Master Thesis

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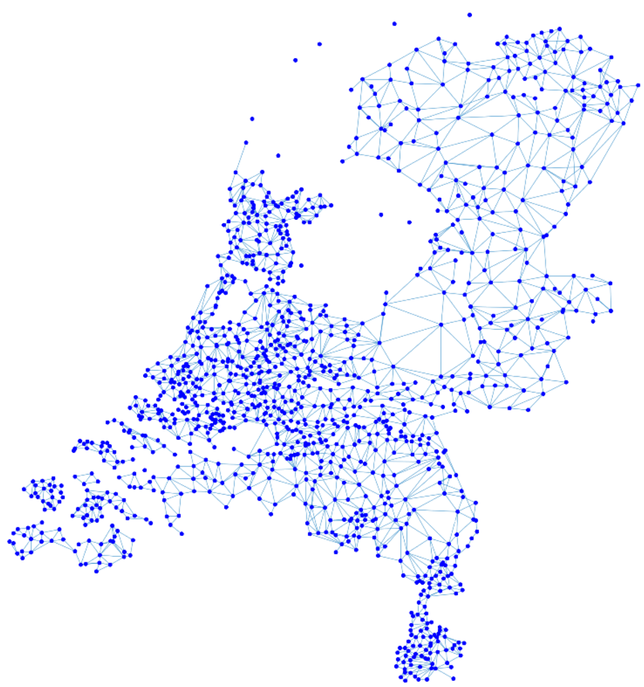
Ioannis Manolopoulos



MSc graduation committee:

Dr.ir. Eric Smeitink
Dr.ing. Edgar van Boven
Dr.ir. Huijuan Wang
Ivan Jokić MSc

TU Delft

Summary

This thesis' research concerns the time-dynamics of a complex geographical network of municipalities, i.e. the Dutch Municipality Network over the period 1830-2019. By analysing 190 years of socioeconomic statistical data and applying contemporary tooling from network science and geographic information systems (GIS), the findings from this research can provide a new approach and supportive methods for policymakers, statistical offices, researchers and companies (to decide when and where to invest).

Due to a continuous administrative process of merging municipalities, the number of municipalities decreases over time. The Netherlands consisted of 1228 mainly rural municipalities in 1830, gradually decreasing to 1016 in 1947 towards 538 mainly urbanised municipalities in 1999. Municipalities constitute a collective network, which enables people to migrate, commute and transact via various infrastructures. In 2022, the current 345 Dutch municipalities vary in number of inhabitants, in liveability, in survivability and in perceived attractiveness. Large urbanised municipalities are faced with problems such as expensive housing due to long-lasting shortage and overpopulation, while smaller rural municipalities experience population decrease and gradual disappearance of establishments. The multifaceted issues that municipalities are dealing with relate to their different urbanisation degrees and underlying network effects, which are researched in this master thesis project.

A temporal network such as the Dutch Municipality Network can be analysed in terms of its (topological) changes over time. In this thesis' research, a link between two municipality nodes in a specific year is defined when at least one of the two following conditions is applicable for that specific year:

- The municipalities have a part of their land border in common (adjacent municipalities)
- A transportation connection is established between two municipalities that are separated by water. Enabling road/railway traffic, these transportation connections can be realised by means of bridges, tunnels and/or dikes.

Linear mathematical models were researched, proposed and applied in this thesis. A multilayer network approach was initially considered, where each aspect of the socioeconomic sectors of municipalities can be represented by a different layer in the network construct. However, the limited availability of sector-related datasets lead to the proposal of an alternative non-layered model, which is based on the observed linear correlation of the population size development per municipality between subsequent years (1^{st} modelling step). The proposed modelling process consists of three complementary steps by taking into account the inter-municipal population migration (2^{nd} modelling step) and municipality mergers (3^{rd} modelling step). The latter two modelling steps concern processes which are intertwined and reveal phase transitions in the temporal network dynamics as the Dutch society shifted from industrialisation and urbanisation towards suburbanisation after 1960. This post World War II transition period is also discovered from data analysis based on a selection of distribution model types; for

example in the slope of the rank-size distribution and in the exponent value τ[k] of the slope of the probability density function that was found from curve fitting the rank-size distribution and the power-law behavior. An important finding is that in each annual instance of the population vector, the exponent value τ[k] fluctuates between 2 and 3, indicating clear power-law-like behavior in the Dutch Municipality Network.

During the period 1830-2019, Dutch municipalities decreased in number and increased in area-size. Both these effects are the results of municipality mergers, a governmental process which intensified during the 1960s and the 1980s. From this research, carried out in close collaboration between CBS experts and EEMCS NAS researchers, is concluded that municipality mergers are mainly driven over time by the changing relative differences in the number of inhabitants living in adjacent municipalities. The driver behind the migration of the population seems to be featured by a push-pull network effect. Its governing law can be captured by the combination of preferential detachment and preferential attachment. Thus on the one hand people feel pushed to move away from smaller rural municipalities and on the other hand pulled towards larger more attractive/urbanised municipalities simultaneously.
From the perspective of network theory, the average node degree of the Dutch Municipality Network remained almost constant at $E[D] \approx 5$ for the entire researched time period (1830-2019). The Netherlands in 1830 consisted of 9 municipality clusters hosting 191 nodes which were disconnected from the graph's giant component. Since 2003, only five Wadden-island municipality nodes remain disconnected from the mainland without any road connection.

To quantify the likelihood of survivability of municipalities, which is influenced by the network effects caused by (neighboring) municipalities, two metrics are proposed: the Abolishment Likelihood Index $p[k]$ (which is the output of the 3rd modelling step) and the Average Neighbor Superiority NS_{av}. Both metrics compare different socioeconomic aspects of municipalities with the aspects of their neighbors; the $p[k]$ compares the population and area-size between neighboring municipalities, while the NS_{av} compares the geographical proximity to sector-related establishments between neighboring municipalities. The Abolishment Likelihood Index $p[k]$ is calculated iteratively per municipality for each year during the period 1851-2019 (with the exception of few years around WW2 where population datasets were not available), while the calculation of NS_{av} is limited to the period 2006-2019. The Abolishment Likelihood Index $p[k]$ is therefore proposed as a more suitable metric to indicate the survivability of municipalities and is used in the model-based simulations to predict which municipalities could be abolished at the end of each annual iteration. The simulations run independently and unaware of the provincial allocation of municipalities in reality. As a result, a predictive 91.7% accuracy is achieved regarding the number of abolished municipalities at province level. Additionally, the overlap between the set of abolished municipalities at national level derived from the model and the set of abolished municipalities in reality is 75.3%.
Having created a model from theory which was empirically tested with time-series of Dutch data, a beneficial next validation step is to enrich this research domain with municipality-related data from other countries.

Acknowledgements

I would cordially like to thank Edgar van Boven for his enthusiasm for the project and the endless hours we spend together in our team of 3 with Ivan Jokić to ensure the quality of the content. I would also like to acknowledge the contribution of Statistics Netherlands experts Gert Buiten, Frank Pijpers , Hans van Hooff and all the others who participated in the interactive *‘Meedenk sessions’* for their invaluable ideas and contributions that shaped the directions of this project.

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1 Introduction

Complexity science invites us to explore real-world networks, represented as complex networks, with the intention of learning about their network properties, their internal dynamics and the governing laws that influence the behavior of their constituent parts. These factors collectively drive networks to reshape over space and time. Networked systems can be analysed in terms of their temporal state changes.
The limitations of our collective governing competencies are reflected in current crises and challenges such as where and where not to timely realise housing for a national population. Advances in complex network science enable us to research complex large-scale systems (for example one in the size of a country) from a combined temporal and spatial network perspective, as mathematical models and contemporary geographical tooling allow for enhancing network research constructs more closely to reality. An example of such a system is the Dutch Municipality Network; the object of this thesis' research. [1]

1.1 Problem Statement

At the end of 2021 a total of 17.5 million people lived in the Netherlands [2]. According to the Statistics Netherlands population and household forecast for the period 2019-2050 [3], this number will increase to 18.3 million in 2035. Figure 1 shows the expected population increase and decrease in the periods 2018-2035 and 2035-2050 at the level of the 40 COROP[1] regions.

At national scale, the Dutch population density has tripled between 1905 and 2010 [4]. As a result, demographic consequences in urbanized areas entail inconveniences such as expensive housing due to long-lasting shortage ([5], [6]), pressure on public resources, traffic congestions and increasingly difficult balancing of social versus economic interests in urban planning. For example, amidst the ongoing housing crisis, the housing shortage resulted in a call for the realisation of 1 million new houses within the coming 10 years [7], while there is currently no overarching governmental orchestration regarding housing realisation and allocation at national scale. Indicating significant regional differences, the 2009 study *Dutch overpopulation pressure and happiness* [4] mentions that for example 50% of the population of the province of Utrecht negatively valued the population density against 30% in the province of Groningen.

The causes that drive urbanisation and rural shrinkage are multi-dimensional and relate to society's gradual shift from rural to urban culture, to (migration) decisions of individuals, to declining birth rates, etcetera.

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[1] COROP (Coördinatiecommissie Regionaal Onderzoeksprogramma) regions are areas in the Netherlands divided for statistical purposes, on the basis that each area contains a core city and a surrounding market area [8]

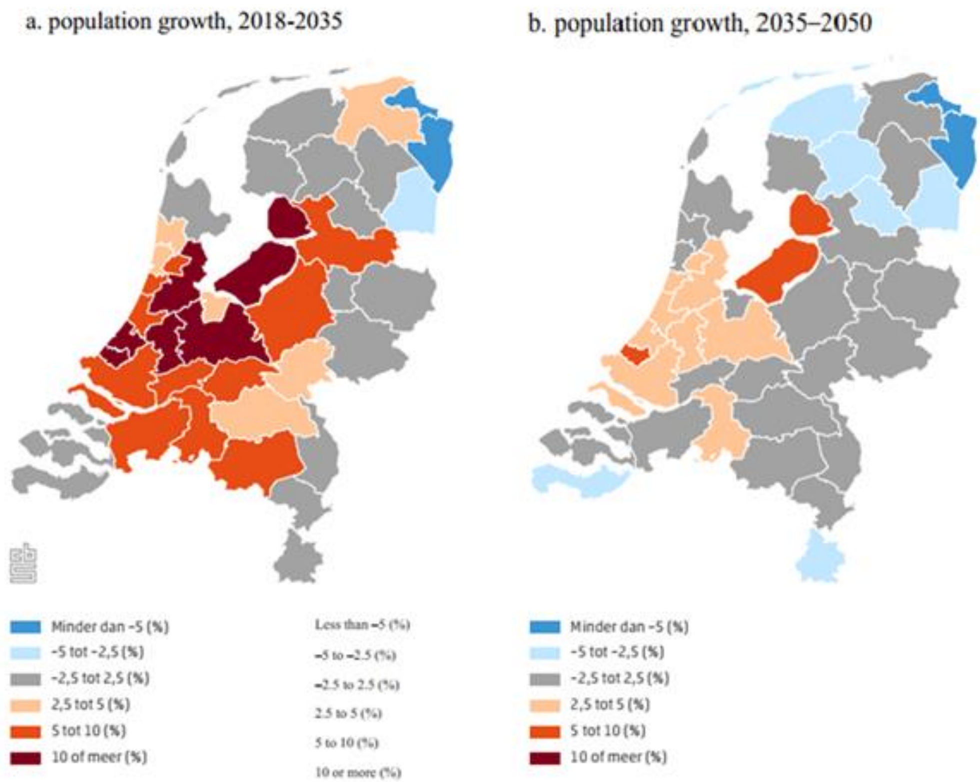

Figure 1 Regional population growth predictions in the Netherlands per COROP area [3]

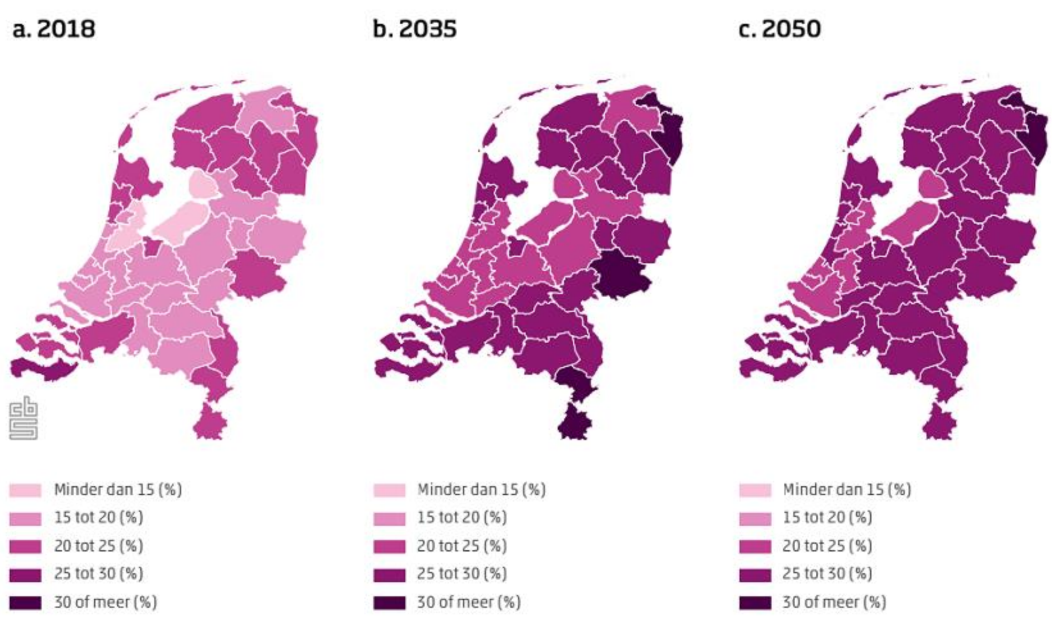

Figure 2: Share of people over 65 years old per COROP area (status 2018 and future predictions) [3]

Researching interdependencies behind driving demographic forces, population properties and sector-related facilities at municipality level, could help supporting the preparation of interventions in urban areas, in current shrinking areas [8] or in areas that are anticipated to shrink. According to the Ministry of Interior Affairs [9] , the Netherlands has 9 shrinking areas (*krimpgebieden or krimpregio's*) and 11 anticipation areas (*anticipeergebieden or anticipeerregio's*) as shown in Figure 3. A shrinking area is defined as an area where the population is expected to decrease by at least 12.5% until 2040, while the decrease in number of households is expected at least 5%. Other areas where the population is declining less rapidly are called anticipation areas. In anticipation areas, the population is forecast to decrease by at least 2.5% until 2040 [9], [10]. Towards 2100, researchers at the University of Washington [11] forecast the entire Dutch population to decrease to 13,5 million people; NiDi/CBS predict a maximum population scenario of 21.8 million people in 2050 [12], while a more recent CBS publication forecasts a maximum population scenario of 20.6 million people in 2050 and a maximum of 22.2 million people by 2070 [13].

Figure 3 shows that shrinking areas and anticipation areas consist of adjacent municipalities located closely to the national borders. Furthermore, due to a continuous administrative efficiency-driven process of merging municipalities, the number of municipalities decreases over time. For example, the Netherlands consisted of 1121 mainly rural municipalities in 1899, gradually decreasing to 1016 in 1947 towards 538 mainly urbanized municipalities in 1999. Regardless their decreasing number, together municipalities constitute a network, which enables people to migrate, commute and transact via various infrastructures. In 2022, the current 345 Dutch municipalities vary in number of citizens, in liveability, in survivability and in perceived attractiveness. As discussed, the specific types of issues that municipalities are dealing with relate to their different urbanisation degrees and underlying network effects, which are researched in this master thesis project.

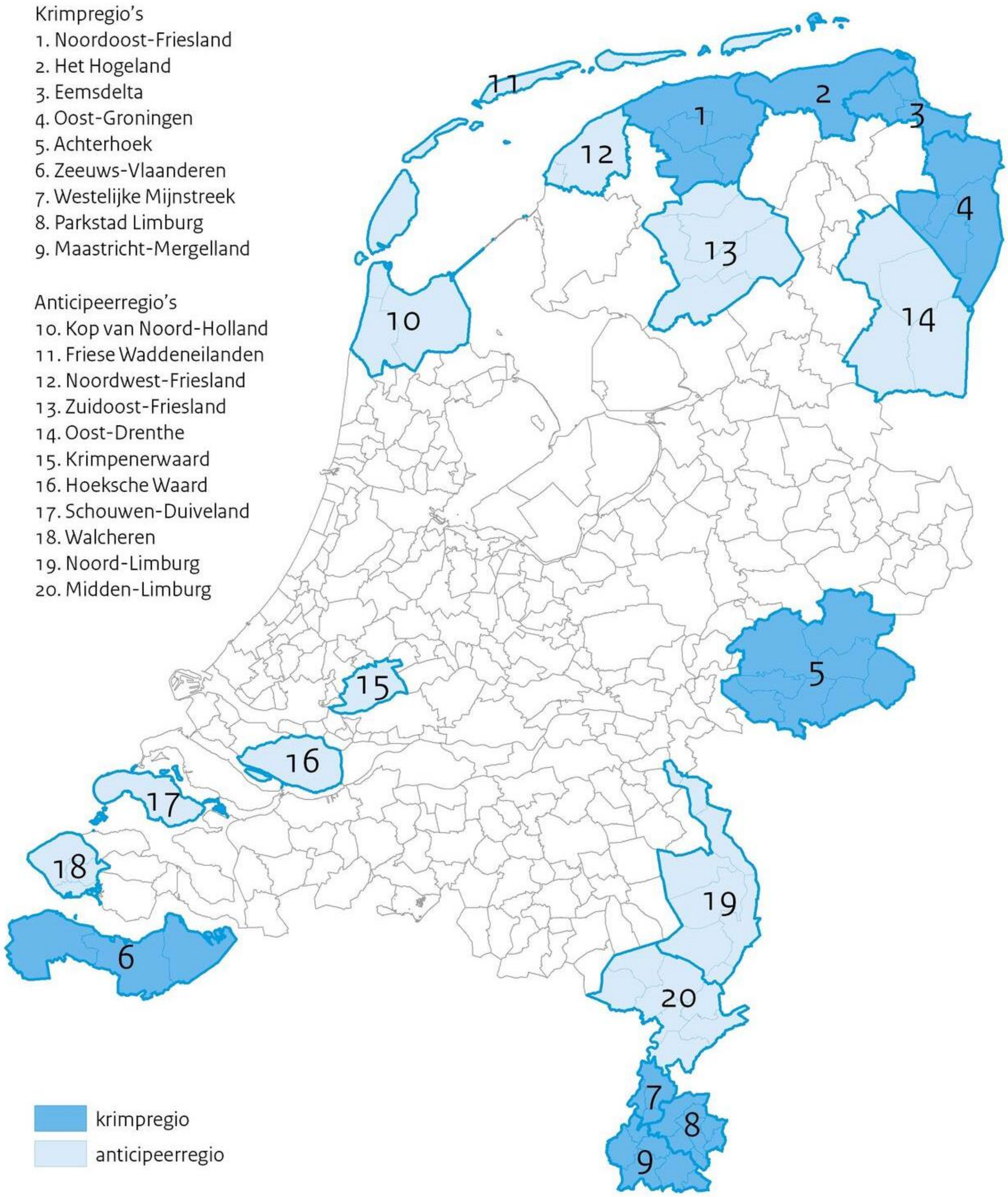

Figure 3 Shrinking areas (in dark blue color) and anticipation areas (in light blue color) in the Netherlands in 2019 [11]

1.2 Research Gap and Research Objective

To the knowledge of the author and the experts involved in this research, municipalities have never been studied before from the perspective of a complex geographical network[2].
The main research gap addressed in this thesis is the lack of scientific publications about spatiotemporal networks that comprise statistics of population dynamics and sector-specific establishments. This thesis' main objective is to contribute to the understanding of dynamic developments among specific types of municipalities by involving geographic information systems and applying advances and tooling from the research domain of complex networks. By bringing together three research domains (Figure 4), the scientific contribution lies in the exploration of the interrelations between the socioeconomic behavior of citizens and the underlying administrative processes and decisions that follow or precede peoples' behavior.

A set of municipality-level administrative units is chosen as research object (rather than cities) for two primary reasons:
1) City boundaries are unofficial and usually ambiguously defined,
2) The dynamics of municipality merging processes are unknown in complex network literature.

This thesis' research aims to connect three research domains:
I. Societal and Economic statistics (including sector related aspects partly qualified as vital),
II. Geographic Information Systems (GIS),
III. Complex Networks and Graph Theory.

Each intersection between two research domains (indicated by numbers 1,2,3 in Figure 4) can provide valuable insight to a suitable research construct, and many of these intersections have been successfully studied in the past (for example, a combination of research fields I and III can be found in [14], [15]). However, the main value of this thesis lies in the intersection of all three research domains. An example is the study and application of metrics from network theory on the Dutch Municipality Network and the interpretation of the results in a geo-socioeconomic context.

[2] In [35], the authors analyse the population distributions of secondary administrative units (usually municipalities) of many countries. However, this publication lacks a geographical network approach and is limited to one annual population instance per country (not a temporal analysis).

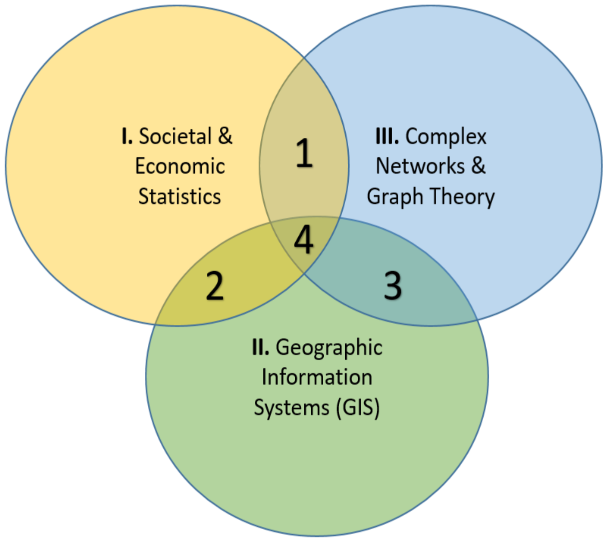

Figure 4 The research domains combined in this master thesis and their intersections

1.3 Research Questions

The research questions formulated during the initial scoping stage of the thesis project and the multi-dimensional character of the research object, required three categories of data to be incorporated in a complementary way into the research construct:
- geospatial data (e.g. municipality borders, locations of townhalls, facilities/establishments),
- population data (e.g. number of citizens per municipality, their age, their migration patterns),
- sector-related data (e.g. number of sector-specific facilities/establishments per municipality).

RQ1: How can we characterize the population distribution in different annual sets of Dutch municipalities which have been recorded since 1830?

RQ2a: Can we define and derive node survivability as a new metric that indicates the survivability of individual municipalities (against the average node survivability of all municipality nodes in the network and the average node survivability in each province) from time series of geospatial data, population data and sector specific data?
RQ2b: Which approaches can be suitable and which approach is optimal to indicate the node survivability of each individual node in a network such as the Dutch Municipality Network?

RQ3a: Which node survivability values, developments and municipality interactions can be observed from the time series of data of each individual municipality node (against the average node survivability of all municipality nodes in the network and the average node survivability in each province)?

RQ3b: Which factors influence the merging process of municipalities?

RQ4: Which existing network metrics could indicate the urbanization degree[3] of individual municipality nodes in the Dutch Municipality Network?

RQ5a: Which type of model can serve as a mathematical fundament for a research construct that can capture and relate time series of geospatial data, population data and sector specific data (about facilities and establishments) of each individual municipality?
RQ5b: Which other modelling ways without a layered approach could be suitable as well?

RQ6a: To what extent are the node survivability values and developments observed from the research construct in line with the statistics about the urbanization degree values of individual Dutch municipalities?
RQ6b: To what extent are the node survivability values, survivability developments and inter-municipal migration developments observed from the research construct in line with the classes of urbanization?

RQ7a: How did the geographical borders (topology) and names of Dutch municipalities change over time as a consequence of the merging process?
RQ7b: Which patterns can be observed from the network topology change over time?

RQ8a: Which Dutch municipalities have continuously existed in each set of municipalities from 1830 to 2019?
RQ8b: Which future municipality mergers can be predicted based on observations from the research construct from the trend and the outcome of RQ8a?

The research questions are answered within chapters 2,3 and 4 while an overarching overview is given in chapter 5.

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3 The urbanization degree is not a network metric; it is an indicator reflecting the degree of concentration of human activities (living, working, transacting) in an area, based on the area's local address density [42].

1.4 Research Relevance and Research Approach

For policy makers it is a challenge to prioritize and implement effective interventions at regional scale, as systemic insight and overview about the dynamics in our networked society and economy are difficult to obtain [16]. It is also a complicated process for companies that operate on (inter)national scale to decide when and where to invest. As a consequence, this thesis project involves exploring new research approaches and empirically testing network models that apply complex network theory and tooling in a geographical sense. This thesis' research can provide a new approach and supportive tooling for policymakers, statistical offices, researchers and companies.

In this research, models and approaches are explored and selected to represent a national municipality network and to examine the survivability of its constituent parts, which are graphically represented as municipality nodes. The survivability of a municipality or cluster of municipalities (such as a shrinking area) can be examined from population characteristics and from the availability (geographical proximity) of sector specific facilities/establishments. As a consequence, the research design is able to distinguish sector-related layers.

From the governmental project *Bescherming Vitale Infrastructuur* ([17], [18]), a set of (sub)-sectors was inventoried and classified vital in the context of vital infrastructure protection. For example, the mitigation approach of the Covid-19 pandemic is based on this classification, as establishments that are not qualified as vital are temporarily closed. In order to increase the relevance of this research, the governmental classification of vital sectors (and their vital infrastructures) is taken into account.

A temporal network such as the Dutch Municipality Network (DMN) can be analysed in terms of its (topological) changes over time. The number and the positioning of the nodes in each annual graph instance are a result of underlying socioeconomic mechanisms, such as population increase, population distribution and migration. These aspects (indirectly) affect the administrative power and executive tasks of individual municipalities. Mergers between municipalities are initiated when municipalities cannot cope with their governmental responsibilities [19], resulting in the discontinuation (abolishment) of (usually small population-sized) municipality nodes–. This efficiency-driven process thus continuously decreases the overall number of nodes in the DMN throughout the period 1830 until present day. Since the vast majority of municipality mergers occurs between neighboring municipalities, approaches from complex network tooling (such as neighbor-level analysis and graph metrics) are used, in order to compare the characteristics of different types of abolished municipalities with their neighbors, and with characteristics averaged at national level. Based on graph metrics analysis, different municipality clusters are defined and correlated with sector-related datasets to provide novel insights.

Over 30 data sources were combined in a structure variable in Matlab, comprising 1467 municipalities that have existed throughout the period 1830-2019. Each municipal entity in the structure variable has a unique identifier that describes municipalities from an administrative point of view (municipality name-related 4-digit CBS code) and a non-unique identifier that follows the merging continuity of municipalities (municipality area-related 5-digit Amsterdam code). These coding schemes, selected and applied in this research, are explained in Appendix 7.3.1.

A multi-layered network approach was initially explored for this research construct, where layers represent sector-related data and the node interactions are governed by a discrete linear state space (DLSS) model described in [20]. At conceptual level, the implementation of the DLSS model for the Dutch Municipality Network is given in 2.2.3. Due to the limited availability of sector-related datasets for the researched time-period (1830-2019) and the implementation complexity of a multi-layered DLSS model for a spatiotemporal municipality network, an alternative non-layered approach was proposed. To capture the time-dynamics of the Dutch Municipality Network, a model was developed which consists of the following 3 complementary modeling steps, where each step deals with a different real-world aspect of municipalities: population growth, population transfer caused by inter-municipal migration and municipality merging process. The model also aims to predict the future survivability of municipalities. Additionally, a selection of sector-related establishments was researched in connection with municipality mergers, graph metrics and node survivability.

Throughout the duration of this research, the (simulated) results and observations derived from the research construct tooling served as proof of concept and enabled valuable assessment by experts from Statistics Netherlands (CBS), in the form of interactive presentation sessions (“Meedenk groepen”). Valuable information and insights from CBS experts were gathered and influenced the project’s directions and units of research.

1.5 Structure of the Thesis

This section describes the structure of this thesis. Chapter 2 introduces the theoretical framework, provides a selection from network science knowledge and proposes the basic network concepts used in this thesis. Chapter 3 applies this knowledge to the Dutch Municipality Network (DMN) research construct and discusses the resulting network-perspective insights in a socioeconomic context. Chapter 4 examines the applicability and validates the selected models introduced in chapter 2 for the DMN, while also introduces the notion of survivability of a municipality. Chapter 5 discusses the overarching research results by joining the main conclusions from chapters 2, 3 and 4. Recommendations for future research are suggested in section 5.2.

2 Theoretical Framework and Methodology

This chapter describes the research framework and methodology of this Master thesis project[4]. This research aims to contribute to the understanding of dynamic developments among specific types of municipalities by means of geographic information systems and applying complex network advances and tooling.

2.1 General Framework

The general framework of this research is designed in such a way that it can capture the properties and time-dynamics of a complex socioeconomic system at municipality level. As the framework serves for modelling a municipality network and its sector-related component parts into a research object [17], the following design requirements and assumptions are taken into account:

1. When merging network topology and dynamic interactions between the nodes in order to provide insight into network behavior, an approach with a time-invariant topology and linear dynamics is preferred [20]. Linearity is the preferred way for approaching the modelling of node interactions because of its simplicity and scaling capabilities. In order to distinguish and group socioeconomic aspects of the municipalities into sectors, a layered approach is tested on usefulness in the research construct.

2. The temporal character of real networks needs to be part of the (conceptual reach of) the research framework. As the available statistical data is recorded in time series of annual datasets, annual network instances are proposed. As a consequence, the mathematical structure is fundamentally discrete (and not continuous). Here, graph theory and network tooling are suitable to deal with discrete and finite sets of integer numbers.

3. In order to model the dynamics and interplay in a real network at municipality level, linear state space equations (described in [20]) can be used to construct the network model. A mathematical model can be defined as a description of a system using mathematical concepts and language to facilitate proper explanation of a system or to study the effects of different components and to make predictions on patterns of behavior [54].

[4] This thesis strongly relates to the ongoing PhD thesis project performed by Ivan Jokic MSc, that focuses on combining control theory and network science. Both thesis projects have in common the assessment, the selection and deployment of mathematical models in order to study complex network behavior in networks with a time-invariant underlying topology.

4. The dynamics within and between municipalities are the result of the interplay of many sector-related aspects of processes. The network effects caused by neighboring municipalities define the states of all municipalities in each subsequent year.

5. Regarding system analysis, if a time-invariant system is also linear, it is the subject of linear time-invariant theory. Non-linear time-invariant systems lack a comprehensive governing theory [55]. That is why in this research a linear system approach is proposed. A time-invariant system has one or more time-independent system functions that are not direct functions of time. A research assumption is made: in a municipality network, its developments follow from indirect functions, not direct functions. A time-dependent system function is a function of the time-dependent input function.

Three modelling steps are proposed towards a research construct.

1. Model a set of municipalities as a network (e.g. as a geographical graph topology),
2. Model a set of sectors (proposed in a layered structure) to reveal interactions in the municipality network (e.g. derived from the International Standard Industrial Classification of All Economic Activities[5] [17],[24]),
3. Enrich the model (stemming from 1 and 2) with dynamics (e.g. annual network instances revealing spatiotemporal dynamics from time series of municipality related statistical data).

After this stepwise modelling, the research proceeds with testing the research construct by means of Dutch municipality related statistical datasets provided by Statistics Netherlands (see appendix section dataset description 7.6).
In section 2.2 the research methodology and the initial ideas on how to model the research construct are described in more detail.
A final research step aims to realise an output toolbox which can aggregate results from the research construct, from derived network metrics and demonstrate indices such as survivability per municipality.

Applying network tooling requires a research construct that mathematically models a set of municipalities as a network, aiming to reveal its spatiotemporal dynamics from time series of municipality related statistical data. Because the researched statistical datasets are predominantly recorded on an annual basis, this research adopts a discrete time approach in the form of annual network instances k, where k is an integer number denoting a calendar year.

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5 The International Standard Industrial Classification of All Economic Activities (ISIC) is a classification system maintained by the United Nations Statistics Division that includes a classification structure of economic activities based on a set of internationally agreed concepts, definitions, principles and classification rules [24]. The current version is ISIC Revision 4, which was published in 2008 and categorizes 21 sections, each denoted with a letter of the Latin alphabet (for more detail see Appendix 7.3.2).

Figure 5 exemplifies an annual instance of a spatial undirected municipality network $G\{\mathcal{N}[k], \mathcal{L}[k]\}$, where $\mathcal{N}[k]$ denotes the set of nodes in year k and $\mathcal{L}[k]$ denotes the set of links in year k. In this spatial graph the geographical coordinates of the municipality town halls determine the position of the nodes in a two-dimensional geographical plane. A link between two municipality nodes exists in a given year when at least one of the two following conditions apply for that specific year:

- The municipalities have a part of their land border in common (adjacent municipalities)
- A transportation connection is established between two municipalities that are separated by water. Enabling road/railway traffic, these transportation connections can be realised by means of bridges, tunnels and/or dikes.[6]

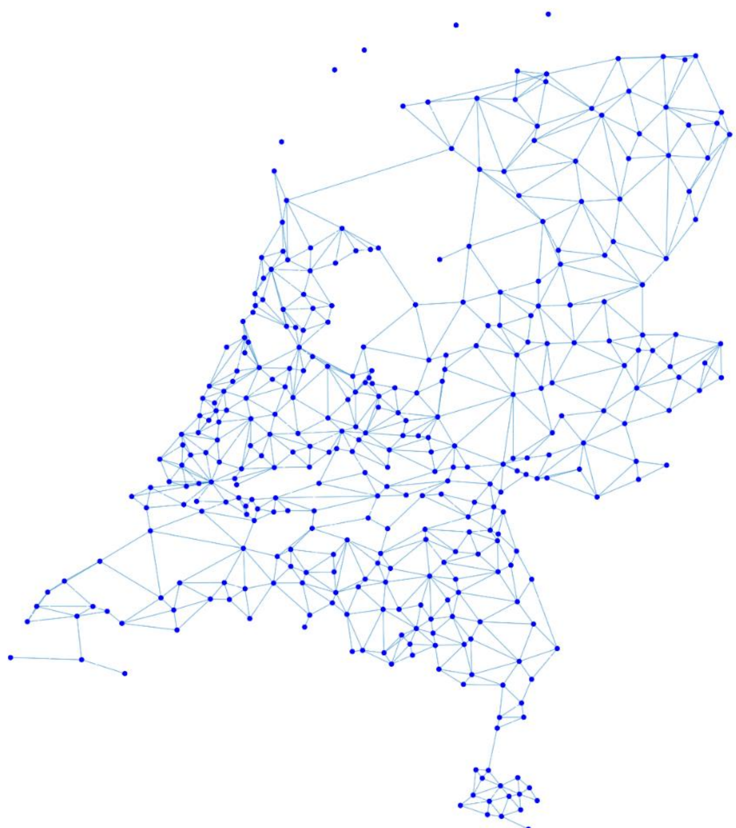

Figure 5 Spatial undirected graph of the Dutch Municipality Network in 2019, with $N[2019]$ = 355 municipality nodes and $L[2019]$= 867 links between neighboring municipalities.

[6] If a pair of municipalities is exclusively connected in a given year via a waterway, a link is not recorded between the municipalities in our research construct. Although there can be a ferry service connecting two municipalities, a single ferry line can (indirectly) connect more than two municipality nodes in contrast to one link exclusively connecting two nodes. This is a consequence of the flexibility that water transport offers, as opposed to a fixed source-destination pair that is a characteristic of land transport modes (such as a bridge). Another characteristic that complicates rigorous analysis is the fact that some ferry services are not available for an entire year. Finally, a (historical) dataset regarding the travel schedule of ferry services could not be found.

This thesis takes the Dutch Municipality Network as an object of research for the empirical part of the study, because Dutch statistical open data is abundantly available and Statistics Netherlands interactively contributed by means of knowledge sharing to this research. Furthermore, a sector-layered approach [21] has been assessed in this research because many sectors of society and economy provide their unique value [15] via geographically dedicated resources which are physically located in municipalities to serve the population (living and working). Figure 6 presents five distinct municipality classes. The definition of the first three classes is based on population size (status 2019), while the definition of the last two classes is based on governmentally predicted population development (towards 2040). The first three classes are defined as follows:

1) largest (4) municipalities are considered municipalities with more than 350K inhabitants,
2) large municipalities are considered municipalities with a number of inhabitants between 100K and 350K
3) average-sized municipalities are considered municipalities with less than 100K inhabitants.

The definition of the last two classes (anticipation and shrinking municipalities) is based on population development forecasts rather than population size, as defined in section 1.1. In terms of their population size in 2019 relating to the first three classes shown in Figure 6, the anticipation and shrinking municipalities together comprise 3 large municipalities (second population size class) and 77 average-sized municipalities (third population size class).

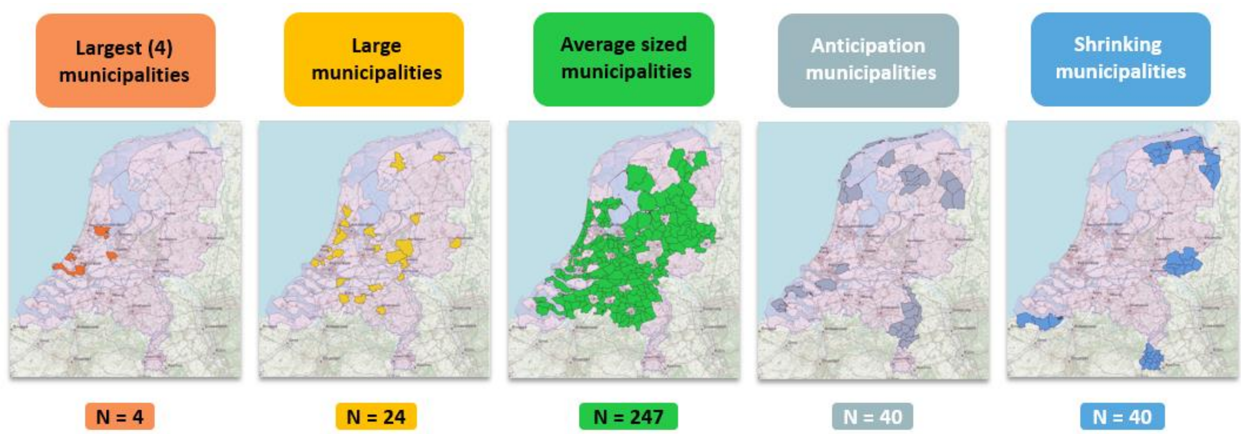

Figure 6 Five distinct classes of Dutch municipalities (status 2019).Here, N refers to the number of municipalities belonging to each class.

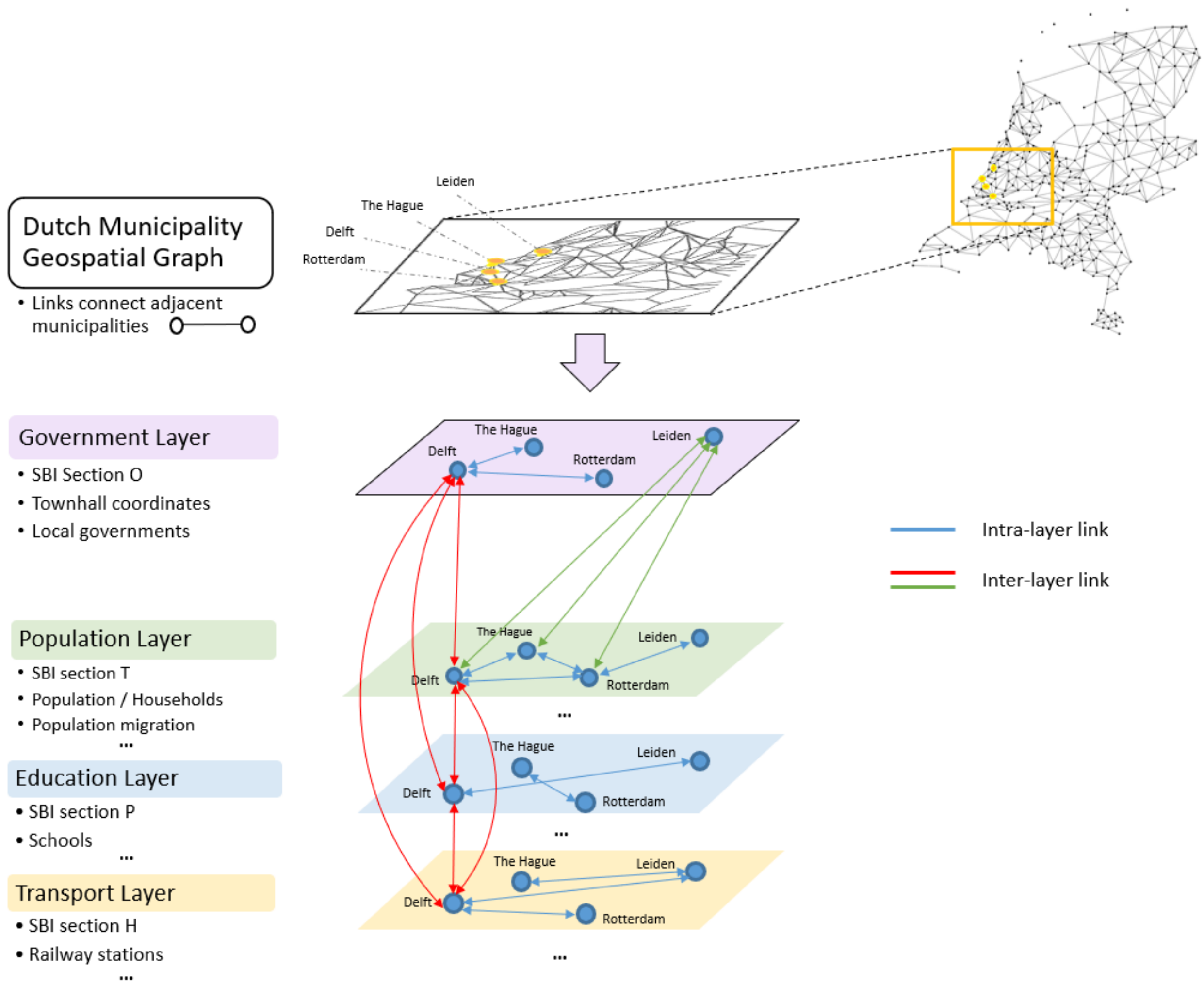

Figure 7 Structure of the multi-layer research construct of the Dutch Municipality Network

Resulting from the above-mentioned research assumptions, requirements and proposed modelling approach, Figure 7 visualizes the structure of the research construct. For simplicity, only 3 out of 21 ISIC section-related layers are shown in this figure.

2.2 Network Science Approach

This section examines possible approaches and mathematical models able to realise the research construct of the Dutch Municipality Network. For the final implementation decision, both complexity of the model and dataset availability are taken into account.

2.2.1 Linear Correlation Model

This section proposes how to model the correlation in the the population change of individual municipalities between two consecutive years k and $k+1$. Under the assumption that the correlation between municipality population between two consecutive years k and $k+1$ on a log-log[7] behaves linearly, the following governing equation is proposed:

Equation 1

$$log(x_i[k+1] - x_i[k]) = c_1[k] \cdot log(x_i[k]) + c_2[k],$$

where $x_i[k]$ denotes the population of the i-th municipality in year k and $c_1[k], c_2[k]$ are time-dependent correlation coefficients. The explicit solution of the logarithmic Equation 1 is:

Equation 2

$$x_i[k+1] = x_i[k] + 10^{c_2[k]} \cdot x_i[k]^{c_1[k]}$$

Note that in this linear correlation model, the population development per municipality is examined independently, without taking into account the network effects caused by other municipalities. In order to take into account the topology of the Dutch Municipality Network and to include network effects into the analysis, the population migration model was developed (described in section 2.2.4).

2.2.2 Discrete Linear State Space Model

In order to incorporate additional socioeconomic aspects and their influence on the DMN time-dynamics, we can consider a general case of a network with linear processes, as defined in [20]. A discrete-time linear state-space model (DLSS) represents a linear model of a (real) system, where the state variables determine the time-dynamics of the system upon which the input variables impact, while the output variables represent the observable variables of the process. The DLSS model governing set of equations in discrete time k is given below, while the block diagram representation is given in Figure 8, where the block element z^{-1} denotes a time delay of one discrete time interval.

Equation Set 3

$$\varphi[k+1] = K \cdot \varphi[k] + \Pi \cdot \psi[k]$$
$$\omega[k] = \Gamma \cdot \varphi[k]$$

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[7] The 'log scale' refers to the common logarithmic scale (logarithm with base 10). The term 'log-log' refers to a plot where both axes are scaled in a logarithmic sense.

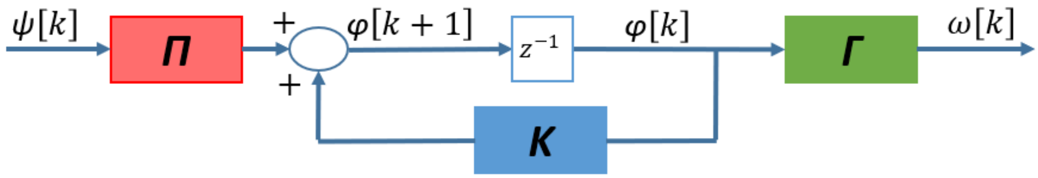


Figure 8 Block diagram representation of the governing set of equations for the DLSS model of a system.

The above governing DLSS difference equation set describes a system with n_i states. Therefore, the $n \times 1$ vector φ represents the state vector, the $m \times 1$ vector ψ represents the input vector and the $p \times 1$ vector ω represents the output vector. The parameters of the model are defined by the $n \times n$ state matrix K, the $n \times m$ input matrix Π and the $p \times n$ output matrix Γ. State variables are variables whose values evolve through time in a way that depends on their values at any given time and on the externally imposed input variables. The values of the output variables depend on the values of state variables.

Extended DLSS

A complex network is composed of N interconnected DLSS systems, each one with linear internal dynamics that can be described by the DLSS governing equation set Equation Set 3. The $N \times 1$ vector n, which contains the number of states n_i for each system i on the network, can be defined as: $n = [n_1\ n_2 \dots n_i \dots n_N]^T$. Similarly, the $N \times 1$ vector m, which contains the dimension of the input vector m_i for each system i on the network, can be defined as: $m = [m_1\ m_2 \dots m_i \dots m_N]^T$. Finally, the $N \times 1$ vector p, which contains the dimension of the input vector p_i for each system i on the network, can be defined as: $p = [p_1\ p_2 \dots p_i \dots p_N]^T$. The extended governing equation that describes the dynamics of the entire network of N interconnected DLSS systems is given below, while a graphical representation is shown in Figure 9.

Equation 4

$$\varphi_e[k+1] = K_e \cdot x_e[k]$$

where the explicit solution of the $\left(\sum_{j=1}^{N} n_j\right) \times \left(\sum_{j=1}^{N} n_j\right)$ matrix K_e is provided in [20].

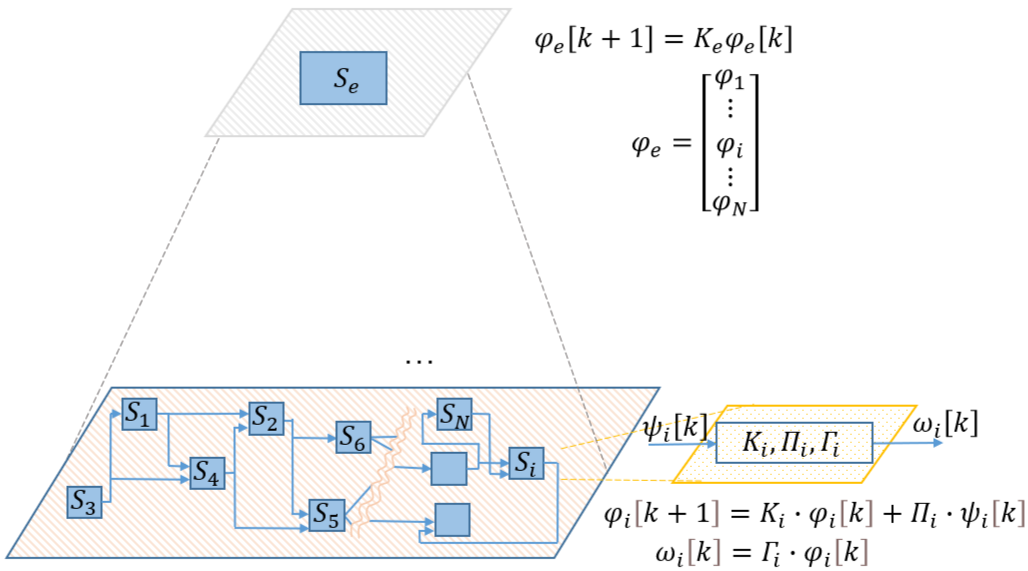


Figure 9 A network of N interconnected DLSS systems (lower part). The dynamics of the entire network represented as a single DLSS system, whose states are composed by concatenating the states of each system in the lower part.

In Equation 4, the $\left(\sum_{j=1}^{N} n_j\right) \times 1$ vector φ_e contains the states of each system i. The explicit solution for the network dynamics, in terms of the dynamics of the individual constituent systems is provided in [20].

Multilayer DLSS

Complexity science includes researching systems with interdependent components, whose interactions can include dynamic types of relationships that form complicated patterns.
A part of network literature has diverted its focus in enriching the well-established existing network theory concepts, in order to comprehensively study complex systems and phenomena, such as social structures. Such systems inherently comprise multiple subsystems and layers of connectivity, which has led to the emergence of new notions in network literature, such as multidimensional networks, multilevel networks, multiplex networks, interacting networks, interdependent (or layered) networks, etcetera. Mathematical representations for all the previously mentioned network concepts have been suggested and surveyed in the literature ([21], [22]). The concept of multilayer networks extends that of mathematical objects such as the above-mentioned network models, in the sense that every one of those models can be mapped and visualised as a multilayer network. [21]

In the extended DLSS governing Equation 4 of N interconnected DLSS systems that form a network with complex linear dynamics, each state of the i-th system, where $i \in \{1,2,\ldots,N\}$, can be abstracted as a node belonging to a different layer, thus enabling a multi-layer representation of the network (Figure 10) . The links between nodes represent the dynamic

interaction, whose intensity is defined by the DLSS model parameters for the i-th system in each year k, i.e. by the matrices K_i, Π_i and Ψ_i . Thus, the i-th DLSS system with n_i state variables can be represented in the topological domain as a node appearing in n_i different layers.
Figure 10 shows the layered representation for the processes of the system i in discrete time k that has $n_i = 3$ states. Therefore, the state variable for this system is a 3 × 1 vector $\varphi_i[k] = (\varphi_1[k]\ \ \varphi_2[k]\ \ \varphi_3[k])^T$, which can be visualised in the topological domain as three nodes belonging to three different layers. Since Figure 10 describes a single system i, in terms of the extended DLSS Equation 4, $N = 1$, hence the dimensions of the input vector $m = 1$ and output vector $p = 1$.

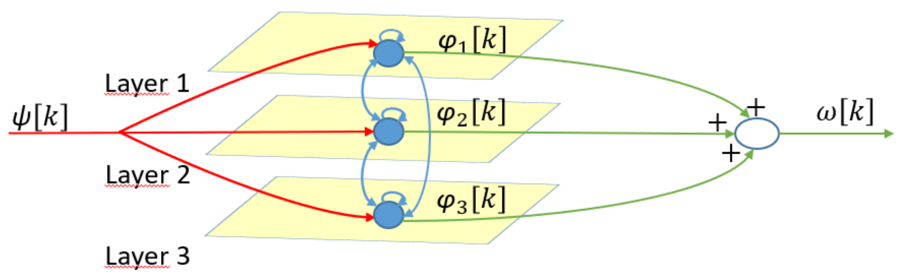


Figure 10 A system i in discrete time k , with $n_i = 3$ states that can be visualised as three nodes belonging to three different layers.

From the analysis above, the extended DLSS governing Equation 4 can be viewed as a linear process on a multilayer network of interconnected systems. Therefore, provided that each system i has the same number of states, each set of state variables φ_i, $i \in \{1,2,\ldots,N\}$ can be viewed in the topological domain as layers of a multilayer network. The explicit solution for the network dynamics, in terms of the dynamics of individual municipality systems is provided in [20].

2.2.3 Multilayer Dutch Municipality Network Model

As an alternative to the linear correlation model described in 2.2.1 for the DMN, in order to incorporate additional socioeconomic aspects and to research their influence on the DMN time-dynamics, a multilayer DLSS model described in section 2.2.2) for the DMN is conceptualised here. Realising a multilayer network of DLSS systems for the DMN can be done by:

1) Mapping the N interconnected DLSS systems in discrete time k with the set of active municipality nodes $\mathcal{N}[k]$ in discrete year k
2) Choosing to represent different aspects of i-th municipality with the n_i state variables of the i-th DLSS system. Moreover, since each state variable models a relevant quantity of a certain socioeconomic aspect of a municipality, N interconnected DLSS systems with n state variables can be represented (in the topological domain) as a multi-layer network comprising N nodes on each layer.

This way, sector-related aspects are represented as nodes of the same DLSS system i in different layers. Sectors can also include the population aspect of municipalities (relating to ISIC households section T).
The interactions between the sector-related states of a system i are quantified by choosing appropriate DLSS model parameters, i.e. matrix K_i, while the dynamic interactions between sector-related states of different municipalities are defined by the $n_i \times m_i$ input matrix Π_i and the $p_i \times n_i$ output matrix Γ_i.

The time evolution of the i-th system's states $\varphi_i[k]$ is defined by the DLSS model governing Equation Set 3. The state matrix K_i of the i-th municipality defines how the values of the municipality's states (layers) in year $k+1$ depend on the values of the municipality's states (layers) in year k. The output matrix Γ_i defines how the state values of the i-th municipality impact the state values of other municipalities, while the input matrix Π_i defines how the state values of other municipalities impact the state values of the i-th municipality.

The layers comprising the multilayer research construct (exemplified in Figure 7 for a selection of layers) are denoted by $\{\lambda\,;\lambda \in \{0,1,...,\Lambda)\}$, where Λ denotes the number of sectors incorporated in the research construct. For a given year k, each layer λ contains the same set of municipality nodes, denoted by $\mathcal{N}_\lambda[k] = \mathcal{N}[k]$, where the number of municipalities in that set equals the number of active municipalities in the DMN in year k , i.e. $|\mathcal{N}[k]\,]| = N[k]$. For a given year k, each layer λ contains a different set of links (depending on the node interactions on that layer) denoted by $\mathcal{L}_\lambda[k]$, where the number of links in that set equals the number of links between nodes on layer λ, i.e. $|\mathcal{L}_\lambda[k]| = L_\lambda[k]$. The sets of links $\mathcal{L}_\lambda[k]$ and nodes $\mathcal{N}[k]$ are time dependent, due to the processes of merging and creating new municipalities.

The set of nodes and links in a given in year k and layer λ constitute the DMN graph for year k and layer λ, denoted as $G_\lambda\{\mathcal{N}[k]\,,\mathcal{L}_\lambda[k]\,\}$.
The intralayer connections in year k between nodes on the same layer λ are defined by the ($N[k] \times N[k]$ intralayer) adjacency matrix $A^{[\lambda]}[k]$.
The interlayer connections of the DMN in year k between nodes on different layers λ_1 and λ_2 are defined by the ($N[k] \times N[k]$ interlayer) adjacency matrix $A^{[\lambda_1\lambda_2]}[k]$.
A multilayer DMN network can be defined as a pair $\mathcal{M}$=($\mathcal{G}$, $\mathcal{C}$) where $\mathcal{G} = \{G_\lambda;\ \lambda \in \{0,1,...,\Lambda\}\}$ is a family of graphs $G_\lambda\{\mathcal{N}[k]\,,\mathcal{L}_\lambda[k]\,\}$ called layers of $\mathcal{M}$ and
$\mathcal{C} = \left\{\mathcal{L}_{\lambda_1\lambda_2}[k] \subseteq \mathcal{N}[k] \times \mathcal{N}[k]\ ;\ \lambda_1, \lambda_2 \in \{0,1,\ldots,\Lambda\}\right\}$ is the set of interconnections between nodes in G_{λ_1} and G_{λ_2}that belong to different layers $\lambda_1 \neq \lambda_2$. The aforementioned notations regarding the adjacency matrices and multilayer network are adapted from the multilayer networks survey publication of Bocaletti et al [21].

The base layer ($\lambda = 0$) represents the government layer of the DMN, since the node geographical positions are determined by the townhall coordinates of municipalities. This layer is a reflection of the Dutch Municipality geospatial graph, denoted in year k by

$G_0\{\mathcal{N}[k]\,,\mathcal{L}_0[k]\,\}$. Figure 5 visualises the topology of the DMN for discrete year $k = 2019$, denoted by $G_0\{355\,,867\}$.

The first layer ($\lambda = 1$) represents the population layer of the DMN. The population layer reflects annual demographic aspects of municipalities such as total population, age distribution and inter-municipal migration.

The remaining layers $\lambda \in \{2, 3, \dots, \Lambda\}$ represent the sector-related facilities/establishments within the municipalities of the DMN. The names of these layers are taken from the sectors identified in [15]. A mapping between the sector-layers and official classification systems such as the United Nations International Standard Industrial Classification of All Economic Activities (ISIC) is provided in Appendix 7.3.2..

2.2.4 Population Migration Model

In order to obtain a more accurate annual population estimation and incorporate real-world migration processes into the network, a linear migration model is proposed for the Dutch Municipality Network. This model takes into account the migration of people between municipalities (inter-municipal migration) on an annual basis, and is applied upon the population linear correlation model per municipality (described in section 2.2.1).
This migration model captures a linear diffusion-like process applied on the Dutch Municipality Network, according to which population is redistributed among neighboring municipalities. In reality, the migration of people is not limited between neighboring municipalities. However, the iterative character of the model and the gradually decreasing average hopcount of the DMN ensure that most source-destination municipality pair combinations are eventually explored within a short number of annual iterations. The migration model distinguishes two opposite migration flows in terms of the population size of the municipalities involved:

1) Forward migration (with rate α), where people migrate from smaller to larger municipalities (in terms of population size)
2) Backward migration (with rate δ), where people migrate from larger to smaller municipalities (in terms of population size)

To implement these migration properties on the research construct, the $N[k] \times N[k]$ migration matrix $Y[k]$ is defined, consisting of elements $y_{ij}[k]$, such that:

Equation 5

$$y_{ij}[k] = \begin{cases} a_{ij}[k] & \text{if } E\left[x_j[k]\right] > E[x_i[k]] \\ 0 & \text{otherwise} \end{cases}$$

The population calculation for the entire $N[k] \times 1$ municipality population vector $x[k]$ due to the proposed migration process takes the following form:

Equation 6

$$E\left[x[k+1]\right] = \left(I + \delta \cdot Y^T[k] + a \cdot Y[k] - \delta \cdot diag(Y[k] \cdot u) - \alpha \cdot diag(Y^T[k] \cdot u)\right) \cdot E\left[x[k]\right]$$

where the $N[k] \times N[k]$ identity matrix is denoted as I and the all-ones vector with dimension $N[k] \times 1$ is denoted as u. The expected population of the following year $E[x_i[k+1]]$ for each municipality i is partly calculated based on the expected value of the previous year for the same municipality $E[x_i[k]]$, therefore the identity matrix $I_{N[k]\times N[k]}$ is added in the beginning of Equation 6 to express that mathematically. The remaining four terms relate to the arrivals and departures that occur on each municipality, caused by both forward and backward migration processes. For arrivals, the term $\delta \cdot Y^T[k]$ reflects the arrivals due to backward migration and the term $a \cdot Y[k]$ refers to the arrivals due to forward migration. For departures, the number of departures due to backward migration is calculated in the term $\delta \cdot diag(Y[k] \cdot u)$ and the number of departures due to forward migration in the term $\alpha \cdot diag(Y^T[k] \cdot u)$.

2.2.5 Graph Metrics

The application of graph metrics on the Dutch Municipality Network an contribute to describing and analysing properties of the (multi-layer) DMN, in order to obtain new insights into DMN time-dynamics. Graph metrics can be used to quantify inequalities between municipalities that result from their (weighted) interaction and position on the geographical graph..

A variety of topological[8] network metrics can be applied to the adjacency matrix $A^{[\lambda]}[k]$ of any layer λ at any annual instance k of the Dutch Municipality Network. Topological metrics can be classified [23] into three classes: 1) *distance*, 2) *connection* and 3) *spectral class*, with each class capturing a different property of the underlying network dynamics.

There are several ways to measure a node's importance. For example, a high degree (*connection* class) is an indicator of strong connectedness for a single node, but it does not necessarily capture the influence a node has on others; For the latter, an eigenvector investigation of the graph's spectra is likely a better estimate for a node's impact on an entire network [24]. Eigenvector centrality is a *spectral class* metric that relies on the notion that a node's centrality is proportional to the sum of its neighbors' centralities (see Table 1).

---

[8] A topological network metric is defined as a metric that can be calculated by using only the adjacency matrix of the graph, without assuming any additional node or link properties [23].

Another *distance* topological metric is betweenness centrality, which can reveal information about a node's importance as an intermediate connector. The betweenness of a node i is defined as the fraction of the number of shortest paths between all possible node-pairs j and m that pass through i over all the shortest paths between nodes j and m. Table 1 below summarises the metrics addressed in this thesis. The first five metrics relate to individual node properties, while the last two relate to a global network property. Degree assortativity is the pairing of nodes with comparable connectivity (number of neighbors). In contrast, degree disassortativity is the pairing of highly connected and less connected nodes [25]. The assortativity coefficient, which is the Pearson correlation coefficient of degree between pairs of connected nodes is used to quantify how assortative or disassortative is a network ($r = 1$ indicates perfect assortativity, $r = -1$ indicates complete disassortativity and $r = 0$ indicates non- assortativity).

Table 1 Graph metrics used in this thesis. [23], [24]

Graph metric	Topological class	Quantified node or graph property	Formula
Degree	Connection (node property)	Number of neighbors	$d_i = \sum_{j=1}^{N} a_{ij}$
Betweenness centrality	Distance (node property)	Node's role as an intermediary (connector)	$B_i = \sum_{i \neq j \neq m} \frac{\sigma_{jm}(i)}{\sigma_{jm}}$
Clustering coefficient	Connection (node property)	Cliquishness of a node's neighborhood	$c_i = \frac{q_i}{\binom{d_i}{2}}$
Closeness centrality	Distance (node property)	Node's participation in the network	$C_i = \frac{1}{\sum_{j \in \mathcal{N} \setminus \{i\}} H_{i \to j}}$
Eigenvector centrality	Spectral class (node property)	Node's influence on a network by measuring the neighbors' characteristics.	$E_i = \frac{1}{g} \sum_{j \in \mathcal{N}} a_{ij} E_j$
Degree Assortativity	Connection (graph property)	Assortative mixing (a bias in favour of connections between network nodes with similar degree)	$r = \frac{\frac{1}{L}\sum_{(i,j)\in\mathcal{L}} d_i d_j - \left(\sum_{(i,j)\in\mathcal{L}} \frac{1}{2L}(d_i + d_j)\right)^2}{\frac{1}{L}\sum_{(i,j)\in\mathcal{L}} \frac{1}{2}({d_i}^2 + {d_j}^2) - \left(\sum_{(i,j)\in\mathcal{L}} \frac{1}{2L}(d_i + d_j)\right)^2}$
Graph Average Degree	Connection (graph property)	Number of neighbors of the majority of the graph's nodes	$E[D] = \frac{\sum_{i=1}^{N} d_i}{N} = \frac{2L}{N}$

Where:

$\mathcal{N}$ is the set of nodes in a graph

d_i is the degree of node i

$\sigma_{jm}(i)$ is the number of shortest paths between nodes j and m that pass through i

σ_{jm} is the number of shortest paths between nodes j and m

q_i is the number of links between the neighbors of node i

$H_{i \to j}$ is the number of hops in the shortest path between nodes i and j

g is a constant (the largest eigenvalue of eigenvector equation $A\mathrm{x} = c\mathrm{x}$, where A is the $N \times N$ adjacency matrix of the graph $G\{\mathcal{N}, \mathcal{L}\}$ and x is a $N \times 1$ vector)

2.2.6 Distributions

In this section, the definitions of statistical distributions and network models examined in this thesis' research are given.

Lognormal distribution

A lognormal random variable is defined as $X = e^Y$, where Gaussian or normal random variable is defined as $Y = N(\mu, \sigma^2)$. The distribution function $F_X(t) = Pr[X \le t] = Pr[Y \le log\ t]$, for real and non-negative t, is defined as:

Equation 7

$$F_X(t) = \frac{1}{\sigma_l \sqrt{2\pi}} \int_{-\infty}^{\log t} \exp\left[-\frac{(\upsilon - \mu_l)^2}{2\sigma_l^2} \right] d\upsilon$$

where $\upsilon \in (-\infty, \log t)$, μ_l is the shape parameter of the lognormal distribution and σ_l is the scale parameter of the lognormal distribution. The probability density function $f_X(t)$ of a lognormal random variable X is defined as:

Equation 8

$$f_X(t) = \frac{\exp\left[-\frac{(\log t - \mu_l)^2}{2\sigma_l^2} \right]}{\sigma_l t \sqrt{2\pi}}$$

The relation between a normal and a lognormal distribution can be described as follows: if X is a random variable whose values are lognormally distributed, then the random variable $Y = \ln X$ follows a normal distribution.

Fermi-Dirac distribution

The distribution function of a Fermi-Dirac random variable X , denoted as $F_X(x)$ is defined as:

Equation 9

$$F_X(x) = \frac{1}{1+e^{-x}} = \frac{1}{2\left(1+\tanh(x)\right)}$$

where $x = \frac{\log t - \mu_f}{\sigma_f}$ is defined for real and non-negative t, while $\mu_f \in (-\infty, \infty)$ and $\sigma_f \in (0, \infty)$ are the distribution's shape and scale parameters respectively. The probability distribution function of a Fermi-Dirac distribution is given below:

Equation 10

$$f_X(t) = \frac{1}{4}\operatorname{sech}^2\left(\frac{1}{2}\right)$$

Degree distribution of scale-free networks

If the degree distribution of a network follows a power law, then the network is considered a scale-free network. More precisely, the probability that the fraction γ of the network's nodes have degree γ is given below:

$$P(\gamma) \approx c\gamma^{-\tau}$$

where $c > 0$ is a constant and τ a factor, independent of the network size N, hence the name 'scale-free'. Typical values of the exponent value γ are found between 2 and 3 in real-world networks. The scale-free network model is a network model proposed for real-world networks. Examples include social networks, the Internet (routers as well as webpages) and biological networks, which consist of few strongly connected and dominant nodes. However a cut-off factor in real-world scale-free networks is convenient (e.g. for curve fitting purposes), as scale-free networks presume infinity, while real-world networks have a finite number of nodes. In economic networks ([15] , [14]) , power-law like behaviour is observed in many human-made networks. Therefore, a limiting factor could be suitable to capture the power-law behaviour in real-world networks, such as for example a municipality network:

$$P(\gamma) \approx c\gamma^{-\tau}e^{-ax}$$

where e^{-ax} is a cut-off factor.

3 Dutch Municipality Network Dynamics

This chapter describes the researched aspects of the Dutch Municipality Network. Section 3.1 presents the municipality reclassification and merging process during period 1830-2019. Section 3.2 analyses the population time-dynamics and employs relevant distribution models. Section 3.3 incorporates sector-related datasets into the DMN (for time-periods corresponding to the availability of each dataset), while sections 3.4- 3.8 explore the DMN from the perspective of network topology and graph metrics.

3.1 Municipality Reclassifications and Mergers

3.1.1 Historical Overview of Reclassifications in the Netherlands

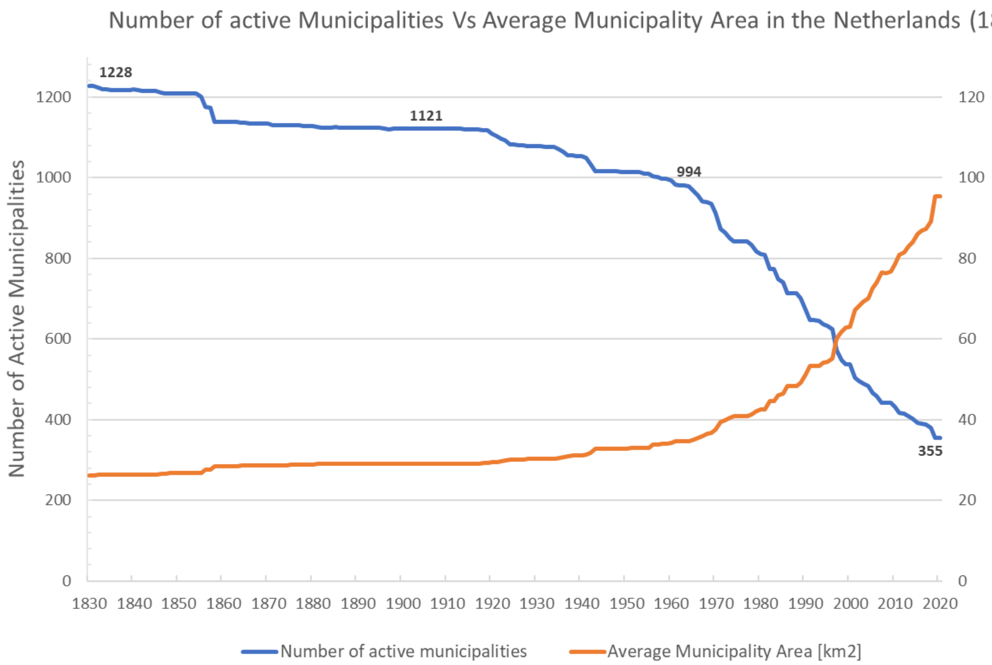
The history of Dutch municipalities dates back to the late 18th century. The term 'municipality' was first used as a designation for local authorities in 1798 in the *Staatsregeling des Bataafschen Volks*, according to which villages and towns were equated under a new form of government called municipality (in Dutch: *gemeente*). It took until the end of 1811 for the municipal system to be fully structured, when the administration of justice, notarial duties and the water board duties (in Dutch: *waterschap* or *hoogheemraadschap*) were organized separately [26]

During the French annexation period (1810-1813), the role of the former Dutch municipalities was reduced to performing administrative tasks. The French Municipal Law of 1811 forced a minimum size of 500 inhabitants per municipality to be established by municipality mergers. On January 1st 1812, the first systematic municipal classification came into effect [27]. Also the size of the territory became a criterion for municipality reclassification/mergers. [26]

In 1812, the Netherlands consisted of 10 provinces containing 1144 municipalities ([28], [29]). After regaining independence from France in 1813, Belgium and The Netherlands were united into The United Kingdom of the Netherlands (1815-1839).[9] [28]. Municipalities that only existed before 1830 have not received a CBS code from Statistics Netherlands yet (see appendix section 7.3.1 for a description of the two coding schemes selected for this research). Instead the so called Amsterdam code was assigned. The Amsterdam code however could not be considered

9 The polity collapsed in 1830 with the outbreak of the Belgian Revolution. With the secession of Belgium, the Netherlands was left as a rump state and refused to recognise Belgian independence until 1839 when the Treaty of London was signed, fixing the border between the two states and guaranteeing Belgian independence and neutrality as the Kingdom of Belgium. [64]

as a unique identifier (such as the CBS code) and that is the reason that a number of municipalities were omitted from the total of 1467 municipalities comprising this research construct, which spans from 1830-2019. Note that there were 1228 active municipalities in 1830, all of which had a CBS code. A historical overview of the active municipalities in the Netherlands on national (Figure 11) as well as on provincial level (Figure 13) can be found below.



Year	Number	Area [km2]
1830	1228	26.2
1840	1219	26.4
1850	1209	26.7
1860	1138	28.5
1870	1134	28.6
1880	1127	28.9
1890	1123	29
1900	1121	29.1
1910	1121	29.1
1920	1110	29.4
1930	1078	30.3
1940	1054	31.2
1950	1015	32.9
1960	994	34.2
1970	913	37.7
1980	811	42.5
1990	672	51.3
2000	537	63
2010	431	78.5
2019	355	95.4

Figure 11 Number of active municipalities in the Netherlands (blue line) and average area size of municipalities (orange line) for years 1830-2019.

Although reclassifications have been taking place since the 19th century, initially they were very few in number and occurred on a small scale regarding the involved area. Due to the 1966 Second Memorandum on Spatial Planning (in Dutch: *Tweede Nota Ruimtelijke Ordening*) from the 1970s onwards, the number and scale of the reclassifications/mergers gradually increased. Urbanization had consequences for urban agglomerations and regions (in Dutch: *agglomeraties and stadsgewesten*), which often crossed municipal boundaries and became more or less an additional government layer while at the same time municipalities got a less important role in this process. [26]

Soon after, in the early 1980s, the emphasis returned to the initial three governmental layers: national government, provinces and municipalities. The municipalities obtained a stronger role again and instead of the existence of a fourth government level of the agglomerations and regions, the municipalities had to intensify their cooperation. Partly in connection with this municipalities had to scale up aiming to strengthen the local government layer and its administrative power. This led to a new wave of reclassifications/mergers in the 1980s and early 1990s, but also to the creation of urbanized city regions (in Dutch: *plusregio's* or *stadsregio's*), in which several municipalities worked together. In the early 1980s a population of at least 5000 was still the guideline for reclassifications, while the national government at the end of the 1990s aimed for municipalities with 25,000 inhabitants or more. [30]

This 3-layer decentralized governance model, initiated during 1982-1986 , intended to give municipalities more scope and responsibilities. Based on the idea that many small municipalities are deemed insufficiently capable of handling increased responsibilities, they were merged into larger municipalities, either by being annexed by an existing municipality (usually neighboring), or by forming a new municipality with other neighboring municipalities.

3.1.2 Types of Municipality Mergers and Reclassifications

From our analysis of 190 years of municipality reclassifications (1830-2019), we distinguish five types of administrative reclassification, which are followed by the discontinuation of the CBS code of the municipalities involved. The CBS code is abolished (becomes inactive) at the end of year k, and the administrative change takes effect at the beginning of the following year $k+1$. So in the scheme below the events are considered to have taken place at the end of year k, and the change takes effect at the beginning of year $k+1$. The five reclassification types are listed below:

- **Type A (Annexation)**: the abolished municipality is absorbed by an existing (usually adjacent) municipality at the end of year k. This process is officially called 'light merger' (in Dutch*: lichte samenvoeging*) and the CBS code of the abolished municipality becomes inactive in year $k+1$. This reclassification type has occurred 542 times in total during the studied time period (1830-2019).
- **Type B (Border split)**: the area of the abolished municipality is split among an existing municipality and a newly formed municipality. This reclassification type is a combination of Type A and Type C, as both processes occur at the same time within the former municipality's boundaries. This reclassification type has occurred 10 times during the studied time period (1830-2019).
- **Type C (Coalition)**: the abolished municipality, along with other neighboring municipalities which are abolished at the end of the same year k, form a coalition by creating a new municipality. The new municipality is assigned a new CBS code at the beginning of year $k+1$, and the CBS codes of the merger participants become inactive at the end of year k. This process is officially called 'regular merger' (in Dutch*: Reguliere samenvoeging*). This reclassification type has occurred 502 times during the studied time period (1830-2019)..
- **Type D (Dutch and/or Frisian Name-change)**: only the official name of a municipality is changed in Dutch or Frisian language, while its borders remain unchanged. The

municipality is assigned a new CBS code at the beginning of year $k+1$, and the old CBS code of the municipality becomes inactive at the end of year k. A main difference between the Amsterdam and CBS coding schemes is that the municipality retains its Amsterdam code when undergoing a name-change. A municipality name-change has occurred 56 times during the studied time period (1830-2019).

- **Type E (Exchanged internationally):** the area of a municipality is exchanged between a neighboring country and the Netherlands. In case a municipality is allocated to a neighboring country, it is recorded in statistics to be no longer part of the Netherlands in year $k+1$. This reclassification type has occurred 2 times during the studied time period (1830-2019). The municipalities Tudderen (Drostambt) and Elten, both annexed after the Second World War by Germany in 1963.

The time-dynamics of the two dominant merger types A and C are given in Figure 12, while the remaining merger types B,D and E occur less frequently and are given in Appendix Figure 49.

The embedded provincial chart in Figure 12 indicates that Type C mergers (coalitions between municipalities) prevailed in Drenthe, Friesland and Zuid-Holland. The first two provinces traditionally consisted of municipalities with the largest average area among all Dutch provinces, until the establishment of Flevoland. Flevoland is the 12th and youngest province of the Netherlands, established in 1986, when the Southern and Eastern Flevopolders, together with the Noordoostpolder were merged into one provincial entity [31]. Since then, it has consisted of six municipalities without any reclassification so far (Figure 13).

Note that, during the course of 190 years, some municipalities were transferred to other provinces. This lead to new demarcations of the associated provincial borders. The provinces of the municipalities of Leimuiden, Noordoostpolder, Oudewater, Terschelling, Urk (2x), Vianen, Vlieland and Woerden have been changed [32]. For this research, due to the lack of geographic datasets reflecting the exact provincial border changes, all the above-mentioned municipalities are assigned to their current province (status 2019). The detailed list of provincial changes and municipality transfers since 1830 can be found in Appendix section 7.4.

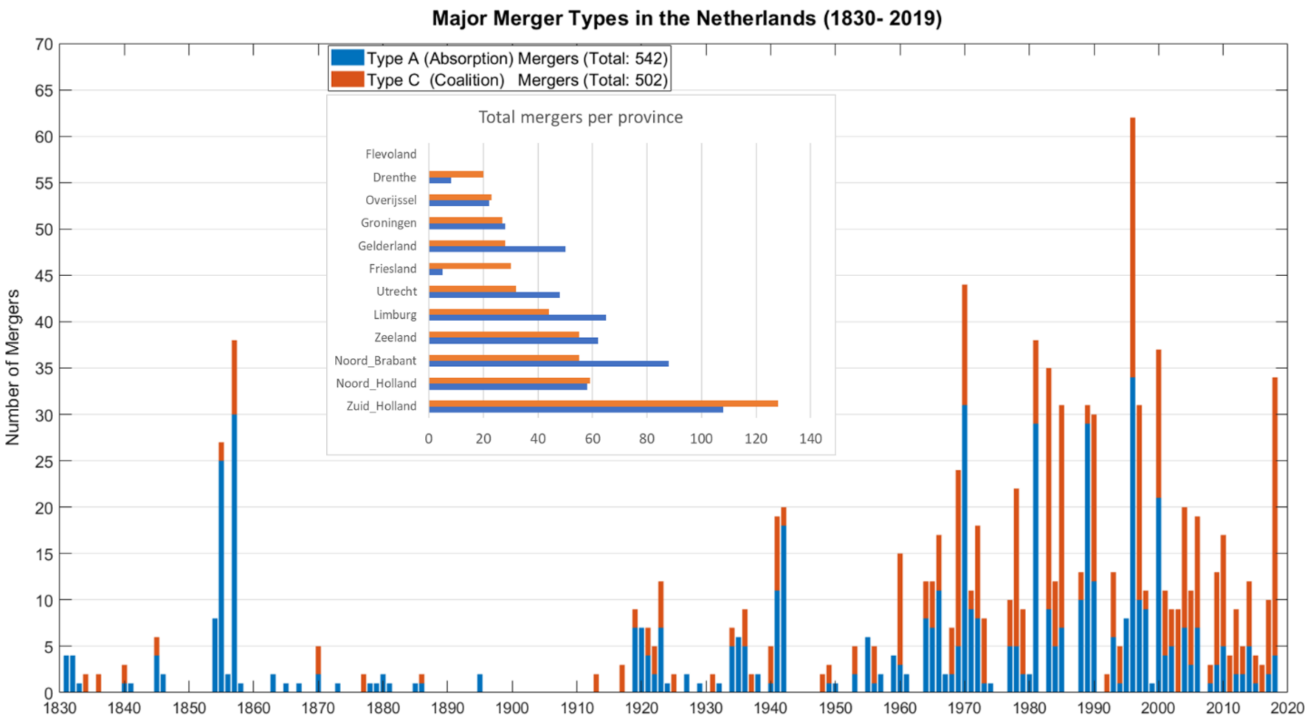


Figure 12 Stacked bar representation of Type A (Absorption) and Type C (Coalition) merger types in the Netherlands. Half of Type A mergers occurred in the period 1966-2000, while almost half of Type C mergers took place during 1990-2018. The three remaining merger types occur less frequently and are given in Appendix Figure 63.

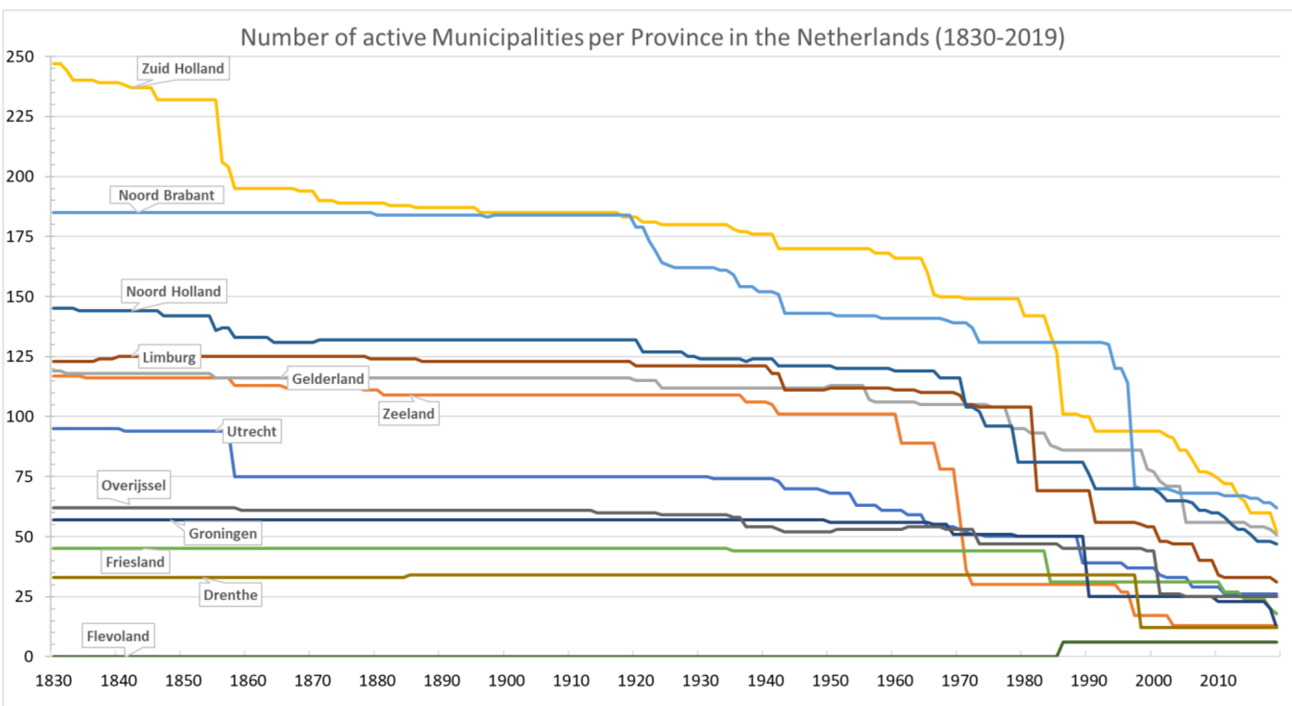


Figure 13 Number of active municipalities per province. Flevoland is the 12th and youngest province of the Netherlands, established in 1986.

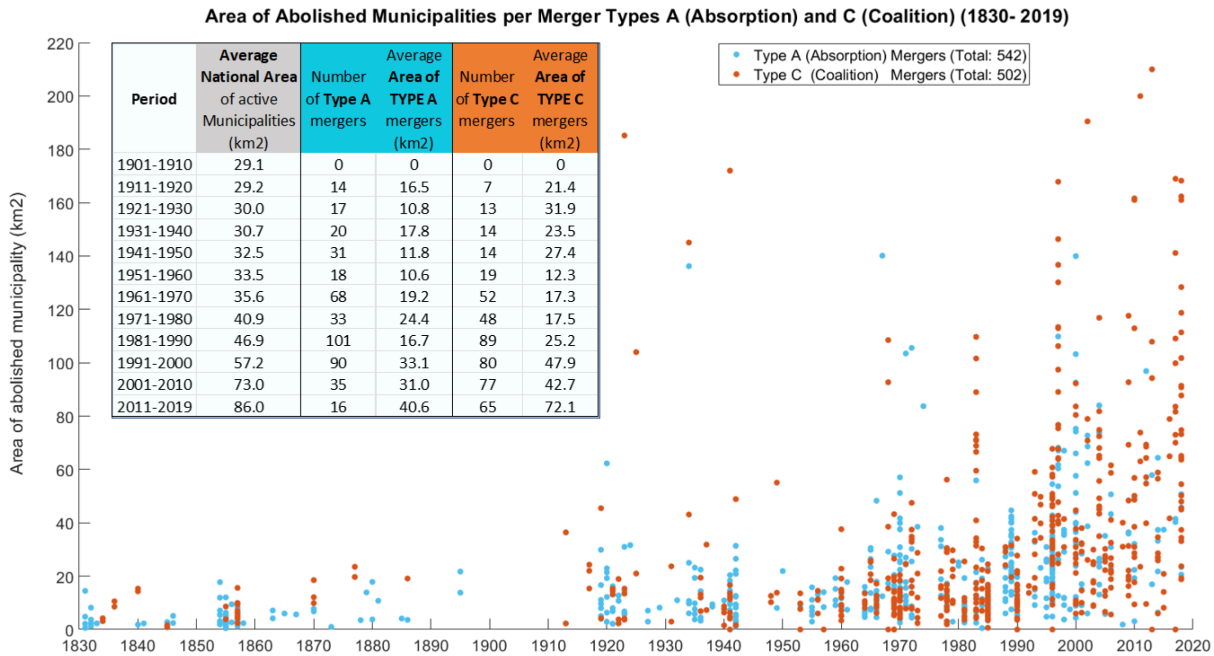
In the 19th and early 20th century, when the government was more centrally orchestrated, individual municipalities were not tasked with many responsibilities, making it easier for small municipalities to survive on their own without the need to cooperate with each other in any form of merger. After the Second Memorandum on Spatial Planning (in Dutch: : *Tweede Nota Ruimtelijke Ordening*) in 1966, in order to keep up with the accelerating progress of urbanization, many (mainly urban) municipalities started annexing neighboring (mainly rural) municipalities. This absorption process (Type A merger) was especially dominant in the period 1966-2000, during which more than half of these mergers occurred (275 out of 542 type A mergers only in 35 years).

From the early 1980's the decentralized 3-layer governance model gave municipalities more administrative duties, and as municipalities were becoming fewer in number but growing larger in area size (see Figure 11), the absorption process slowly started giving way to an intermunicipal cooperation process under more 'equal terms' (Type C merger). During the period 1990-2018, almost half of the total type C mergers took place (240 out of 502 total type C mergers in less than thirty years). This shift of the dominant merger type (Figure 12) can likely be attributed to the fact that municipalities were becoming larger in size (and thus in administrative power); large enough to avoid being absorbed by a neighboring municipality, but not large enough to survive on their own. For this reason, these municipalities had to form a coalition with one or more of their neighbors in order to successfully cope with their increasing municipal obligations. In fact, during the period 2001-2018, there were almost 3 times more type C mergers than type A (142 Coalitions and 52 Absorptions).

To further explore the correlation between the size of a municipality and its associated merger type, Figure 14 compares the average area of different merger types (Type A vs Type C) of abolished municipalities against the national average for the last twelve decades. For almost the entire studied time-period, it holds that the average area of abolished municipalities participating in a Type C (Coalition) merger was always larger than the area of municipalities that were absorbed in a Type A merger, except for the period 1961-1980. This finding validates the assumption that municipalities collaborating in a Type C merger are large enough to avoid being absorbed by (larger) neighbors, but not large enough to survive on their own (when compared to the national average of the active municipalities). For the period 1961-1980 when Type C municipalities were smaller than Type A, the vast majority of Type C mergers during this twenty-year period happened in Zeeland (35) , North-Holland (28) and South-Holland (14).

When compared with the national average, the area of abolished municipalities regardless their associated merger type was always smaller for each decade examined, except for 1921-1930 where the average area of Type C abolished municipalities was slightly larger than the national average. The majority of Type C mergers in that period took place in Noord-Brabant.
Overall, during the entire reclassification period (1830-2019), only 120 out of 1054 (11.3%) abolished municipalities (Types A, B or C) had larger area than the average national area each year. On a province level, only 170 out of 1054 (16.1%) abolished municipalities (Types A, B or

C) had larger area than the average provincial area each year. This indicates that the relatively smaller municipalities are more likely candidates to be abolished than larger municipalities.



Period	Average National Area of active Municipalities (km2)	Number of Type A mergers	Average Area of TYPE A mergers (km2)	Number of Type C mergers	Average Area of TYPE C mergers (km2)
1901-1910	29.1	0	0	0	0
1911-1920	29.2	14	16.5	7	21.4
1921-1930	30.0	17	10.8	13	31.9
1931-1940	30.7	20	17.8	14	23.5
1941-1950	32.5	31	11.8	14	27.4
1951-1960	33.5	18	10.6	19	12.3
1961-1970	35.6	68	19.2	52	17.3
1971-1980	40.9	33	24.4	48	17.5
1981-1990	46.9	101	16.7	89	25.2
1991-2000	57.2	90	33.1	80	47.9
2001-2010	73.0	35	31.0	77	42.7
2011-2019	86.0	16	40.6	65	72.1

Figure 14 Square kilometer area of different types of abolished municipalities (scatter plot) and comparison with the national average area per decade (embedded table). Abolished municipalities involved in Type C mergers are typically larger than Type A municipalities.

3.1.3 Municipality Merging Process

Initiative

The national government leaves the initiative for a reclassification primarily to municipalities. Municipalities are the first to act when it comes to finding solutions to better tackle their social tasks. In the case of evident administrative strength problems of municipalities, for which they are unable to find solutions themselves, the responsibility of the provinces may mean that they use their powers as laid down in the arhi Act (*Wet algemene regels herindeling*) to steer the discussion and take on a moderating role that can lead to a reclassification advice initiated by the province. Depending on whether the province initiated the reclassification process or not, the province assumes either a more influential coordinative role in the merging process (in the first case) or a less influential role to facilitate the process (in the latter case). In exceptional cases the province will take initiative to ‘enforce’ the merging process to municipalities, for example when the administrative power of one has weakened to the point where local tasks are not being carried out and the municipality’s financial state is poor. A definition of administrative power is given as “the ability of municipalities to perform their statutory and non-statutory tasks and to enter into the necessary social and administrative relationships for this purpose” [19]. The definition shows that municipalities do not have to perform their tasks completely independently in order to have administrative power; they can also do this in collaboration with, for example, other municipalities, which may a be first step[10] to a Type C (Coalition) merger, especially in the last three decades with increased frequency (Figure 12). After all a municipality with limited administrative power also influences the quality of regional operation.

Motives

A motive for merger or reclassification may be the expectation that a larger municipality is able to produce a more professional and business-like administration. Another motive may be that a densely populated municipality needs more space, for example for housing, and for this reason receives land from or is merged with smaller municipalities in the vicinity. Municipalities that are considering a reclassification often have common characteristics that make them a suitable match and each other's natural partner. Another possibility is that municipalities are complementary to each other. An example of this is the combination of urban facilities with the green and open landscape of the countryside. Together they increase the quality of life of the entire area. A municipal reorganization can therefore lead to several villages, centers and/or cities being located within a new municipality, each with its own characteristics, culture and identity. [30], [19]

Assessment Criteria

The concerned municipalities are responsible for the submission of a reclassification draft (advice) for inspection to the government. In addition, the government uses a number of criteria on the basis of which reclassification advice is assessed. For each reclassification advice, this includes an assessment based on the local and regional circumstances, developments and context. Because these circumstances differ per case, it is not possible to develop an exhaustive checklist that will lead to an unambiguous outcome in all cases. The assessment criteria must be viewed in a holistic way. The government assesses reclassification advice by municipalities on the basis of the following criteria: [19]

- Support base
- Administrative power
- Internal coherence and proximity to governance
- Regional cohesion

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[10] Sometimes, this collaboration between municipalities does not lead to a merger, but rather remains as a partnership between municipalities (in Dutch: *gemeenschappelijke regeling*), where tasks are delegated between municipalities albeit the involved municipalities avoid a merger and manage to stay autonomous.

Since the above-mentioned criteria are not easily translated into exclusively numerically-driven data, the proposed conditions for municipality abolishments in this thesis are based on purely scientific observations of past reclassifications . Therefore the proposed Abolishment Likelihood Index of municipalities (described in section 4.2) should not be considered as a clear guideline for the future survivability of municipalities, as social local/regional circumstances are not taken into account in this research.

3.2 Population Time-Dynamics

In this section, the time-dynamics of the population of Dutch municipalities are examined. The population distribution over time is governed by processes such as natural population growth and movements of people (i.e. international immigration/emigration and intermunicipal migration). Analysing the changes in the population distribution over 190 years of statistical data can help in the understanding of the underlying mechanisms behind population and merger dynamics of the Dutch Municipality Network.

Both the processes of municipality merging and establishing new municipalities influence the population distribution dynamics over time. However, the migration of people in time is a continuous governing process that directly drives the population distribution and as a consequence indirectly drives the processes of municipality merging and establishing new municipalities.

In 1830, the Netherlands had a population of 2.61 million people [33] living in 1228 municipalities, increasing to 17.41 million citizens in 2019. The total population of the Netherlands in the period 1830 − 2019 is presented in Figure 15. Although the total population of the Netherlands displays a steadily increasing trend during the entire researched period, the regional population growth significantly varies, as shown for example on province-level on the right part of Figure 15.
In contrast to population increase, during the same period the number of municipalities $N[k]$ decreased from $N[1830] = 1228$ to $N[2019] = 355$, which reflects a driving force for the population distribution dynamics within Dutch municipalities.

The population of Dutch municipalities in year k is defined by the $N[k] \times 1$ vector $x[k]$, where $N[k]$ is the number of active municipalities in year k. The population of the i-th municipality in year k is denoted by $x_i[k]$. The total Dutch population $X[k]$ in year k is obtained by the summation of the population of the $N[k]$ active municipalities in year k :

Equation 11

$$X[k] = \sum_{i=1}^{N[k]} x_i[k]$$

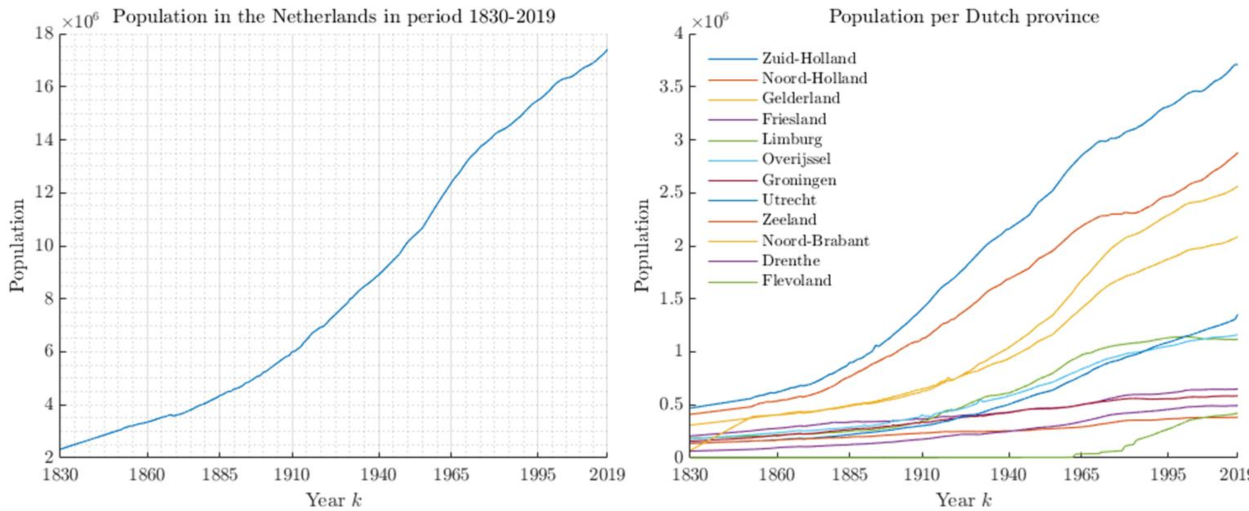


Figure 15 Population of the Netherlands and the population per Dutch province (1830 – 2019)

Over the entire researched period $k \in \{1830, 2019\}$ the population distribution is heavy-tailed. The arithmetic mean and the variance of both the population vector $x[k]$ and the logarithm of the population vector $\log x[k]$ over time are presented in Figure 16.

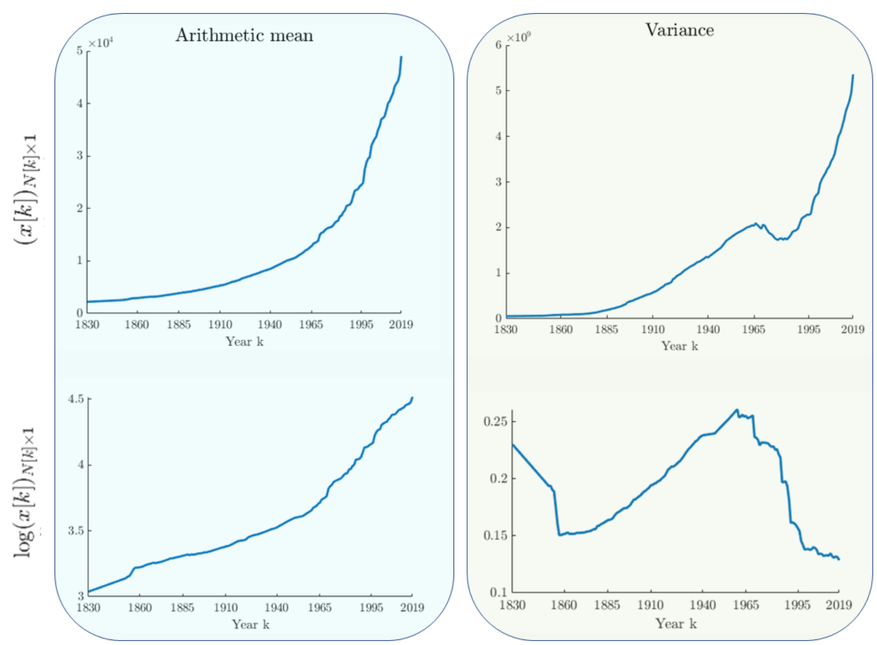


Figure 16 Arithmetic mean (left-part) and Variance (right-part) of the population vector $x[k]$ (upper-part) and logarithm of the population vector $log(x\,[k])$ (lower-part) in period $k \in \{1830, 2019\}$.

The variance of the logarithm of the population vector $log(x\,[k])$ in Figure 16 seems to reveal more information regarding the underlying merging process of the DMN, compared to the variance of the population vector $x[k]$. For example, the variance of the logarithm of the population vector $log(x\,[k])$ peaks around 1960 and starts decreasing afterwards, a phase transition which variance could indicate the transition from the urbanisation to suburbanisation period, which was enabled as workers started to massively commute by car and public transport. The tipping point of the variance also chronologically coincides with an intensified municipality merging process that started during the same period (presented in Figure 12). A merger results in the removal of a node from the left tail of the DMN population distribution and in a population spike of a stronger neighboring municipality, that annexed the abolished municipality. The wave of mergers that took place after 1960 (see Figure 12) negatively impacted the left tail of the population distribution, as will be discussed later in this chapter (in Figure 19).
For each year from 1830 until 2019 the population distribution per municipality is fitted by a lognormal and a Fermi-Dirac distribution, defined in sub-section 2.2.6. In the literature, the Fermi-Dirac distribution is also referred to as the log-logistic distribution [34]. The fit of both distribution functions is presented for the years 1830, 1920 and 2010 in Figure 17.

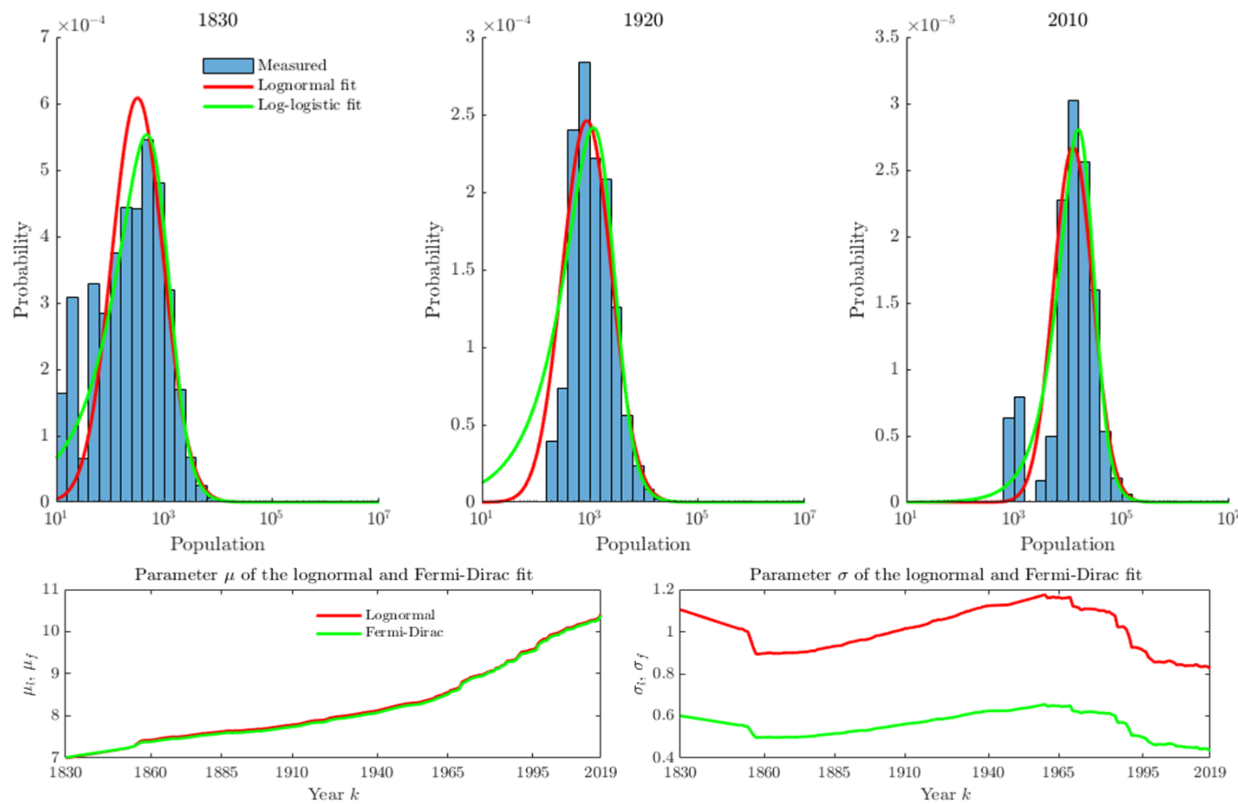


Figure 17 Measured population distribution versus fitted with a lognormal (red color) and a Fermi- Dirac distribution function (green color) for the years 1830, 1920 and 2010 (upper part). Estimated scale parameters μ_l, μ_f (left-lower part) and estimated shape parameters σ_l, σ_f (right-lower part) of the lognormal distribution fit (red color) and Fermi- Dirac distribution fit (green color) during period 1830-2019

To determine how likely the population distribution seems to follow a lognormal or a Fermi-Dirac distribution, both assumptions are tested by using two types of goodness-of-fit tests, i.e. the Anderson- Darling (AD) and the Kolmogorov-Smirnov (KS) test. Both tests provide a p value that quantifies how likely the assumption holds. These tests are based on measuring the difference (distance) between the assumed distribution model and the actual distribution. Using each assumed distribution model, artificial datasets are created and the distances are computed for each model. Finally, the p value represents the ratio of the artificial distance measures that are larger than the measured distance from the empirical data. If the computed p values are close to 0, the measured data does not seem to follow the assumed model. On the contrary, the closer the$p$ values are to 1, the more likely it is that the assumption holds. A common threshold that determines the acceptable plausibility of the assumption of these tests is usually $p \geq 0.05$. The p values of both goodness-of-fit tests are provided for both the lognormal and the Fermi-Dirac distribution of the population distribution in Figure 18. The results of both the AD and the KS test are consistent and imply that the plausibility of the population distribution per municipality following the Fermi-Dirac probability is higher than of the lognormal distribution, over the entire period (1830 − 2019).

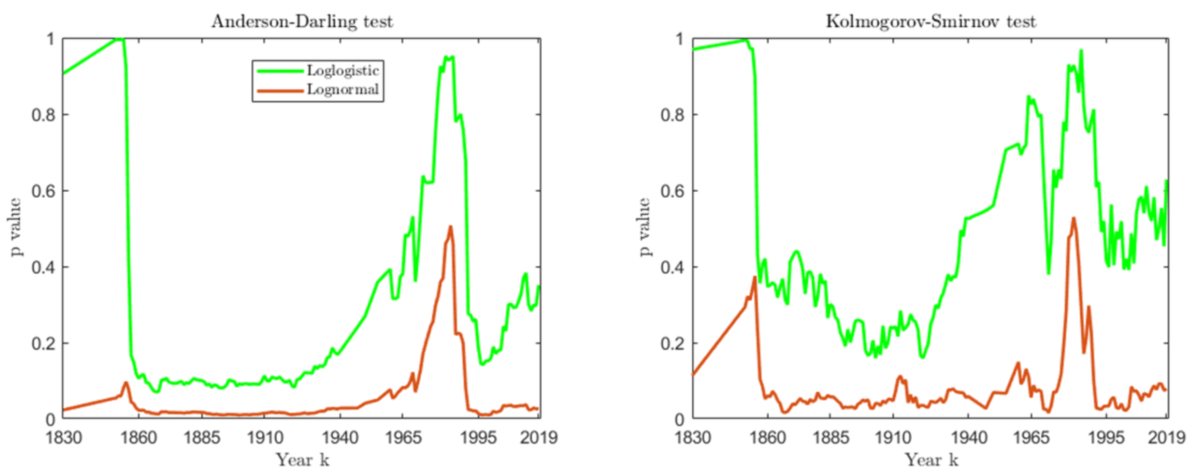


Figure 18 Anderson-Darling test (left part) and Kolmogorov-Smirnov test (right part) results of the lognormal (red color) and the Fermi-Dirac (green color) fit of the population distribution in the period (1830 − 2019).

As both the number of municipalities $N[k]$ and the population per municipality $x[k]$ is changing over time, the estimated parameters of the fitted distribution models, namely the scale parameter $\mu[k]$ and the shape parameter $\sigma[k]$ are time-varying. The fitted distribution functions for each year are plotted in Figure 19.

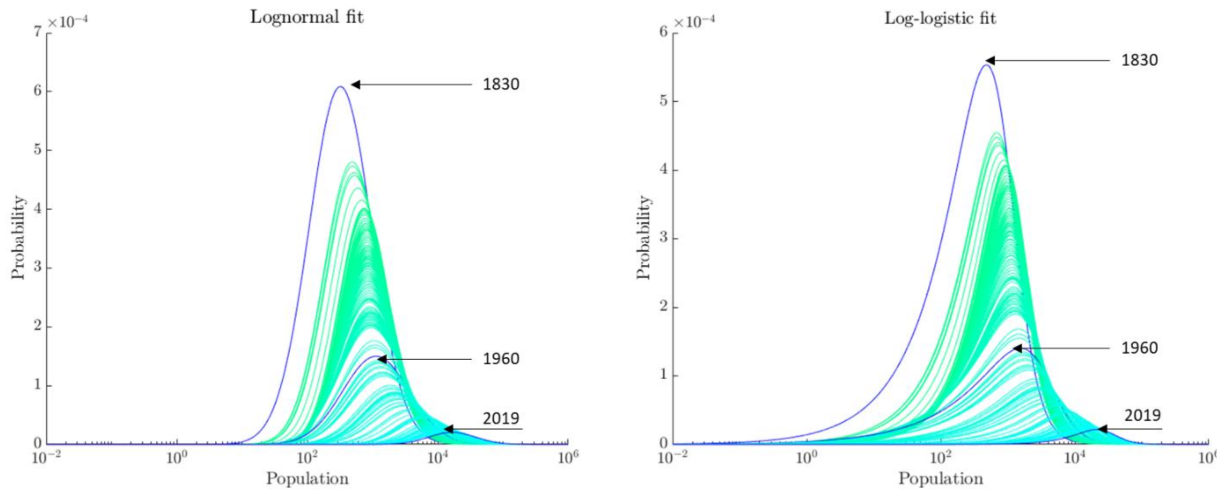


Figure 19 Fitted population distributions for each year during the period 1830-2019 with a lognormal distribution function (left-part) and with a Fermi-Dirac distribution function (right-part).

The aggregated lognormal distribution estimates of the population distribution in period 1830 − 2019 are and presented on the left part of Figure 19, while the aggregated Fermi-Dirac estimates are presented on the right part of Figure 19. The following observations regarding the Dutch population distribution and the underlying municipality merging process can be made from the time dynamics of the fitted distribution functions:

1) The peak probability is decreasing over the entire period, as the scale parameter μ is monotonically increasing (see left-lower part of Figure 17).
2) The probability density function is continuously shifting to the right over the entire period, as the total population of the Netherlands increased almost 8 times between 1830 and 2019 (see Figure 15).
3) From 1851 until 1960 the fitted distributions continuously widen, as in this period the shape parameter σ is monotonically increasing (see right-lower part of Figure 17).
4) Starting from 1960, an intensified merging process took place, which is reflected in the intensified horizontal rightward shifting of the population distribution since that period. During this merging process, municipalities with lower population than their neighbors were abolished and annexed by larger neighbors.

3.2.1 Rank-Size Distribution

Rank-size distributions and the Zipf's Law are a common research tool for analysing the population distribution in cities within a country. Few scientific publications have considered municipality population as a research object (for example [35]), however, to the best of the author's knowledge, none have researched the population dynamics from a temporal geographical municipality network's perspective. For the entire researched period (1830 – 2019) the rank-size distribution is analysed and the slope of the distribution is estimated. The upper part of Figure 20 shows the actual population rank-size distribution (blue dots) and the fitted line (red) on a log-log scale for years 1830, 1920 and 2010, while the lower part of Figure 20 presents the estimated slope of the population rank-size distribution for the entire period (1830– 2019)

The presented population rank-size distribution over almost two centuries reveals a general trend of population increase per municipality (vertical movement of the dots in the upper part of Figure 20), which is equivalent to the horizontal movement of the lognormal/Fermi-Dirac distribution fit over time (in Figure 19). The analysis of the estimated slope reveals two opposite trends in people's migration patterns over time:

- Since 1860 the slope started increasing from values ≈ 0.65 and peaked at ≈ 0.85 in 1960. This increasing trend of the slope of the population rank-size distribution indicates an underlying process until 1960, during which bigger municipalities (in terms of population) were growing faster in population, compared to smaller-population municipalities
- Since 1960, the estimated slope changed its trajectory and started decreasing from 1960 until the present day. Thus, in this period an opposite underlying process took place, during which the population growth of the biggest municipalities occurred at a slower pace compared to the fast growth rate until 1960. It is possible that this turning point indicates the beginning of suburbanization in the Netherlands enabled by mass transportation and day to day commuting.

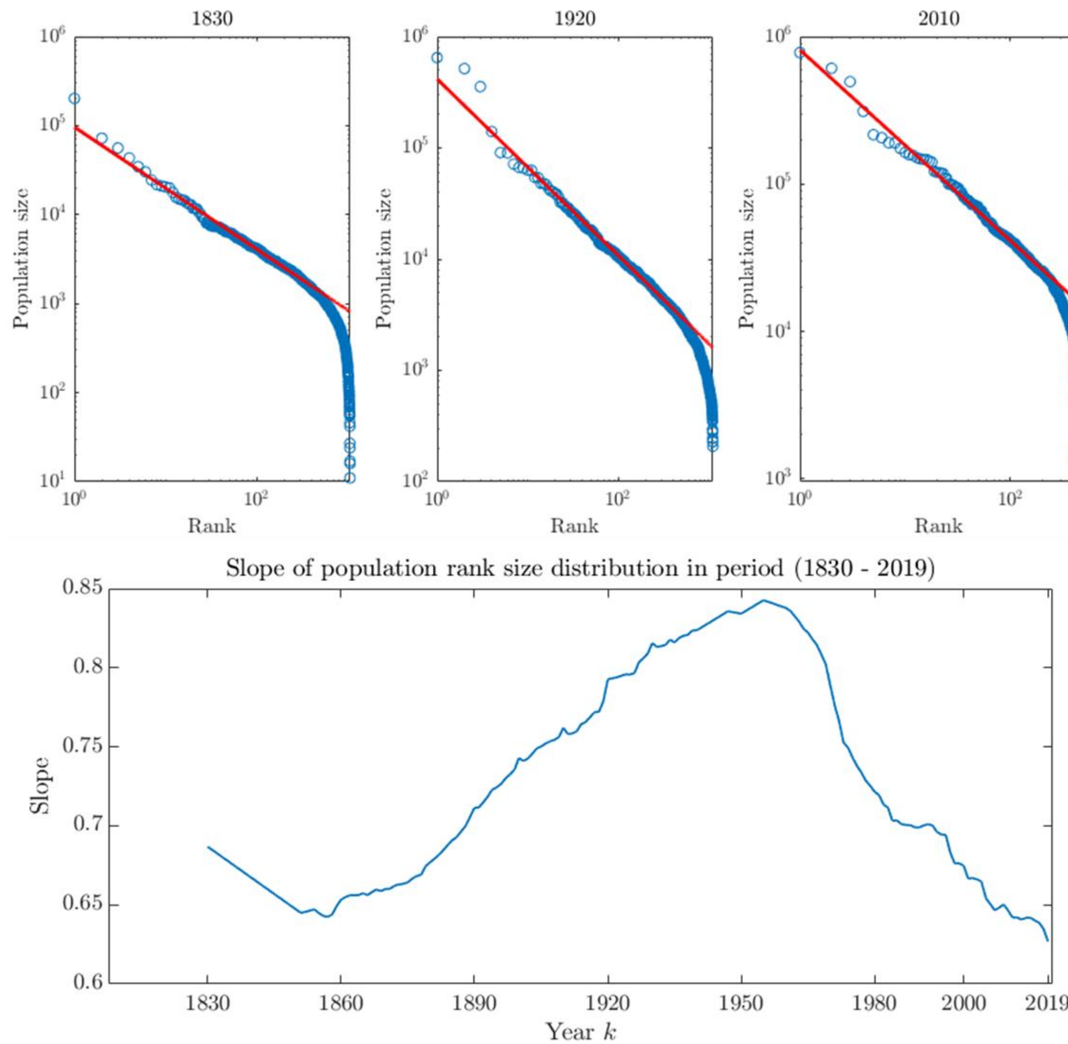


Figure 20 Population rank-size distribution per municipality and the estimated ranking slope in years 1830, 1920 and 2010 (upper part). Estimated slope of the population rank-size distribution in period (1830 - 2019) (lower part).

3.2.2 Power-Law Fitting

From the population vectors, we observed in each year of the researched time series that the exponent value $\tau[k]$ of the probability density function of the power-law fitted population distribution varies between 2 and 3 (upper part of Figure 21). The maximum exponent value occurred in 1865 at $\tau[1856] = 2.69$. During the period of industrialization and urbanisation in the Netherlands, the exponent value had a decreasing trend with the lowest values occurring at $\tau[1947] = 2.11$ and $\tau[1961] = 2.17$. Revealing power-law behavior in general, the exponent value of the probability density function of the Dutch population vector started increasing again since 1961. During the last decade, the exponent value returns to its mid-19th century values, such as $\tau[2013] = 2.62$ and $\tau[2019] = 2.63$. The time-dynamics of the exponent value display

similar trends as the slope of the rank-size population distribution (for example Figure 22 plots the fitted power-law for 1851). Likely the Dutch Municipality Network, belongs to the class of scale-free networks as time series of population developments seem to follow a power-law distribution. An exponential cut-off function is applied to both sides of the logarithmic population scale in the probability density function (for example to determine the slope of the power-law fit in Figure 22), in order to exclude the municipalities with the largest population (right-hand side of the population axis) and the municipalities with very low population (left-hand side of the population axis).
This scale free behavior has also been observed in community structures of many real-world networks. The beginning of the industrialisation and urbanisation around 1850 chronologically coincided with the maximum value of $\tau[k]$, indicating that the surface limitations of a small-sized country like the Netherlands were not yet hindering the quickly growing Dutch population, while municipalities existed with a few hundreds of citizens. The phase transition in the exponent value of $\tau[1961]$ (upper part of Figure 21) is likely an indicator of the beginning of the suburbanisation period in the Netherlands, in line with the phase transition of the rank-size population distribution that occurred during the same period (Figure 20).

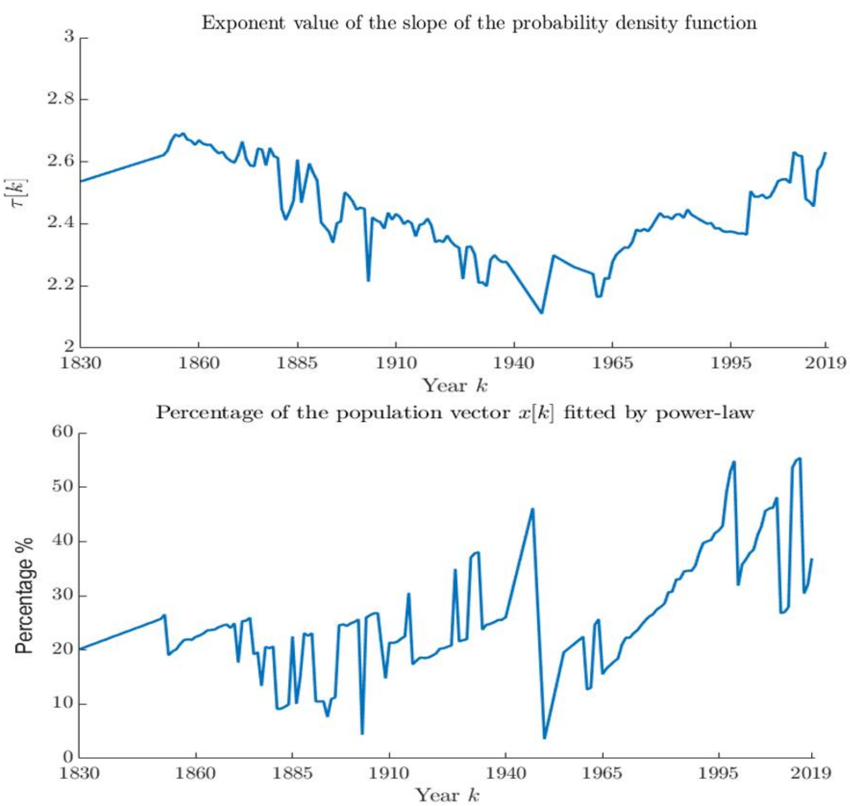


Figure 21 (Upper part) Exponent value τ[k] of the slope of the probability density function that was found from curve fitting of the population distribution per municipality in the period 1830 − 2019.(Lower part) The percentage of the N[k] × 1 vector x[k] that is fitted by a power-law fit in the period 1830 − 2019.

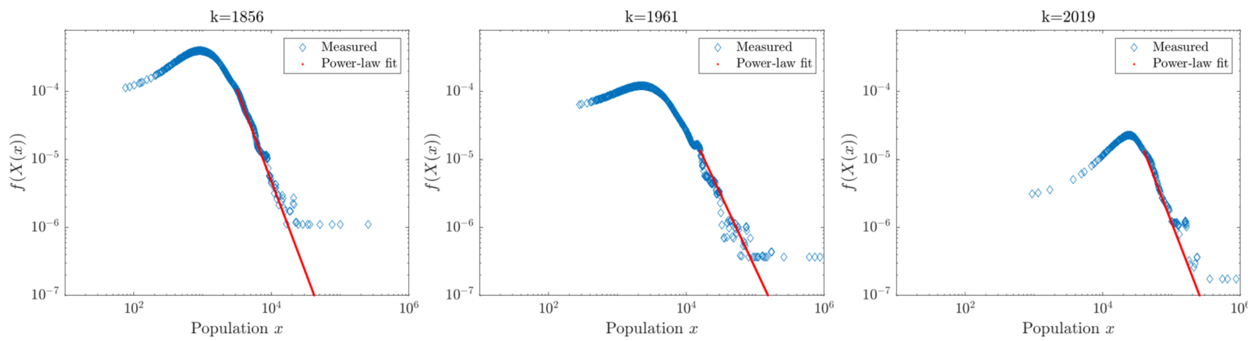


Figure 22 Probability density function of the actual Dutch municipality population (blue points) and power-law fit (red line) in years $k \in \{1856, 1961, 2019\}$

3.3 Sector-related Layer Datasets

This section includes a neighbor-level analysis on sector-related datasets of municipalities and introduces the concept of Average Neighbor Superiority as a possible indicator for the vitality of municipalities. This section also discusses the urbanisation degree of municipalities and the abolishments of municipalities with regard to selected datasets from the education layer (ISIC section P) and the transport layer (ISIC section H).

3.3.1 Proximity to Facilities

We explored a CBS dataset regarding the average proximity to facilities for municipalities during the period 2006-2019. The proximity dataset contains average travel distances for residents of Dutch municipalities from their home address to the nearest facilities (for example school, general practitioner or supermarket). These data proximity values are calculated as an average over all residential addresses in the area [36]. The dataset also provides the number of facilities located within a certain distance from the residential addresses within each municipality's boundaries, but this metric seems to favor small-sized municipalities. For this reason, we decided to use the 'average distance to facility' statistic type, which naturally scales with the municipality's area size.

Classification of Facilities

The proximity dataset contains a wide variety of different types of facilities, some of which are incomplete for certain time periods and/or certain municipalities. For the majority of facilities, the data start from 2007. Table 2 below classifies the facilities for which data is available (almost) consistently into three types:

- Essential Facilities
- Education Related Facilities
- Entertainment Facilities

The facilities categorized as essential are in accordance with the corresponding vital sectors defined in the Dutch BVI-report (see Appendix section 7.3.2)

Table 2 Types of facilities for which the Average distance to the nearest facility is available per municipality in period 2006-2019

Essential Facilities	Education Facilities	Entertainment Facilities
GP (General Practitioner)	Childcare (*Kinderopvang*)	Café, bar, club
GP Station (*huisartsenpost*)	Schoolcare for primary	Cafeteria, fastfood restaurant
Hospital incl. outpatient clinic	Primary school	Department store
Hospital excl. outpatient clinic	Secondary school	Performing acts excl. festivals
Pharmacy	Secondary vocational (VMBO)	Music venue
Restaurants incl. pickup/delivery (café)restaurants	Higher education (HAVO,VWO)	Cinema
Supermarket		Hotel
Other daily necessities incl. food-shops		Sauna
Train station		Solarium
Major interchange station (*belangrijk overstapstation*)		Attraction (Amusement park, zoo and indoor playground)
		Library
		Ice rink

Average Distance to Facilities per Municipality Type

We wanted to investigate a possible correlation between different types of municipalities and the proximity to facilities that they offer. There were in total 140 abolished municipalities (discontinued CBS code) during the period 2006-2019, 32 of which were Type A (Absorption) and 101 Type C (Coalition) mergers. In the meantime, there briefly existed two municipalities that were both established (new CBS code) and abolished within this time-period, both of which were involved in a Type C merger. Table 3 below shows how many currently (in 2019) inactive municipalities were active in each year of the dataset.

Table 3 Number of active municipalties in year k that were abolished between 2006-2019 per merger type A and C

Year *k*	Active Municipalities in year *k* that were abolished between 2006-2019 Type A	Active Municipalities in year *k* that were abolished between 2006-2019 Type C
2006	32	99
2007	25	87
2008	25	87
2009	24	85
2010	21	75
2011	16	64
2012	16	60
2013	14	54
2014	12	51
2015	7	44
2016	6	41
2017	6	38
2018	4	30
2019	4	30

Figure 23 -Figure 25 plot the average distance in kilometers to each facility for every type of municipality mentioned in Table 3 per available year in the dataset (2006-2019), against the average distance to the same facility for all the municipalities that existed in 2019 (355 active municipalities). Note that the number of Type A abolished municipalities is rather small after 2014, which causes the sample-space for the period 2015-2019 to be limited, thus causing the calculated average distances for this municipality type to not be very representative of the typical characteristics of a municipality that is absorbed by its stronger neighbor (Type A Absorption merger type).

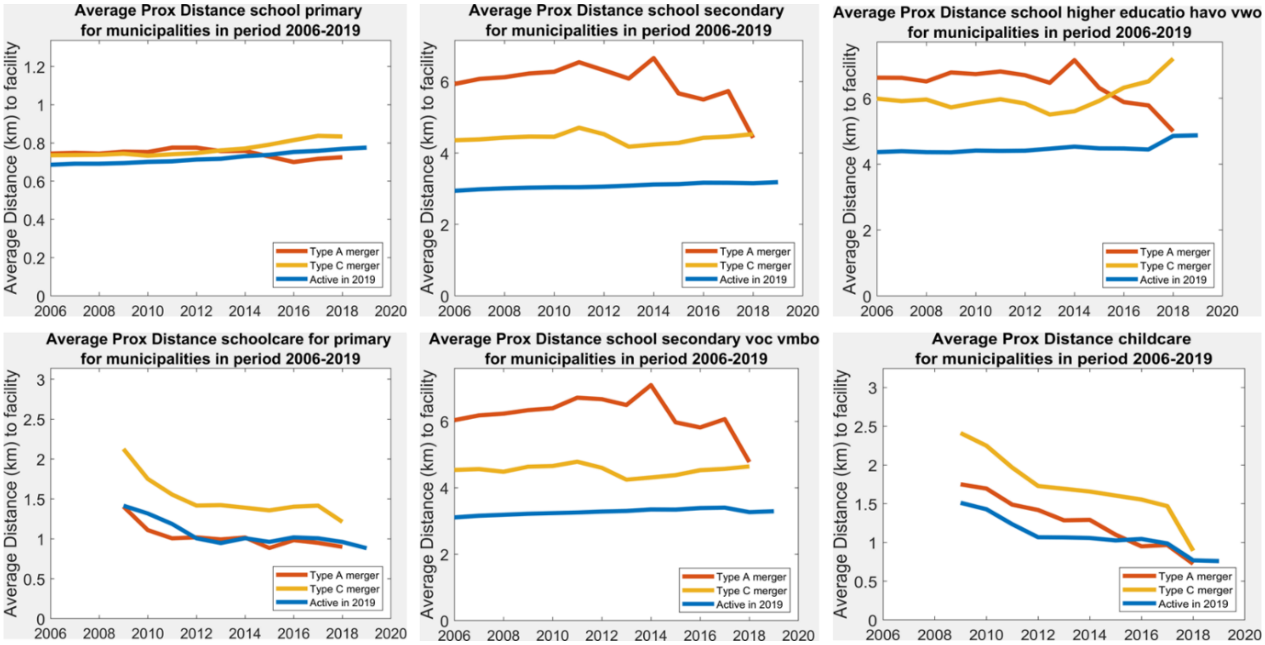


Figure 23 Average travel distance to the nearest educational facility for all the residents of three different municipality types (Type A abolished municipalities in RED, Type C abolished municipalities in ORANGE and active municipalities in 2019 in BLUE)

The presence of a at least one primary school in every neighbourhood is considered vital for the Dutch educational system, therefore the average distance to a primary school is just below 800m for the citizens of all Dutch municipalities (at least from 2006 onwards, as seen in the top left part of Figure 23), regardless of the status of the municipality (active or abolished). A different pattern holds for secondary (vocational) and higher education, where the active municipalities clearly offer closer proximities to these educational institutes compared to municipalities that were abolished. Furthermore, Type A abolished municipalities offered the longest average travel distance to the nearest secondary (vocational) school and university, while they were almost at the same level with active municipalities when it comes to childcare and primary schoolcare facilities.

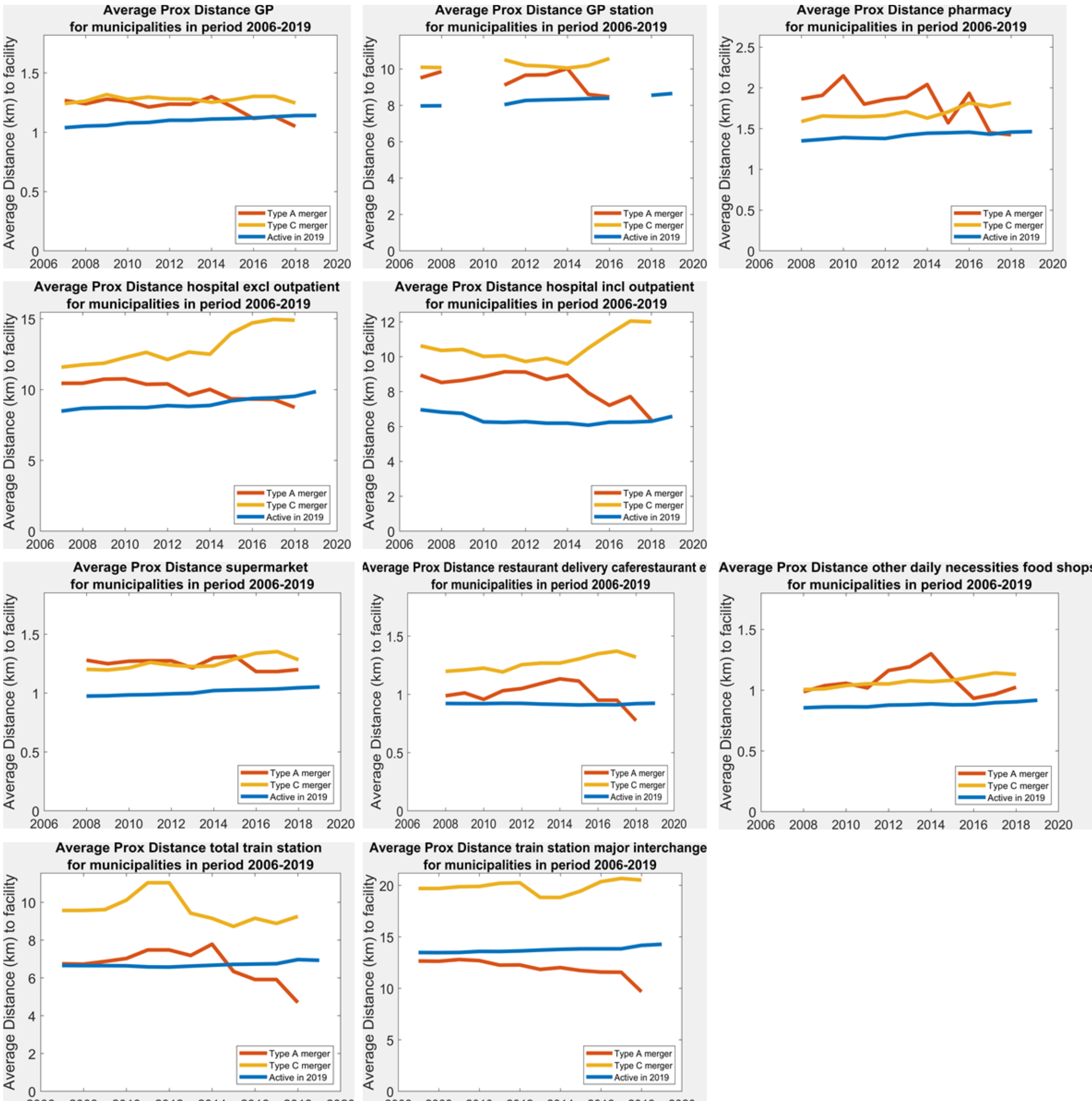


Figure 24 Average travel distance to the nearest essential facility for all the residents of three different municipality types (Type A abolished municipalities in RED, Type C abolished municipalities in ORANGE and active municipalities in 2019 in BLUE)

Similar to educational facilities, active municipalities offer the shortest travel distances to almost all essential facilities than Type A and Type C municipalities, except for train stations after 2015. This can be attributed to two factors: 1) Type A abolished municipalities are usually the smallest municipality type in terms of area size, so it is logical that the residential core within these municipalities is concentrated around the train station area, thus shortening the average travel distance for all residents. 2) Not all active municipalities have a train station, and certain (island) municipalities strongly increase the national average travel distance to the nearest train station. With other essential facilities, there is no clear distinction between Type A and Type C abolished municipalities in terms of average travel distance to the nearest facility.

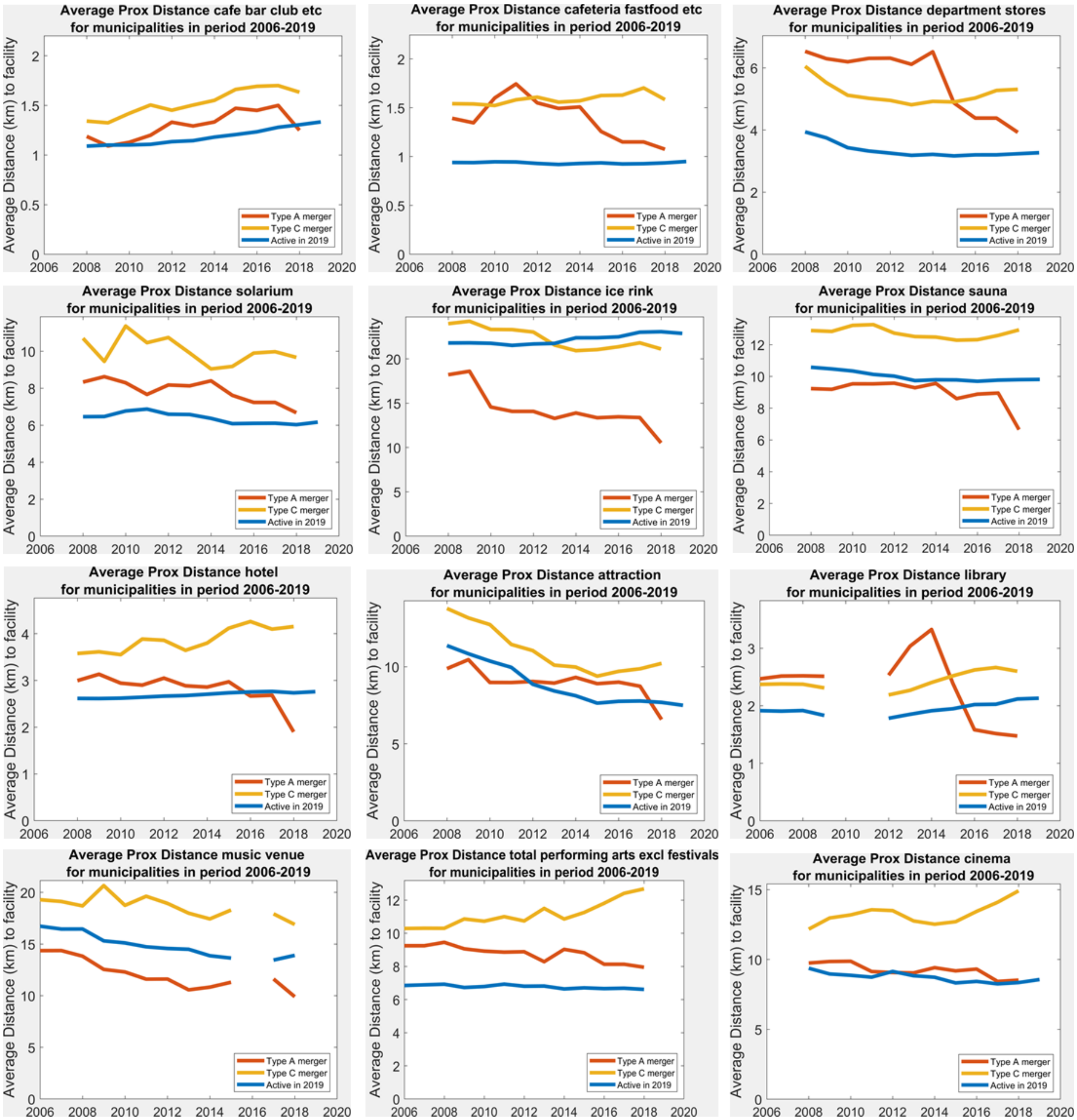


Figure 25 Average travel distance to the nearest entertainment facility for all the residents of three different municipality types (Type A abolished municipalities in RED, Type C abolished municipalities in ORANGE and active municipalities in 2019 in BLUE)

There are certain types of entertainment facilities that absorbed (Type A) municipalities seem to offer closer proximities to, compared to active municipalities. For example, these municipalities offer shorter travel distances to saunas, music venues and ice rinks for the entire studied period, and to department stores, hotels and libraries for the last 4 years. This observation regarding the latter facility group can likely be attributed to the limited sample of Type A municipalities that were abolished during the last 4 years of the time series (20 municipalities were abolished in total during 2016-2019). On the other hand, the consistent pattern for entertainment facilities such as saunas, music venues and ice rinks could indicate that the presence of such entertainment facilities is not vital enough for the small-sized Type A municipalities to survive on their own without being absorbed by a stronger neighboring municipality. On the other hand, the annexation of the smaller Type A municipality with such entertainment facilities by a more urbanised neighboring municipality might in fact benefit the quality of life of the entire area, as seen in the motives of municipality mergers in sub-section 3.1.3.

Neighbor level analysis

In the vast majority of Type A mergers during the period 1830-2019 (89% out of 542 mergers in total), the abolished municipality was absorbed by a neighboring municipality [11]. We wanted to investigate if the proximity to facilities that different types of municipalities offer can be considered a criterion for their survivability. In other words, how important is the proximity to facilities for the survivability of a municipality. For this reason, for each municipality we compared the average distance to every facility type against the average distance of all its neighboring municipalities for the same year.
For example, let the average distance to a facility in year k for abolished municipality i be $\Delta_i(k)$, and the average distances to the same facility of the n neighboring municipalities $j_1, j_2, \ldots, j_n$ in year k be $\Delta_{j_1}(k), \Delta_{j_2}(k), \ldots, \Delta_{j_n}(k)$. Finally, let $m \leq n$ be the number of neighbors who have shorter average distance to a facility than municipality i itself , i.e. it holds that $\Delta_i(k) > \Delta_{j \in \{1,\ldots,m\}}(k)$. Then, for each and municipality i we define the Neighbor Superiority for a facility in year k as: $NS_i(k) = 100 \cdot (m/n)$, which reflects the percentage of the neighbors who offer shorter distances to a facility than municipality i itself. Consequently, we define the Average Neighbor Superiority for a facility for the entire period of existence of municipality i as: $NS_{av,i} = \overline{NS_i(k)}$, where $k \in \{2006, \ldots, abol\}$. The Average Neighbor Superiority for municipality i therefore reflects the arithmetic mean of all the Neighbor Superiorities for municipality i over the time-period within the proximity dataset that municipality i was active, and $abol$ marks the year that the municipality's CBS code was

11 In the remaining 11% of the cases, the abolished municipality i is a neighbor of another abolished municipality j. In this case, both municipalities i and j are annexed in the same year (multiple merger) by the absorbing municipality p. In this merger example, the following neighbor pairs hold: (i, j) , (j, p)

abolished. For the municipalities that were still active in 2019, it is assigned $abol = 2019$, which is the last year of the proximity dataset. Finally, for each of the three municipality types (active in 2019, abolished Type A, abolished Type C), we calculate the overall Average Neighbor Superiority NS_{av} for all the municipalities that belong to one of the following classes: 1) active municipalities, 2) abolished Type A municipalities and 3) abolished Type C municipalities. The overall NS_{av}^{F} is calculated as the arithmetic mean of the $NS_{av,_i}$ over all the municipalities that belong to one of the three aforementioned classes. The results are presented in Table 4.

In 26 out of the 28 total facilities F researched (Table 4), it holds that:

$$NS_{av,\text{active municipalities}} < 50\% < NS_{av,\text{Type C municipalities}} < NS_{av,\text{Type A municipalities}}$$

This means that:

- A significant percentage of the neighbors of Type A (Absorbed) municipalities offered on average shorter distances to almost all facilities than the abolished Type A municipalities themselves,
- A slightly less but still significant percentage of the neighbors of Type C (Coalition) municipalities offered on average shorter distances to almost all facilities than the abolished Type C municipalities themselves,
- On average, less than half of the neighbors of active municipalities in 2019 offered shorter proximities to almost all facilities than the active municipalities themselves.

These findings could in turn indicate that abolished Type A municipalities are surrounded by 'stronger' neighbors, which could explain why such municipalities are absorbed by 'stronger' neighboring municipalities. For example, on average 3 out of 4 neighbors of abolished Type A municipalities offered closer distances to the nearest hospital or secondary school than the abolished municipalities themselves.
On the other end of the scale, on average only around 43% of the neighbors of active municipalities in 2019 offered closer proximities to any type of facility than the active municipalities themselves, which could explain why these municipalities were still active in 2019.

Additionally, the NS_{av} for each individual municipality belonging to the same categories as in Table 5 was calculated for the three facility types. This calculation could be an indicator about the future survivability of existing municipalities, since municipalities with 'stronger' neighbors tend to be annexed (Type A merger) or to merge with other neighbors (Type C merger). The findings are presented in Appendix 7.1.2, 7.1.4 and 7.1.2, where the urbanisation degree of municipalities and their population are also shown.

Table 4 Average Neighbor Superiority (NS_{av}) for different types of municipalities and facilities

Essential Facilities	NS_{av} active in 2019	NS_{av} Type A	NS_{av} Type C	Education Facilities	NS_{av} active in 2019	NS_{av} Type A	NS_{av} Type C	Entertainment Facilities	NS_{av} active in 2019	NS_{av} Type A	NS_{av} Type C
GP (General Practitioner)	43.5	62.6	50.1	Childcare (*Kinderopvang*)	41.1	68.5	54.4	Café, bar, club	42.7	75.3	57.8
GP Station (*huisartsenpost*)	39.2	68.5	59.0	Schoolcare for primary	40.2	59.9	54.4	Cafeteria, fastfood restaurant	42.9	54.5	47.1
Hospital incl. outpatient clinic	45.7	65.7	50.8	Primary school	37.3	57.0	43.5	Department store	48.7	59.1	55.5
Hospital excl. outpatient clinic	48.7	75.8	61.8	Secondary school	47.7	76.6	56.7	Performing acts excl. festivals	41.1	56.0	51.6
Pharmacy	49.7	66.8	59.2	Secondary vocational (VMBO)	47.9	75.4	56.7	Music venue	29.6	51.2	47.7
Restaurants incl. pickup/delivery (café)restaurants	42.7	53.5	52.6	Higher education (HAVO,VWO)	48.6	74.8	55.9	Cinema	32.6	58.5	55.8
Supermarket	42.5	59.5	50.1					Hotel	34.9	59.3	55.0
Other daily necessities incl. food-shops	41.9	56.9	47.6					Sauna	41.8	63.7	60.4
Train station	49.4	72.0	57.6					Solarium	50.3	55.3	56.1
Major interchange station (*belangrijk overstapstation*)	50.7	59.6	59.7					Attraction (Amusement park, zoo and indoor playground)	49.9	74.8	55.3
								Library	49.6	71.9	57.6
								Ice rink	42.7	65.9	55.3
NS_{av} column-wise average values	45.4	64.1	54.8		43.8	68.7	53.6		42.2	62.1	54.6

3.3.2 Primary Schools

In this sub-section we investigate the relation between primary school closures or fusions with other schools and how this affected the population characteristics of municipalities, and possibly the survivability of them.

We analysed a dataset with the locations of schools that were closed, or merged with other schools during the period 1997-2021 [37], [38]. There were 1477 school closures or fusions in 590 municipalities, out of which 260 municipalities had their CBS code abolished and 197 municipalities had their Amsterdam code abolished as well. The correlation between the abolishment of municipalities and school closures does not seem to follow a recognizable pattern, although in most cases a school closure followed around 16 years after a municipality was abolished.

To correlate school closures with the population characteristics of municipalities, we used a CBS dataset [39] revealing the age breakdown of the total population of Dutch municipalities during the period 1988-2021. Children aged 0-12 years old are (soon-to-be) primary school attendees. We plot the ratio of the age group 0-12 to the total population of each municipality, for a selection of municipalities that belong to one of the three following classes:

- Figure 26: Large municipalities (>100K inhabitants in 1988)
- Figure 27: Small municipalities (<20K inhabitants in 1988) with at least one primary school closure or fusion during period 1997-2021
- Figure 28: Small municipalities (<20K inhabitants in 1988) without any primary school closure or fusion during period 1997-2021

In all 9 large municipalities plotted in Figure 26 we observe a similar pattern of children-to-total population ratio: the value starts around 13 , slightly increases in mid-2000s and then drops again towards its original levels. There are many school closures/fusions in these municipalities, but there are also new schools being established, while these places continuously attract more population from (abroad) immigration, so the children ratio is not declining as much as the next figure.

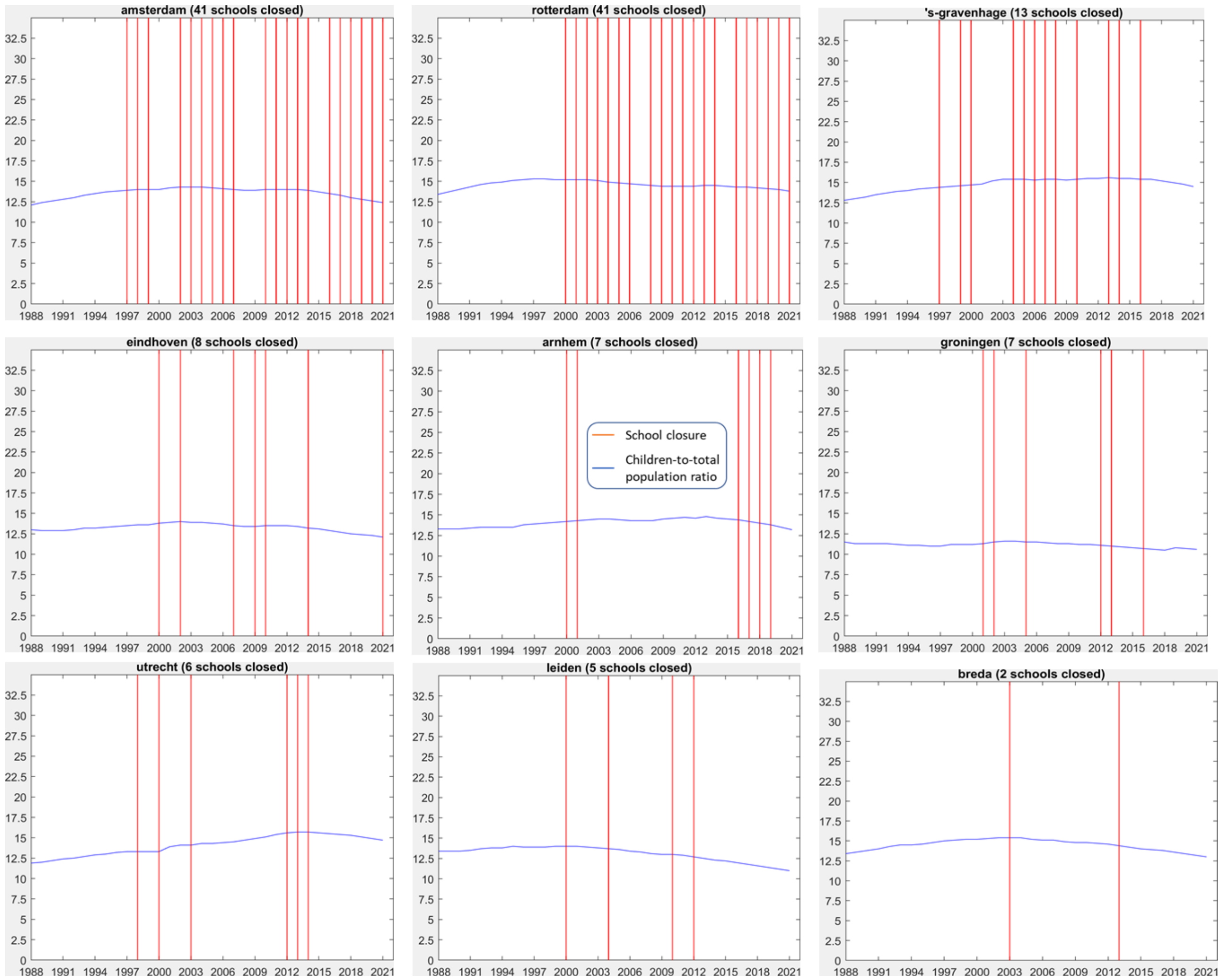


Figure 26 Ratio of Children aged 0-12 to total population of large municipalities (>100K inhabitants in 1988) (blue line) and primary school closures within the municipalities (vertical red lines) during period 1988-2021

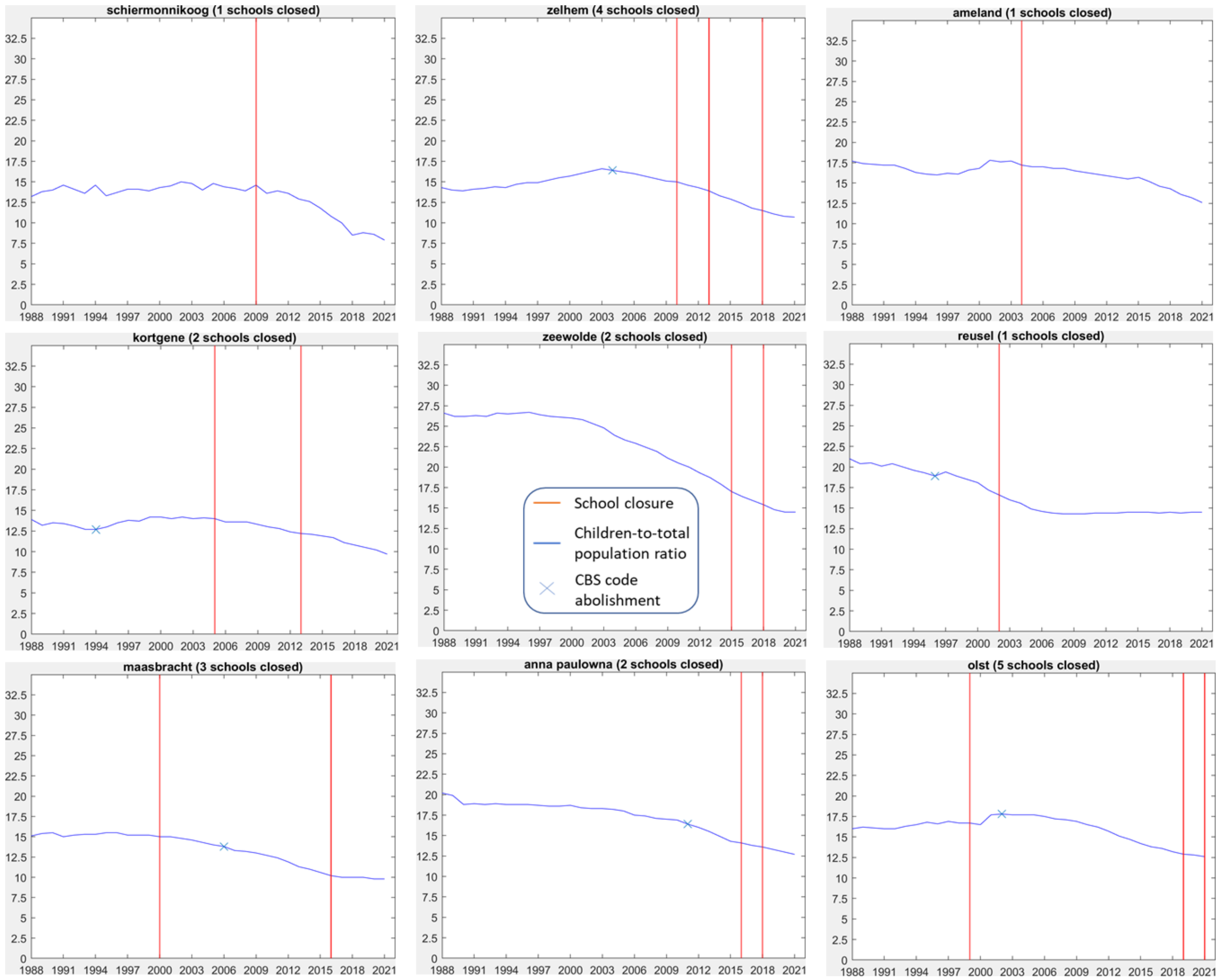


Figure 27 Ratio of Children aged 0-12 to total population of small municipalities (<20K inhabitants in 1988) (blue line) with at least one primary school closure or fusion (vertical red lines) during period 1988-2021

Figure 27 shows the children-to-total population ratio for municipalities at the opposite end of the population scale, which had less than 20K inhabitants in 1988. In these plots, an 'X' mark on some population figures indicates that the municipality was abolished (its CBS code was discontinued at the year of the mark), but its Amsterdam code was given to the new municipal entity after the merger, which means that this was the most populous municipality in that merger. For this reason, the population ratio of this municipality is extended beyond its CBS code abolition, and the remaining population values are taken from the new municipality (with the same Amsterdam code as the abolished municipality) that did not exist before.

Contrary to large municipalities, small municipalities with at least one primary school closure demonstrate a different trend, one with declining children ratio, which seems to have been triggered by a school closure, or at least influenced at some degree by it. Smaller municipalities don't have that many schools, so a school closure can likely have more impact than in bigger municipalities.

Here, it can be argued that this declining trend of children-to-total population ratio is a manifestation of population aging, which is an almost global phenomenon during recent decades. And that is true to a certain extent and has indeed affected these plots. However, if we plot the children-to-total population ratio in small municipalities that didn't suffer from a school closure in the same period, we observe a different pattern in a lot of cases. For example, for the municipalities shown in Figure 28, the ratio does not decline as rapidly as in Figure 27 in recent years. Given that municipalities in both Figure 27 and Figure 28 belong to the same population class (< 20K inhabitants in 1988) and that their only difference is the existence or absence of a closed primary school, one could argue that the closing/fusion of a primary school can have a negative effect in the children-to-total population ratio in small municipalities.

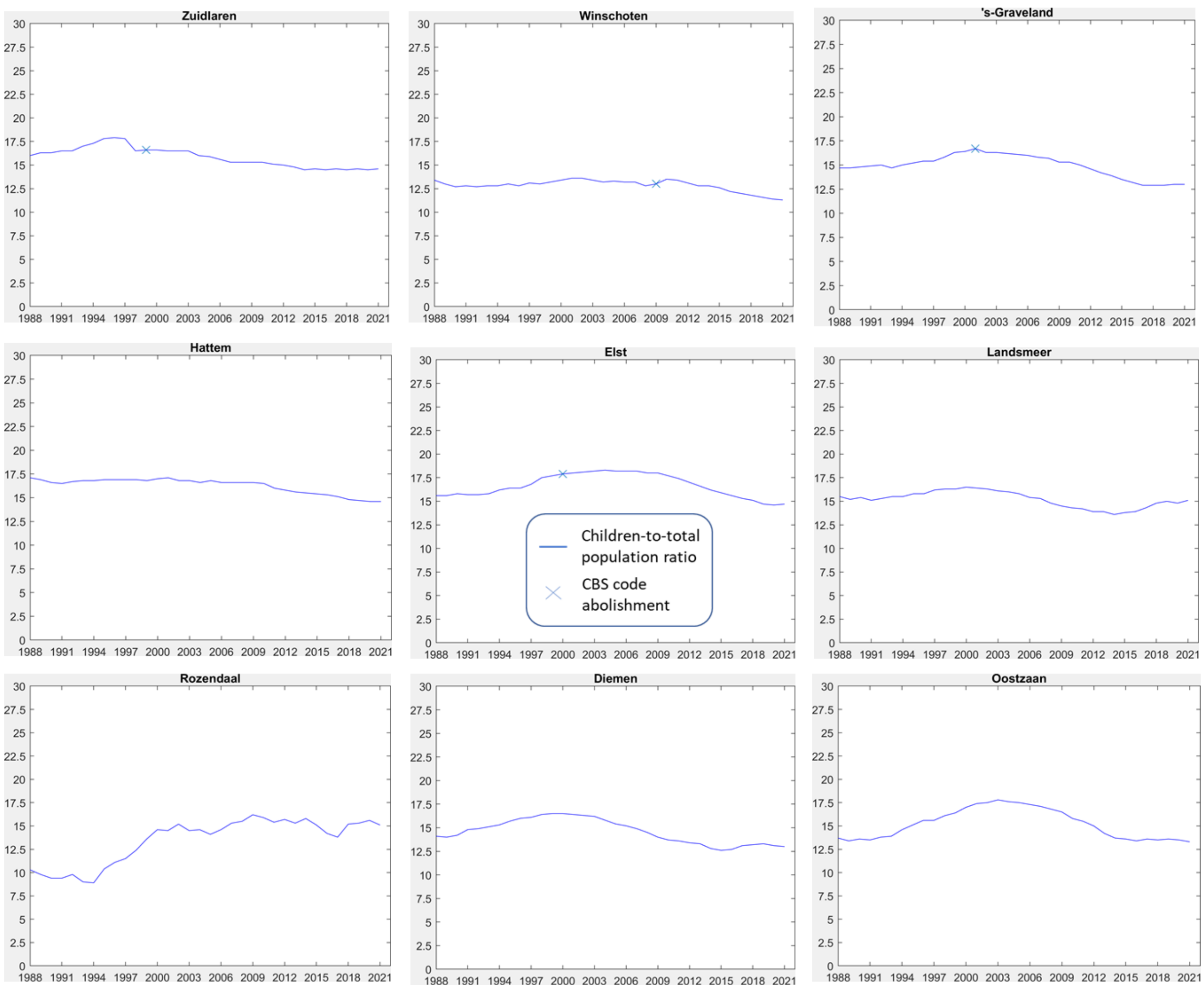


Figure 28 Ratio of Children aged 0-12 to total population of small municipalities (<20K inhabitants in 1988) (blue line) without any primary school closure or fusion during period 1988-2021

3.3.3 Railway Stations

We explored two datasets regarding railway stations:
--The locations of existing NS (Nederlandse Spoorwegen) railway stations. The dataset lists the types of 401 railway stations in the Netherlands (status of March 2021) [40], which we classified into two main categories: Intercity/Megastations (60 stations) and Sprinter/Other stations (341 stations, mainly stoptreinstations which NS refers to as Sprinter train stations).
--The locations of railway stations in the Netherlands which were closed down in the period 1891-2006 [41]. The dataset also contains the year of closure for most stations. The dataset lists 538 stations that stopped their function during the aforementioned period.

Table 5 Active and Closed Railway stations per province. The average time difference between the station closure and the municipality abolishment is based on the municipality's Amsterdam code abolition

Province	Total Active Stations	Total Closed Stations	Closed Stations in Abolished Municipalities	Average Time Difference between station closure and municipality abolishment
Friesland	24	49	41	65.6 years
Zeeland	9	31	24	35.5 years
Noord_Brabant	35	58	40	48.3 years
Drenthe	9	20	13	56.2 years
Groningen	30	52	32	56.2 years
Limburg	38	28	16	52.8 years
Overijssel	36	75	31	43.5 years
Zuid_Holland	52	46	18	52 years
Utrecht	33	34	13	48.3 years
Noord_Holland	62	69	23	43.1 years
Gelderland	65	76	22	68 years
Flevoland	8	0	0	0 years
TOTALS:	**401 stations**	**538 stations**	**273 stations**	**52 years**

Table 5 presents the active and closed railway stations per province in the Netherlands. Out of the 538 closed railway station, 66% of them were located in municipalities that had their CBS code abolished, while 50% were located in municipalities that had both their CBS and Amsterdam code abolished. Municipalities in Friesland and Zeeland have the highest correlation between abolishment of municipalities and closure of stations within those municipalities. On national average, the time difference between a station closure and a municipality abolishment seems to be around 52 years (the closure of the station comes chronologically first).
In addition, 27% of closed stations are located in shrinking or anticipation municipalities (status 2019). These observations are visualized in Figure 29.

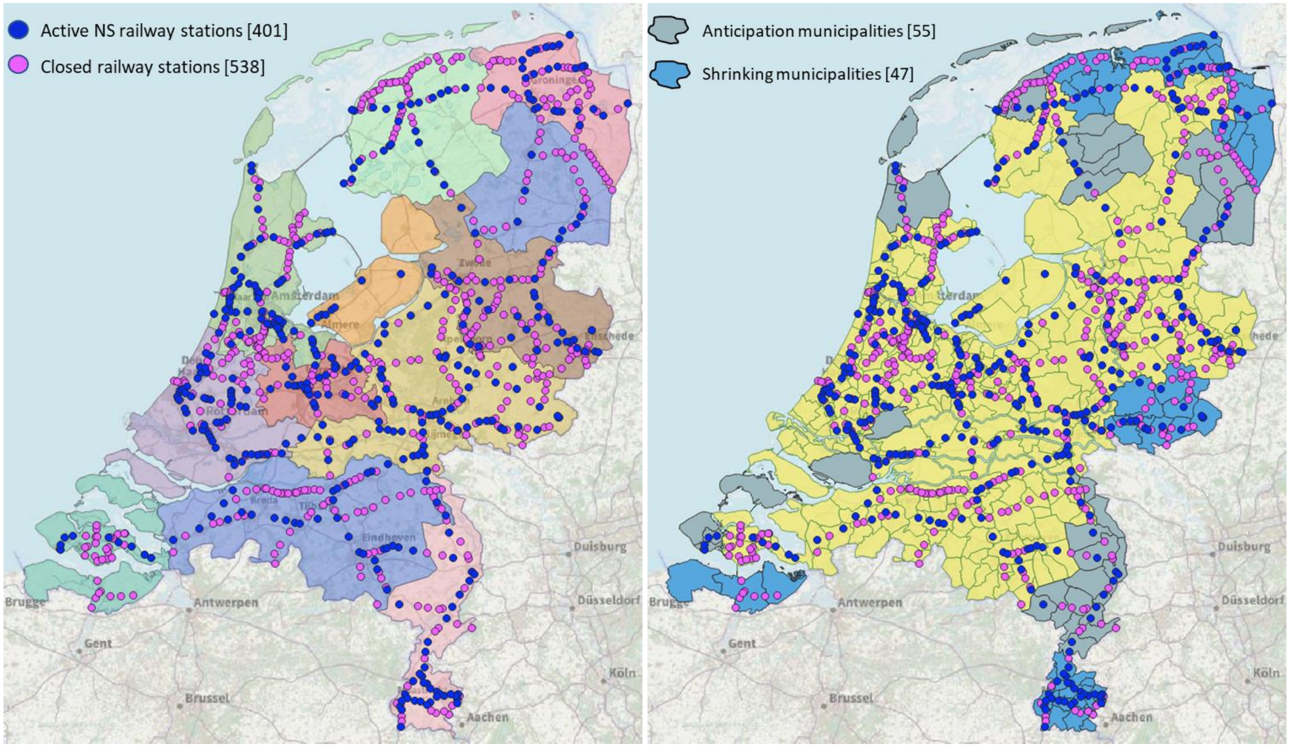


Figure 29 Maps of active NS railway stations in 2021 (blue) and closed railway stations during period 1891-2006 (purple): per province (left figure) and per shrinking and anticipation municipalities (status 2019) (right figure).

There are 5 classes of urbanisation for municipalities (in Dutch: *Stedelijkheidsklasse* or STED), defined by CBS based on the local address density of each municipality. The five urbanization degrees are based on class boundaries of 2,500, 1,500, 1,000 and 500 addresses per km².
The following STED classes are distinguished: [42]

1. Very strongly urban (local address density of 2 500 or more);
2. Highly urban (local address density from 1,500 to 2,500);
3. Moderately urban (local address density from 1,000 to 1,500);
4. Slightly urban (local address density from 500 to 1,000);
5. Non-urban (local address density less than 500).

Table 6 shows the number of municipalities belonging to each urbanisation class and the number of active train stations, further categorized into Intercity/Mega stations and Sprinter/Other stations. The table's last column shows the total number of closed train stations per urbanisation degree, counted within the 2019 municipal boundaries.

Table 6 Active NS Train Stations in 2021 and closed train stations in period 1891-2006 per Urbanisation Degree (STED) of municipalities in 2019

STED	Number of Municipalities	Total Active Train Stations	Intercity/Mega Active Stations	Sprinter/Other Active Stations	Total Closed Train Stations
1	20	66	19	47	35
2	74	127	31	96	110
3	75	70	7	63	100
4	128	99	1	98	178
5	58	39	2	37	115
Totals	355	401	60	341	538

The majority of active train stations are located within highly urbanised municipalities (STED 2), while the majority of closed train stations were located in areas that are currently classified as slightly urban (STED 4). The general trend is that, the more urbanised a municipality is, the more active stations exist within its boundaries (relatively to the number of municipalities belonging to that urbanisation class). This explains the disproportionately large number of active train stations (193 out of 401) which are concentrated only within municipalities with STED 1 and 2 (94 out of 355 municipalities). On the contrary, less urbanised municipalities have more closed stations than active stations (Figure 30). In addition, more urbanised municipalities have more intercity and mega stations than Sprinter and other train station types (Figure 31).

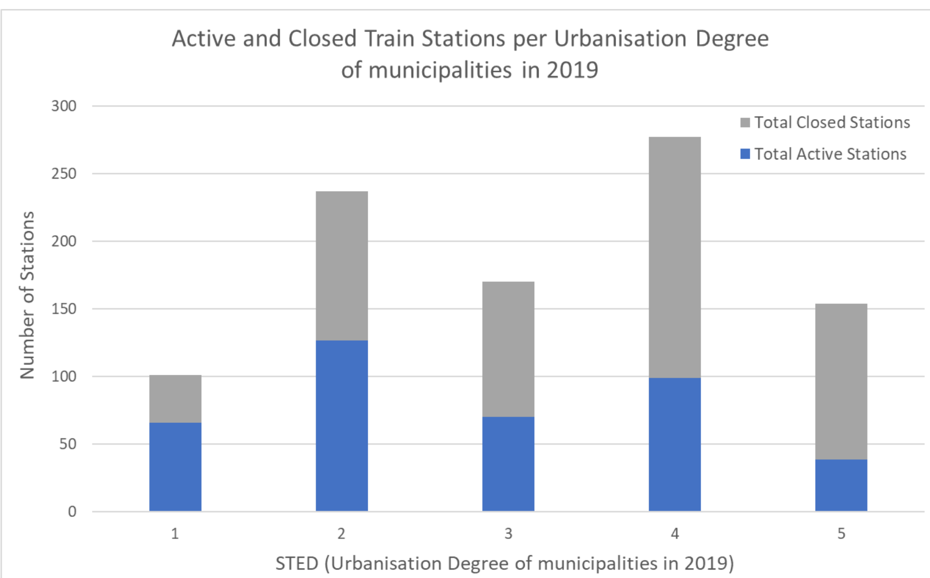


Figure 30 Number of total active NS train stations (status 2021) and total closed stations during period 1891-2006 per Municipality Urbanisation Degree (STED)

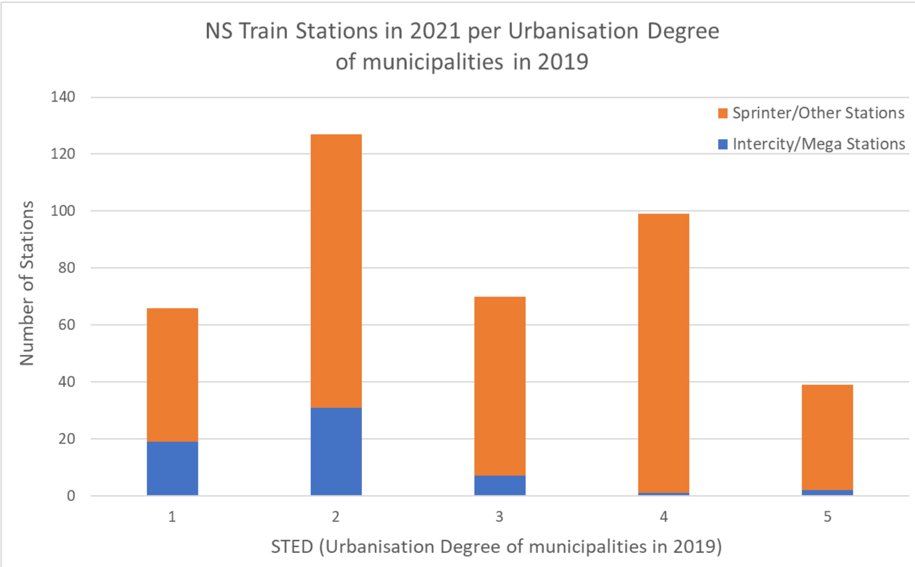
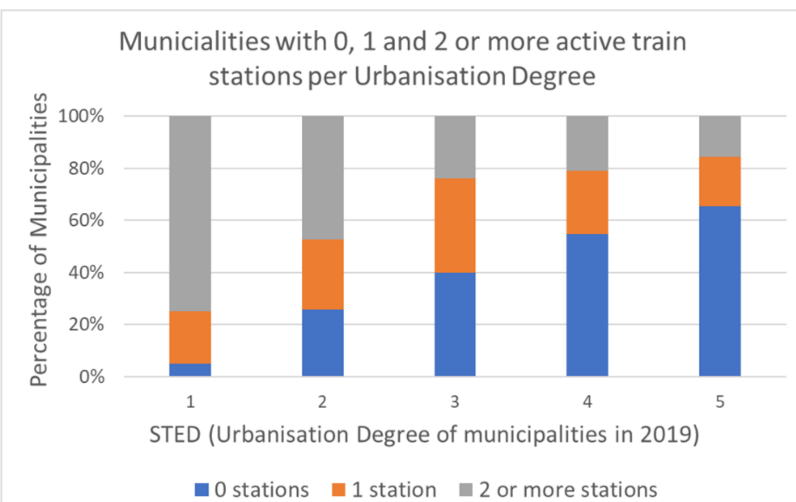


Figure 31 Number of Intercity/Mega and Sprinter/Other NS train stations per Municipality Urbanisation Degree (STED)

When investigating the actual distribution of the station within municipalities with different urbanisation degrees, we learn from Figure 32 that 44% of municipalities don't have any active train station within their boundaries, one fourth of municipalities have only one active train station, and 29% of municipalities contain two or more active train stations. The stacked-percentage columns in Figure 32 demonstrate that the probability of finding a municipality with zero train stations increases rapidly when choosing less and less urbanised municipalities. Map Figure 33 visualises the distribution of active and closed railway stations within the 2019 municipality polygons.



STED	Municipalities with 0 stations	Municipalities with 1 station	Municipalities with 2 or more stations
1	1	4	15
2	19	20	35
3	30	27	18
4	70	31	27
5	38	11	9
Totals	158	93	104

Figure 32 Stacked-percentage bar representation (left) and table with absolute values (right) of different urbanisation-degree municipalities that have 0 (blue), 1 (orange) and 2 or more (grey) active train stations within their 2019 borders.

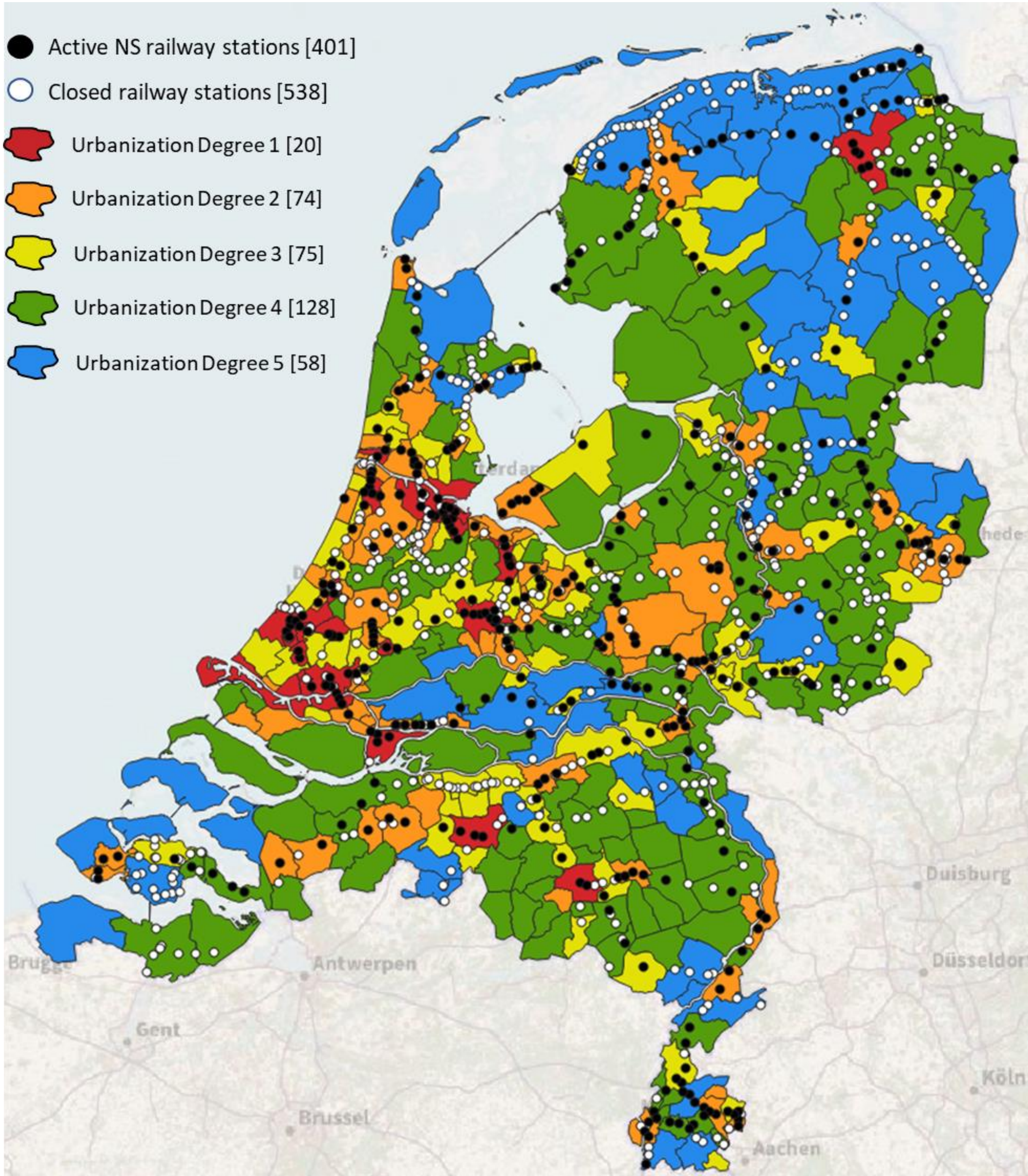


Figure 33 Map of the 355 Dutch municipalities in 2019 per Urbanisation Degree (STED), showing the total active NS train stations (status 2021 – blue dots) and total closed stations during period 1891-2006 (white dots)

3.4 Network Topology Overview

Figure 35 plots the evolution of the geographic layer of the Dutch Municipality Network during 1830-2019 in twelve annual graph instances. In 1830, there were 12 island municipalities (without any road connection to the mainland). In addition, there were 9 municipality clusters which were disconnected (disconnected graph components) from the mainland municipality network (the giant component); these separate clusters comprised 191 municipality nodes in total (Figure 34). As the age of industrialization was progressing, several roads were constructed to connect – among others- the isolated parts of the country, thus gradually decreasing the number of disconnected clusters and the island municipalities. Since the opening of the Westerscheldetunnel on March 2003, which connected the Zeeland municipalities Borsele and Terneuzen, there were no more disconnected components in the Dutch Municipality Network; only 5 disconnected island-municipality nodes in the Waddenzee remain until the present day. The increasing connectedness trend of the Dutch Municipality Network is also reflected in its link density , which was steadily rising from 0.0039 in 1830 to 0.0137 in 2019.

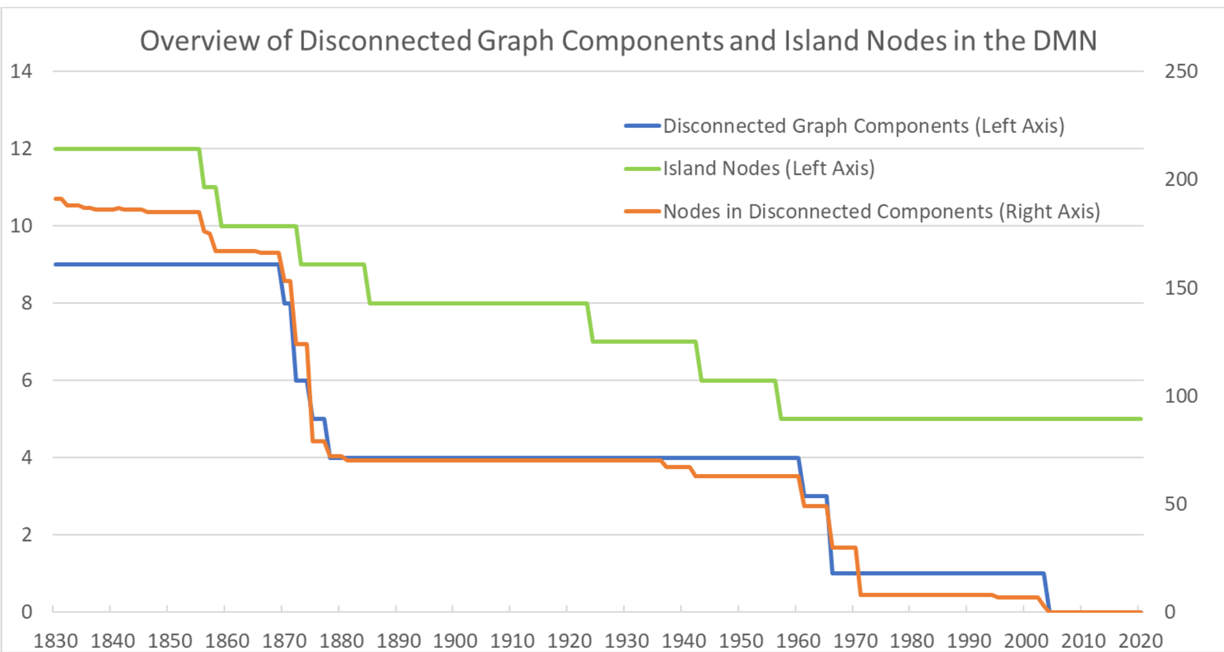


Figure 34 Overview of Disconnected Graph Components and Island Nodes in the DMN during period 1830-2019. Since the opening of the Westerscheldetunnel on March 2003, which connected the Zeeland municipalities Borsele and Terneuzen, there were no more disconnected components in the Dutch Municipality Network; only 5 disconnected island nodes remain until present day.

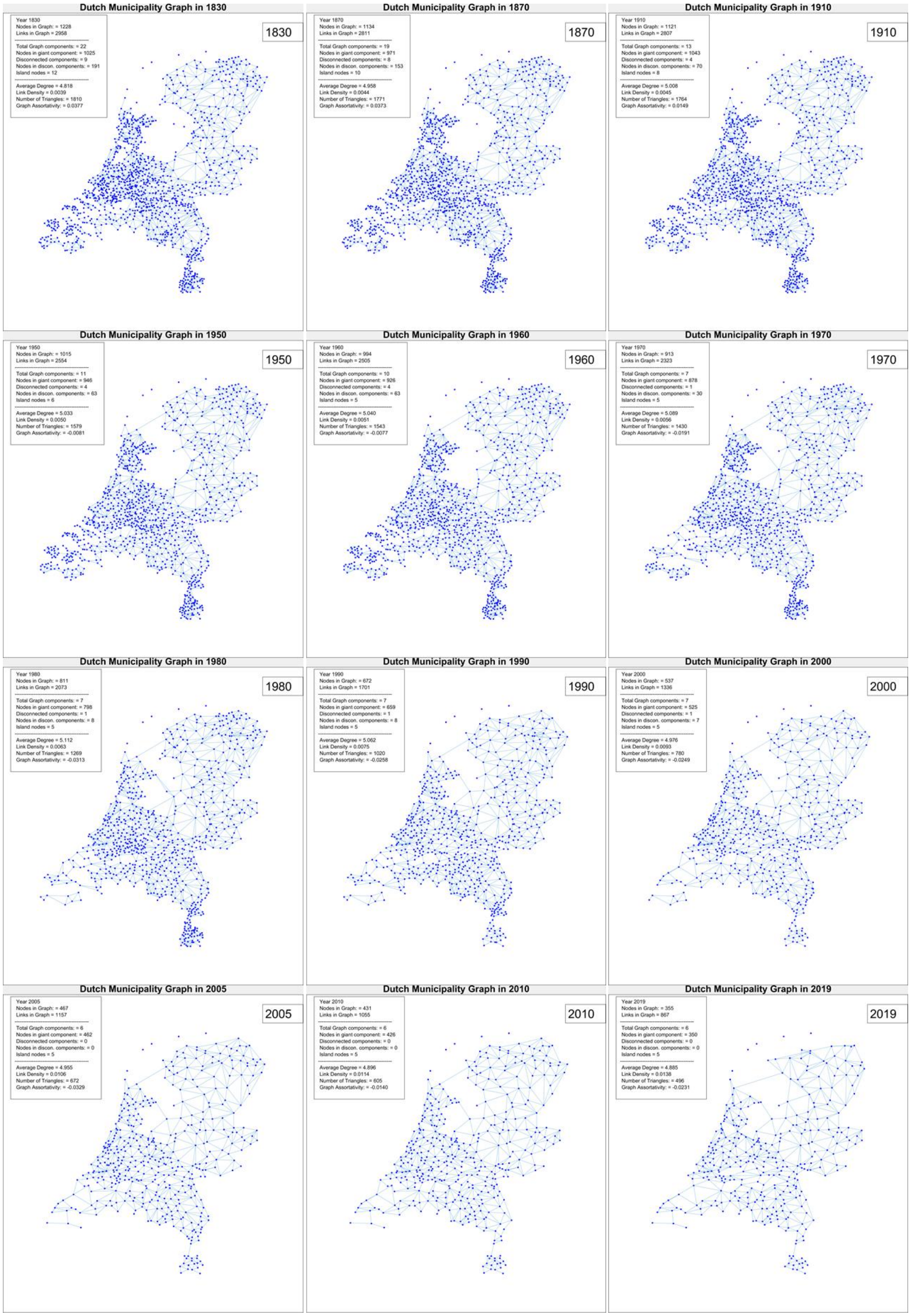


Figure 35 Evolution of the Dutch Municipality Graph during 1830-2019. Shorter time-intervals are chosen between the graph instances from the 1960s, due to the intensification of the municipality merging process ever since.

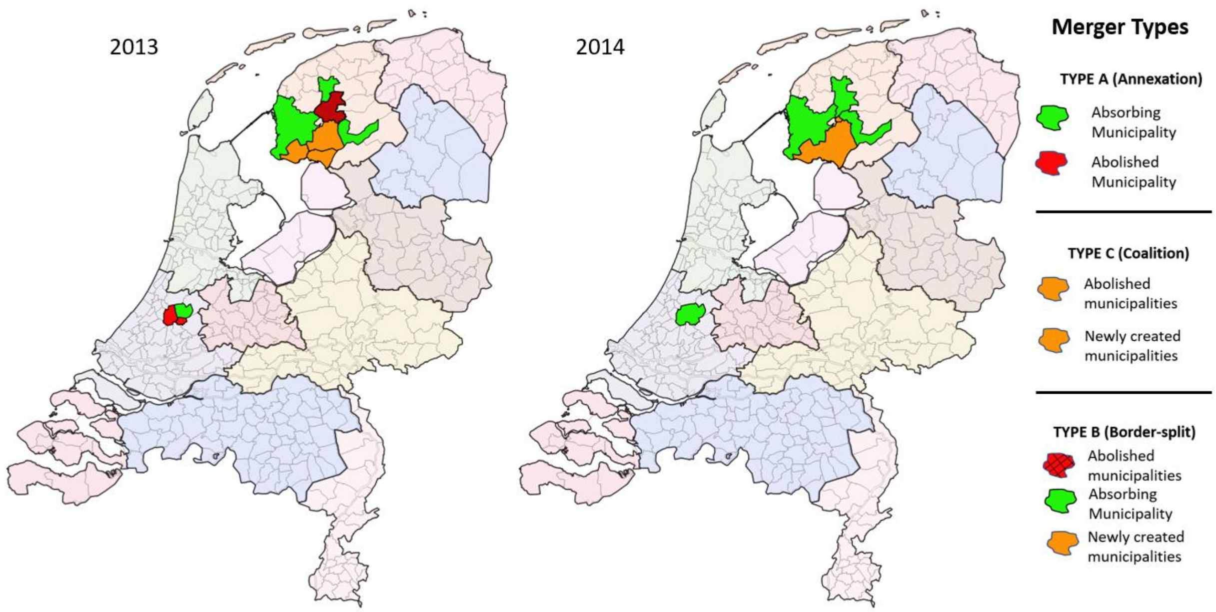


Figure 36 Example of three merger types occurring at the same year (end of 2013).

Figure 36 shows an example of how the topology of the DMN changes as a result of the merging process of municipalities. It concerns two Type A abolished municipalities, one Type C abolished municipality and 1 Type B abolished municipality. The municipalities are abolished at the end of 2013, and the changes come into effect in the municipality network topology in the beginning of the following year 2014. The merger constituents in each merger type are as follows:

TYPE A (Annexation) Abolished Municipality	Province	Merger Target (Absorbing Municipality)
Rijnwoude	Zuid-Holland	Alphen aan den Rijn
Boskoop		

TYPE C (Coalition) Abolished Municipality	Province	Merger Target (New Municipality)
Gaasterlân-Sleat	Friesland	De Friese Meren
Lemsterland		
Skarsterlân		

TYPE B (Border-split) Abolished Municipality	Province	Merger Target (Absorbing and New Municipalities)
Boarnsterhim	Friesland	Leeuwarden / Heerenveen / Sûdwest Fryslân / De Friese Meren

3.5 Graph Average Degree

Figure 37 presents the time dynamics of the nodes and links in the DMN (upper part) and their correlation (lower part) during period $k \in \{1830, \ldots, 2019\}$. The correlation of the number of nodes $N[k]$ and number of links $L[k]$ can be fitted with a linear function that has slope 2.5, which is roughly half the average degree of the DMN for the entire studied period.

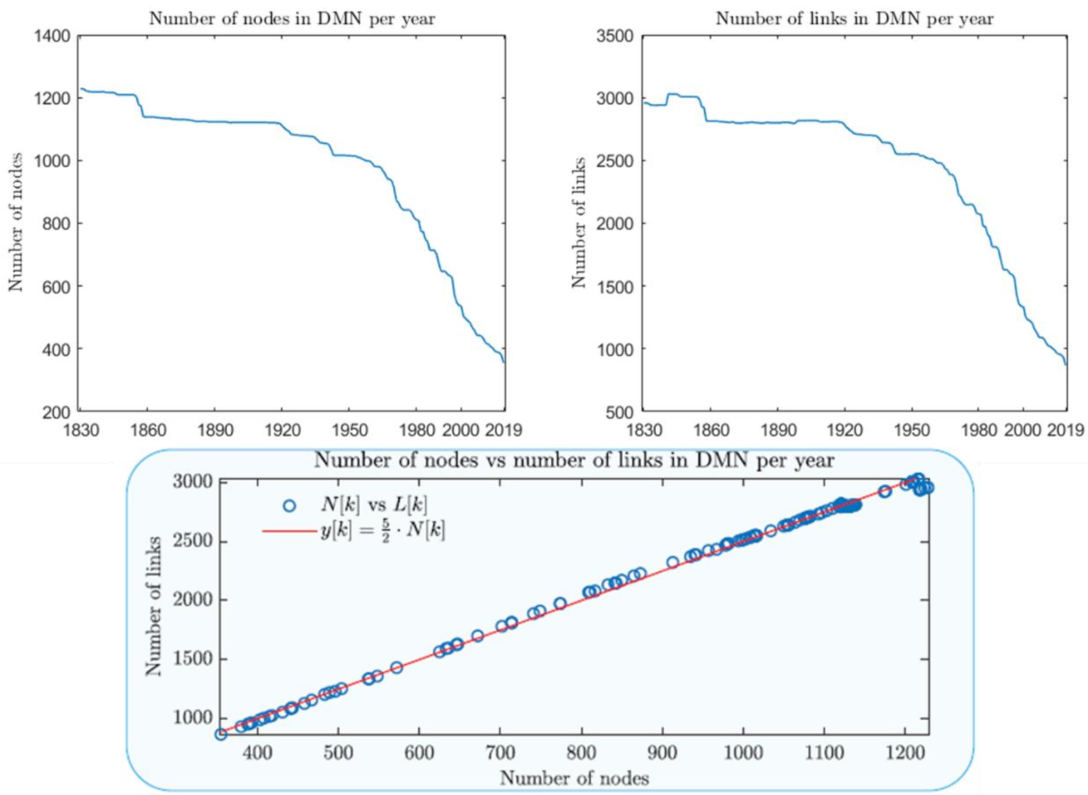


Figure 37 Number of nodes (upper left) and number of links (upper right) in the DMN during the period k ∈{1830, 2019}. Number of nodes vs number of links (lower part) in the DMN since k = 1830 until k = 2019.

Figure 38 plots the node degree distribution of the DMN for each year during the period 1830-2019, while Figure 39 shows the normalized node degree distribution of the DMN during period 1830-2019. The Y-axis in Figure 39 reflects the percentage of active municipalities in each year that had the specific number of neighbors shown on the X-axis. For the entire researched time period 1830-2019, the average network degree $E[D] \approx 5$ remained constant, meaning that the average Dutch municipality was always neighboring with 5 adjacent municipalities. In terms of the mode of the node degree distribution (i.e. the degree value that occurs more often), 4 was the dominant node degree during the first half of the 19th century, while from 1870 until 2019 the mode of the degree distribution equals the average network degree $E[D]$. The standard deviation of the normalised degree distribution has an overall decreasing trend, starting from $\sigma = 2.03$ in 1830 and ending with $\sigma = 1.87$ in 2019 (Figure 39), which indicates that an increasing number of municipalities tends to have a node degree value closer to the network's expected degree $E[D]$.

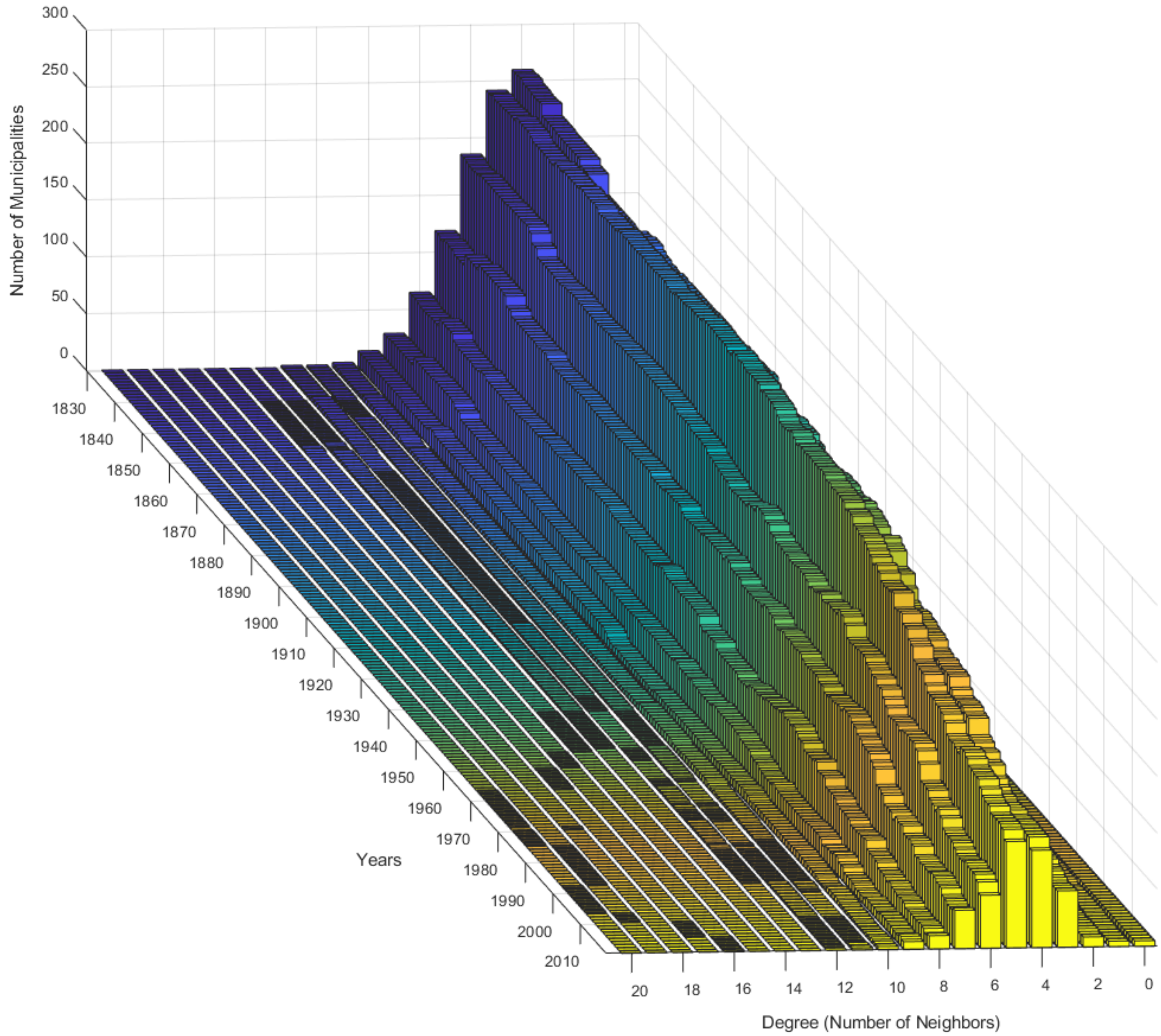


Figure 38 Node degree distribution of the DMN during the period 1830-2019.

The maximum node degree found in the entire studied period is 20. The municipality of Rotterdam had 20 neighbors in years $k \in \{1967-1978,\ 1980-1985,\ 1998-2006\}$. Since 2015, Rotterdam is neighboring with 16 municipalities, which is the maximum node degree found in the DMN during the most recent years. This decrease in the maximum node degree is caused by the merging of other smaller municipalities in the Rotterdam region.

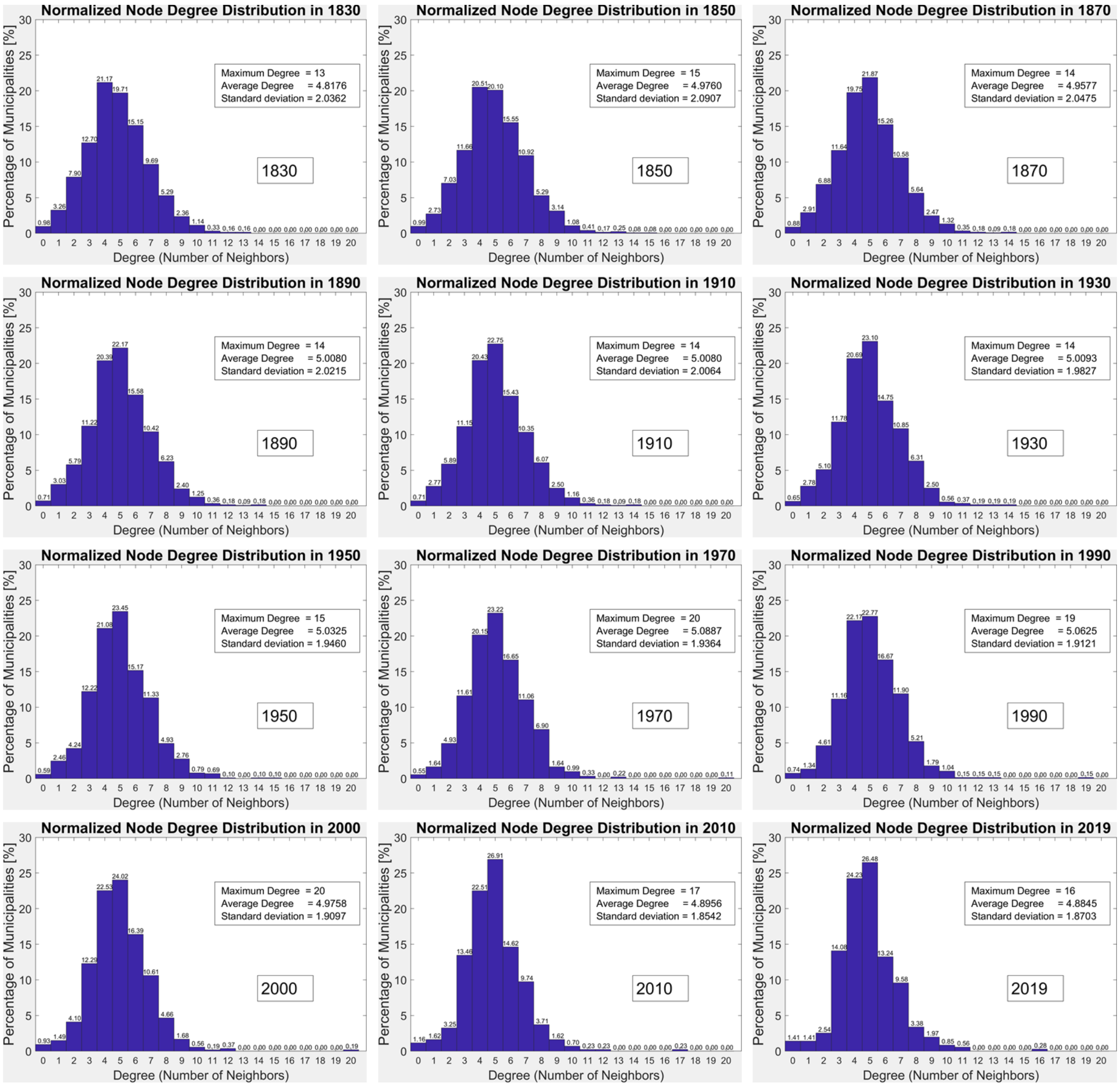


Figure 39 Normalized Node *Degree Distribution in 12 annual instances of the DMN during period 1830-2019. Throughout the entire studied period, the average Dutch municipality was neighboring with 5 adjacent municipalities.*

3.6 Degree Assortativity

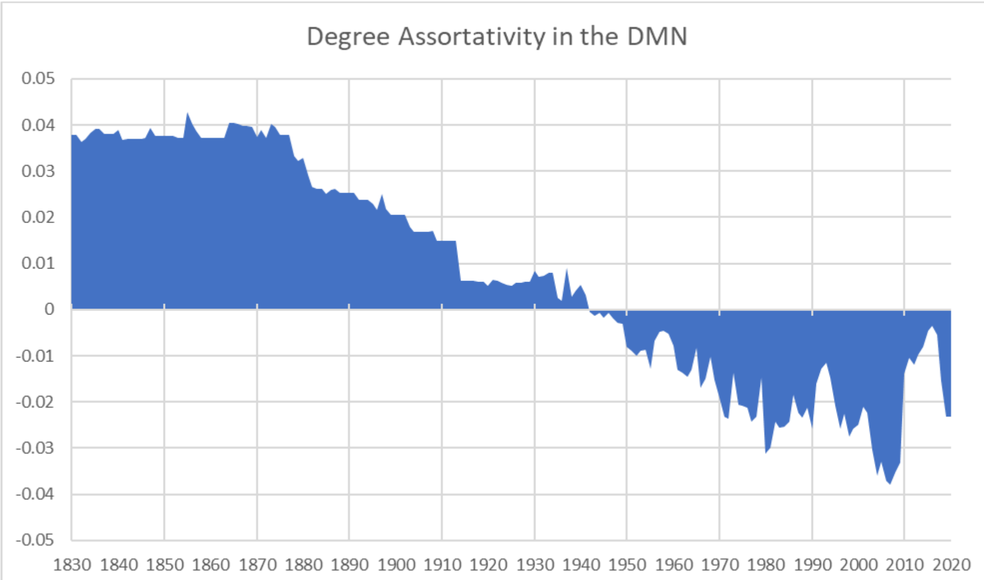


Figure 40 Degree assortativity in the DMN during period 1830-2019

Throughout the period 1830-2019, the Dutch Municipality Network degree became slightly disassortative, meaning that after the Second World War, on average, high degree nodes are connected to nodes with low(er) degree and, on average, low degree nodes are connected to high(er) degree nodes. In 1830, the network was more assortative and the peak assortativity value occurred in 1855 at 0.042. This meant that high degree nodes were, on average, connected to other nodes with high degree and low degree nodes were, on average, connected to other nodes with low degree. Throughout the period 1830-2019, the assortativity displays a generally decreasing trend with slight fluctuations (Figure 40). The values were zero around 1941, which indicates random assortativity, and the DMN assortativity has been negative ever since. The minimum assortativity occurred in 2007 at -0.038. Since the DMN has negative assortativity values since 1941, it can be argued that the country's reorganisation after WW2 and the subsequent urbanisation process lead to wider urbanisation-level differences between municipalities, thus creating a network where high-degree urbanised population-core municipalities are usually surrounded by low(er)-degree less urbanised municipalities.

3.7 Betweenness Centrality

As discussed in sub-section 2.2.4, the betweenness centrality measures how often each municipality node appears on a shortest path between any two nodes in the DMN graph. A proposed assumption is that municipalities with a high betweenness centrality would have more (important) transportation establishments such as train stations within their borders, compared to municipalities with zero or few train stations. That is because the locations of (interchange) train stations in a railway network are typically part of the most frequently traversed train routes across the country. Likewise, nodes with high betweenness centrality in a network act as intermediate 'connector' nodes for the entire network.

On the Dutch Municipality Network in 2019, the top-4 highest betweenness centrality municipalities are Apeldoorn, Nijmegen, Arnhem and Amsterdam, which have in total 7 intercity/Mega stations and 15 Sprinter/Other train stations within their borders. The findings in Table 7 support the assumption regarding the correlation of high betweenness centrality nodes and the existence and high concentration of (important) train stations within these municipality nodes. More specifically:

- Municipalities with 2 or more train stations have on average twice the betweenness centrality of municipalities with 0 or 1 train stations within their borders.
- Municipalities with 1 or more Intercity/Mega stations have on average 2.3 times higher betweenness values than municipalities with no Intercity/Mega stations
- Municipalities with 0 Intercity/Mega stations and municipalities with 0 or 1 train stations are generally more rural (having an average urbanisation degree STED of 3.6), while municipalities with at least one Intercity/Mega station are on average more urbanised (STED 1.9). The average urbanisation degree of all Dutch municipalities in 2019 is 3.3.

The municipality categories based on the columns of Table 7 are visually presented on the map in Figure 41. 90% of all NS train stations are concentrated within the 104 blue-colored municipality polygons on the left part of Figure 41, i.e.in high betweenness centrality nodes with at least 2 train stations within their borders.

Table 7 Correlation between average betweenness centrality of municipalities and the number of active (Intercity/Mega) train stations within their 2019 boundaries.

Municipalities in 2019	Municipalities with 0 or 1 train stations	Municipalities with 2 or more train stations	All municipalities	Municipalities with 0 Intercity/Mega stations	Municipalities with 1 or more Intercity/Mega stations
Number of municipalities	251	104	355	301	54
Average Node Betweenness	0.018	0.037	0.024	0.020	0.046
Average Urbanisation Degree (STED)	3.6	2.8	3.3	3.6	1.9

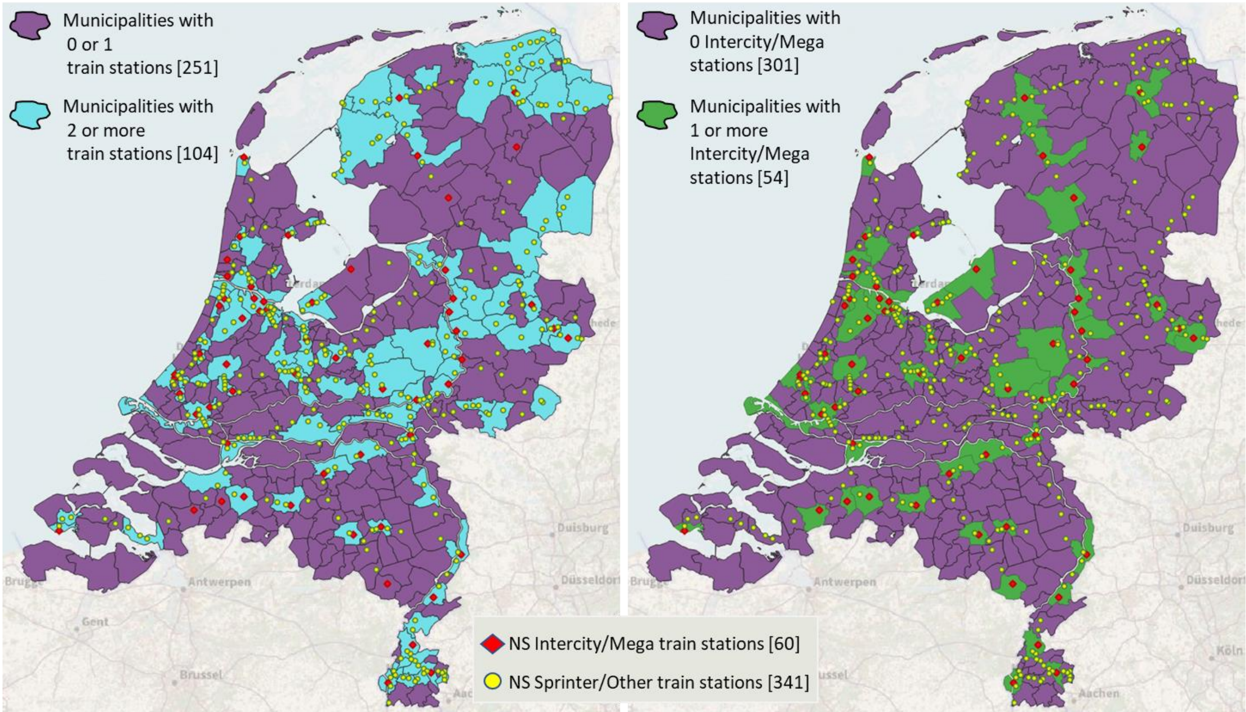


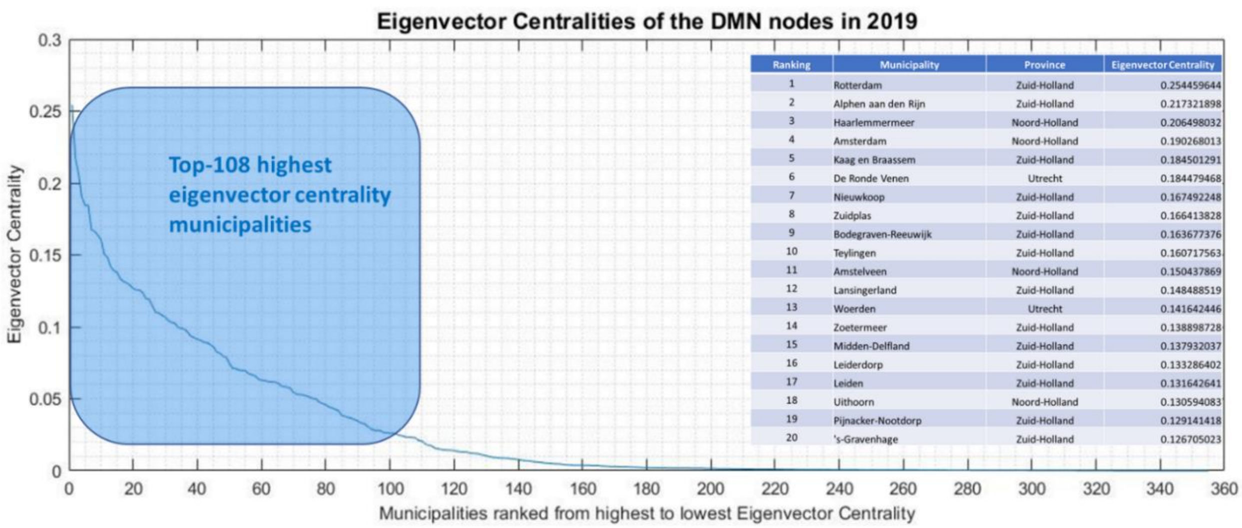
Figure 41 Visualisation of the 2019 municipalities based on the classifications of Table 7 regarding the number and type of train stations within the municipalities

3.8 Eigenvector Centrality

According to a 2006 demarcation of the Randstad region [43], there are 108 municipalities in 2019 that constitute the Randstad region (left part of Figure 43). More specifically, the polygon geometries of these 108 municipalities overlap with the Randstad boundaries by more than 90%. According to [43], The Randstad area spans three provinces (South-Holland and Utrecht in their entirety, and the southern part of North-Holland south of Alkmaar), although more recent sources consider Almere in the province of Flevoland as part of the Randstad region as well [44]. The Randstad area is one of the largest metropolitan regions in Europe, as well as one of the most important and densely populated economic areas in northwestern Europe. The Randstad hosts more than 10 million people on a total population of almost 18 million, while containing the top 4 cities in terms of population in the Netherlands. Having reached this status, the municipalities that are part of the Randstad became highly urbanised and have a strong internal cohesion through intermunicipal cooperation. In fact, the average value of the urbanisation degree (STED) distribution of the municipalities that belong to the Randstad is 2.5, the distribution’s standard deviation is 1.06 and the majority of them (39 municipalities) have a STED value 2.

The average degree (number of neighbors) for Randstad municipalities in the 2019 DMN graph is 5.18, which is slightly higher than the national average of 4.88. The comparison with the national average in this case does not reveal any insight about the Randstad municipalities, because the degree centrality metric assumes that all neighbors are equal; only the number of neighbors matter. However, in many circumstances, the importance of a link increases when it connects important nodes. The eigenvector centrality is based on the idea that a node's importance is determined by how important its neighbors are. The centrality of a node depends on how central its neighbors are, which depends on the centrality of their neighbors, and so forth. Given the high (economical) importance of the Randstad region, it is assumed that it mostly consists of 'important' municipalities, hence most municipalities within the Randstad region are likely connected to strong(er) neighbors.

Figure 42 plots the eigenvector centrality distribution of the 355 municipality nodes in the DMN graph of 2019. The right part of Figure 43 shows the polygons and the ranking order of 108 municipalities that have the highest eigenvector centrality score in 2019, on top of the Randstad area demarcation. Remarkably, 98 out of these 108 municipalities are located within the Randstad region. This finding confirms that, under the assumption that eigenvector centrality indicates nodes with important neighbors, the Randstad municipalities are indeed such an important cluster of urbanised municipalities.



Ranking	Municipality	Province	Eigenvector Centrality
1	Rotterdam	Zuid-Holland	0.254459644
2	Alphen aan den Rijn	Zuid-Holland	0.217321898
3	Haarlemmermeer	Noord-Holland	0.206498032
4	Amsterdam	Noord-Holland	0.190268013
5	Kaag en Braassem	Zuid-Holland	0.184501291
6	De Ronde Venen	Utrecht	0.184479468
7	Nieuwkoop	Zuid-Holland	0.167492248
8	Zuidplas	Zuid-Holland	0.166413828
9	Bodegraven-Reeuwijk	Zuid-Holland	0.163677376
10	Teylingen	Zuid-Holland	0.160717563
11	Amstelveen	Noord-Holland	0.150437869
12	Lansingerland	Zuid-Holland	0.148488519
13	Woerden	Utrecht	0.141642446
14	Zoetermeer	Zuid-Holland	0.138898728
15	Midden-Delfland	Zuid-Holland	0.137932037
16	Leiderdorp	Zuid-Holland	0.133286402
17	Leiden	Zuid-Holland	0.131642641
18	Uithoorn	Noord-Holland	0.130594083
19	Pijnacker-Nootdorp	Zuid-Holland	0.129141418
20	's-Gravenhage	Zuid-Holland	0.126705023

Figure 42 (Graph) Value distribution of the eigenvector centralities for the DMN nodes in 2019. The municipality-nodes on the X-Axis are ranked from highest to lowest eigenvector centrality.

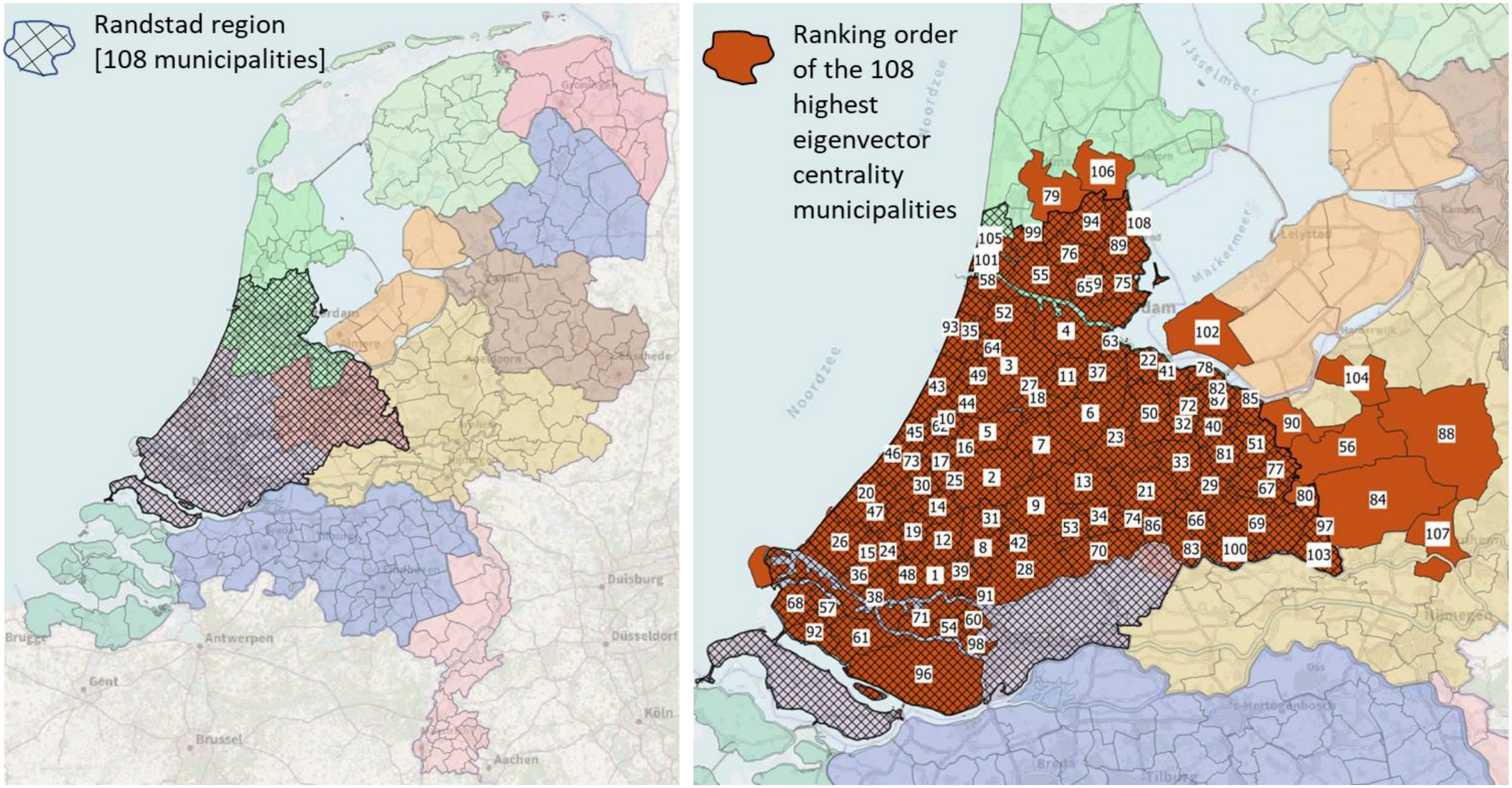


Figure 43. Left part: the Randstad region in the Netherlands (2006 demarcation on top of the 2019 municipality polygons). Right part: the ranking order of the top-108 highest eigenvector centrality municipalities in the2019 DMN graph on top of the Randstad region (shaded). Only 10 municipalities out of the top-108 eigenvector municipalities are not part of the Randstad region.

3.9 Graph Metrics and Urbanisation Degree of Municipalities

This section investigates whether the graph metrics described in sub-section 2.2.5 are correlated with the urbanisation degree (STED) of municipalities. Urbanisation statistics are available per municipality for the period 2004-2019. To quantify the correlation, the Pearson correlation coefficient R is calculated for each metric and each year, and Figure 44 to Figure 46 plot the value distribution of each metric per urbanisation degree as well as the average value of each metric per urbanisation degree for years 2004 and 2019.

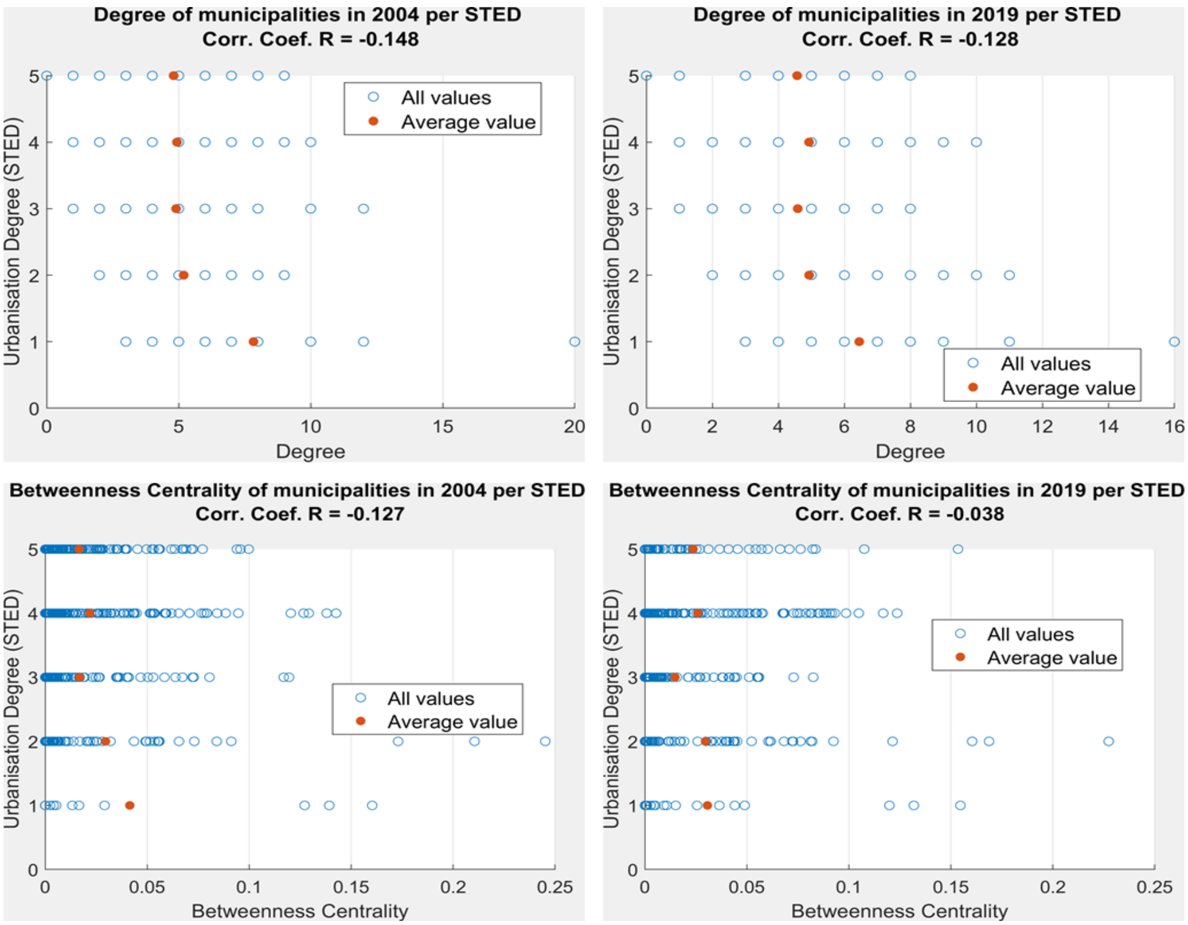


Figure 44 Correlation between Degree (upper part) and Betweenness centrality (lower part) of municipalities per urbanisation degree (STED) in 2004 (left part) and in 2019 (right part)

The highest value in the Pearson correlation coefficient R is observed for the eigenvector centrality. The correlation increases from $R = -0.353$ in 2004 to $R = -0.410$ in 2019. The correlation can also be visually observed in Figure 46 as the average eigenvector centralities shift towards lower values (to the left of the X-axis) for a decreasing urbanisation degree (upwards shift in the Y-axis). The remaining graph metrics (degree, betweenness centrality, closeness centrality and local clustering coefficient) are not highly correlated with the urbanisation degree of municipalities. A map visualisation of the graph metrics mentioned in this section can be found in the appendix section 7.2 in Figure 60 and Figure 61.

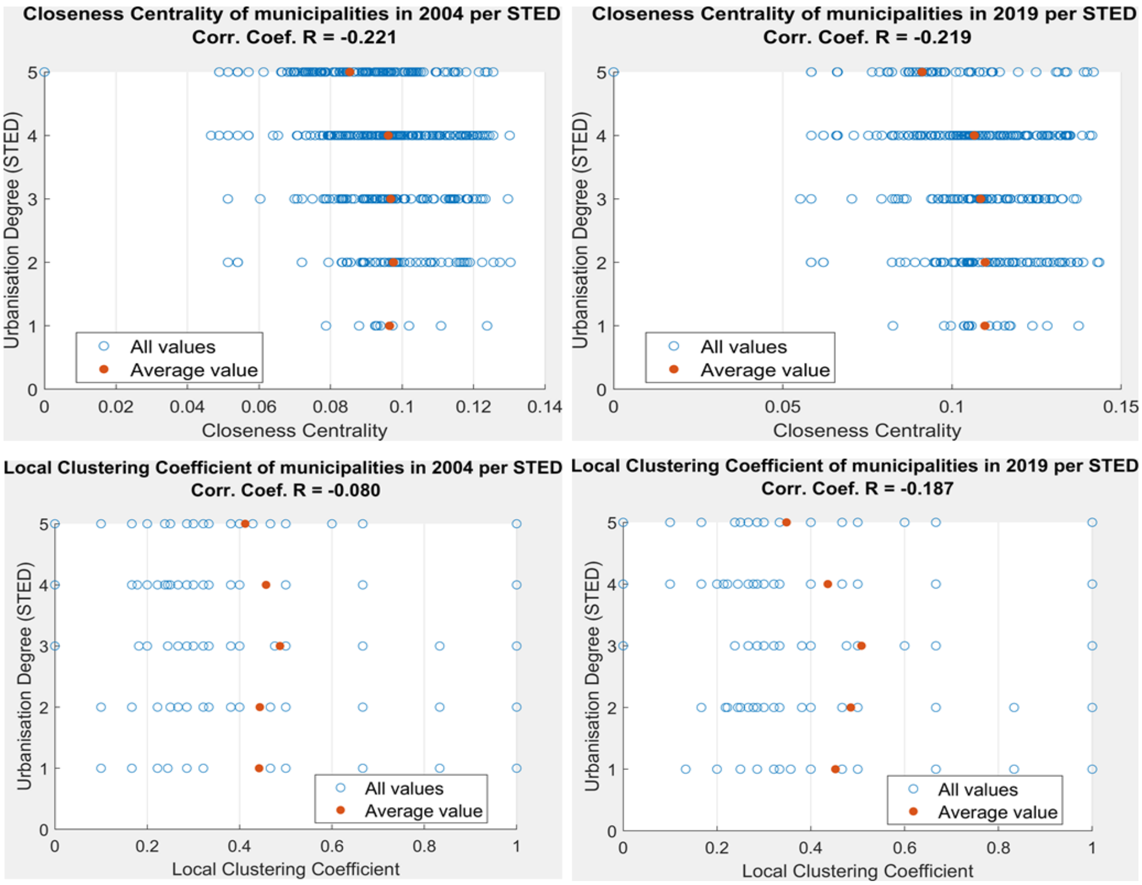


Figure 45 Correlation between Closeness centrality (upper part) and local Clustering coefficient (lower part) of municipalities per urbanisation degree (STED) in 2004 (left part) and in 2019 (right part)

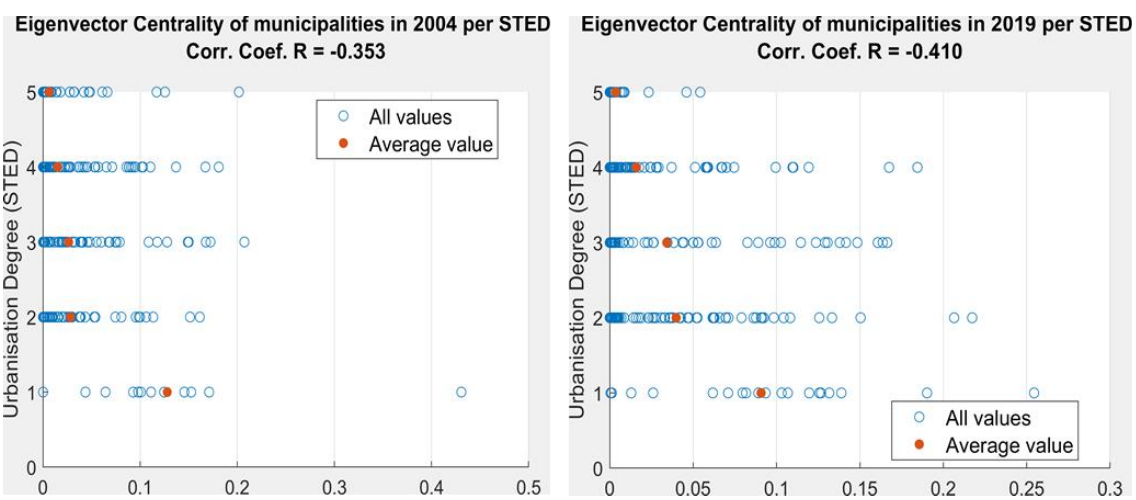


Figure 46 Correlation between Eigenvector centrality of municipalities per urbanisation degree (STED) in 2004 (left part) and in 2019 (right part)

4 Dutch Municipality Network Model Validation

This chapter selects, applies and validates the theoretical models described in section 2.2. Due to the limited availability of continuous sector-related datasets for the researched time period (1830-2019), the multilayer DLSS model for the DMN described in sub-section 2.2.3 cannot be realised. Instead, an alternative non-layered approach was proposed, which is applied and validated in this chapter. The model consists of the 3 complementary modeling steps, two of which were described theoretically in sub-section 2.2.1 (first step) and 2.2.4 (second step). The third modelling step is introduced in section 4.2 and the entire modeling process is validated in section 4.3.

4.1 Population Dynamics per Municipality

Based on available annual population datasets per municipality for years $k \in \{1830, \dots, 2019\}$, a consistent correlation pattern was observed in the population development of individual municipalities between two consecutive years k and $k+1$. This correlation holds for individual municipalities independently (without taking into account the network topology and network effects caused by other municipalities) and can be approximated by a linear function on a log-log scale (as defined in Equation 1.

Let the $N[k] \times 1$ vector $Y[k] = log(x[k+1] - x[k])$ denote the logarithm of the population development of Dutch municipalities that occurred between years $k+1$ and k, and let the $N[k] \times 1$ vector $Z[k] = log(x[k])$ denote the logarithm of the population vector of Dutch municipalities in year k. The visual correlation between the random variables $Y[k]$ and $Z[k]$ can be observed in Figure 47 for three selected intervals featured by the equidistant years 1851, 1935 and 2019. This correlation can be mathematically approximated as follows:

Equation 12

$$E[Y[k]] = c_1[k] \cdot E[Z[k]] + c_2[k]$$

where coefficients $c_1[k]$ and $c_2[k]$ reflect the two parameters of the fitted line in year k, namely the slope ($c_1[k]$) and the additive constant ($c_2[k]$).

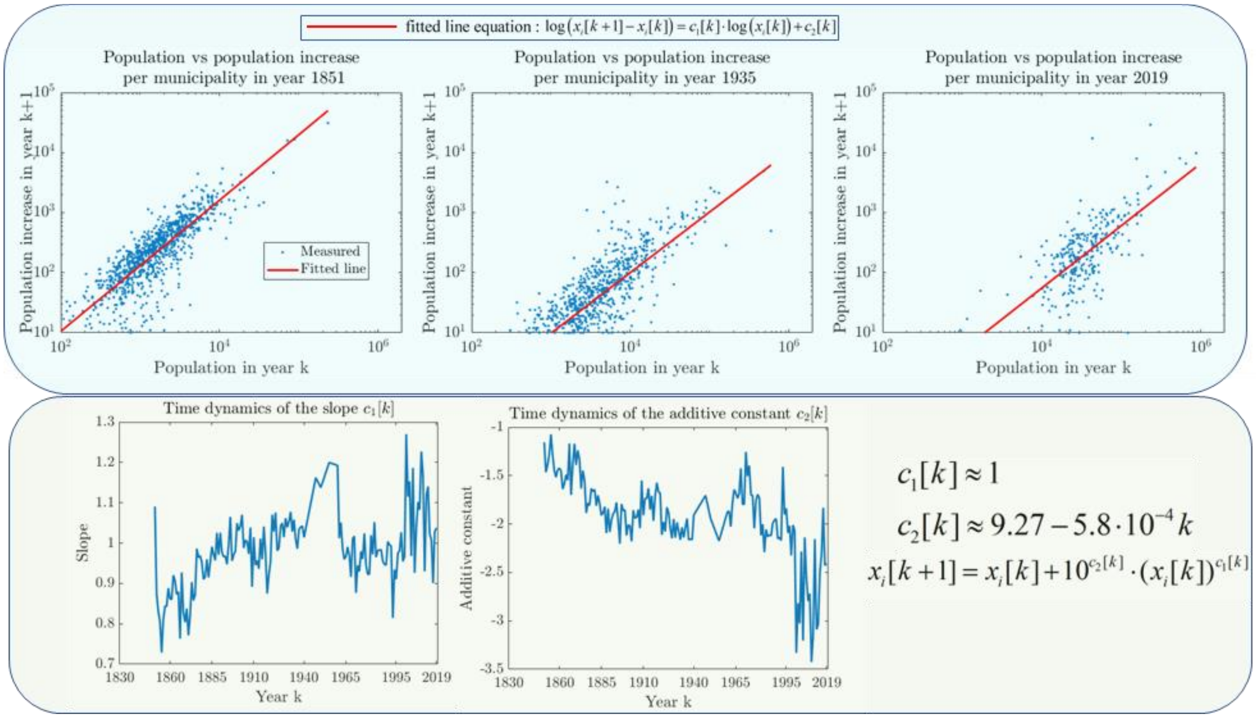


Figure 47. Logarithmic population increase between two consecutive years ($log(x[k+1]-x[k])$), for chosen equidistant years $k = \{1851,1935,2019\}$, along with a fitted linear function (red lines on the upper part of the figure). The time dynamics of parameters $c_1[k]$ and $c_2[k]$ are plotted on the lower part of the figure for the period 1851-2019.

Figure 47 shows that the slope parameter $c_1[k]$ fluctuates around 1, while the additive constant $c_2[k]$ has an overall decreasing trend. Therefore, an approximation over the years k can be expressed as follows:

Equation Set 13

$$c_1[k] \approx 1$$
$$c_2[k] \approx 9.27 - 5.8 \cdot 10^{-4} k$$

The equation that governs the population dynamics in the model is obtained by importing the coefficient values from Equation Set 13 into Equation 12:

Equation 14

$$E[x_i[k+1]] \approx \left(1 + e^{c_2[k]}\right) \cdot E[x_i[k]],\ i \in N[k]$$

The coefficients $c_1[k]$ and $c_2[k]$ deviate due to different time resolution during the aforementioned time-periods that we lack annual population data. In addition, due to the intensified municipality merging process that took place in the last three decades, both coefficients considerably oscillate during this time period. This can be explained as follows: small municipalities (with relatively low population) are being annexed by larger neighbors, thus creating more abrupt spikes in the population of these large absorbing municipalities after a merger.

By combining the population growth of individual municipalities introduced by the linear correlation model in sub-section 2.2.1 (Equation 1) and defined in the current sub-section (Equation 12), with the population redistribution due to the proposed migration process in in sub-section (Equation 6) , the governing equation of the annual population evolution per Dutch municipality in the DMN model takes the following form:

Equation 15

$$E\left[x[k+1]\right]=(1+c_2[k])\cdot\left(I+\delta\cdot Y^T[k]+a\cdot Y[k]-\delta\cdot diag(Y[k]\cdot u)-\alpha\cdot diag(Y^T[k]\cdot u)\right)\cdot E\left[x[k]\right]$$

4.2 Municipality Merging process and Node survivability

As described in section 3.1.1 in detail, the number of Dutch municipalities has constantly been decreasing since 1830. The number of active municipalities in year k is denoted as $N[k]$. At the end of each year, a set of municipalities is abolished (denoted as $N_a[k]$), a process which is a result of the interplay between the central government, the province and the involved municipalities. The case where both the CBS code and the Amsterdam code of a municipality are abolished is considered, and if the codes have different year of abolishment, the year that the Amsterdam code was abolished is kept. On the other hand, due to water reclamation, few new municipalities have been established throughout the Dutch history, which are denoted as $N_e[k]$. A graphical representation of the time dynamics of the above mentioned processes is presented Figure 48. For the DMN model, the equation that determines the active set indicating the active set of municipalities in year $k+1$ is proposed as follows:

Equation 16

$$N[k+1]=N[k]+N_e[k]-N_a[k]$$

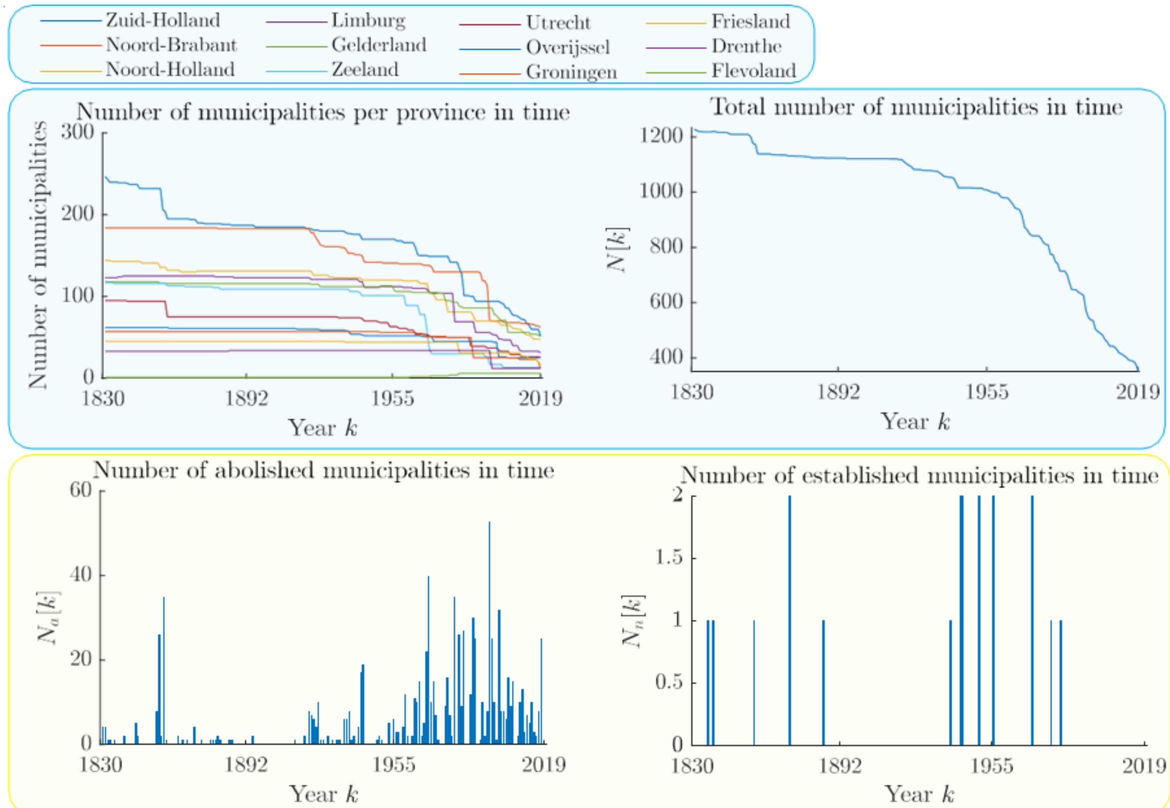


Figure 48 Number of municipalities for each of the 12 Dutch provinces in period k ∈{1830, 2019} (upper-left figure). Total number of Dutch municipalities in period k ∈{1830, 2019} (upper-right figure). Number of abolished (lower-left figure) and newly established municipalities (lower-right figure) in period k∈{1830, 2019}.

In order for the model to follow reality as close as possible, the number of active municipalities in reality in year $k+1$ determines the number of abolished municipalities in year k in the model. Since the establishment of new municipalities occurs very rarely compared to the abolishment of municipalities, it is usually the case that $N_a[k] = N[k+1] - N[k]$, which means that the model does not take into account newly established municipalities and the number of abolished municipalities per year in reality is the same as for the model. However, the model is not aware which municipalities are abolished each year in reality (only how many), and makes its own decisions which municipalities to abolish every year. For this reason, an indicator of the likelihood of abolishment for municipalities was proposed and named it Abolishment Likelihood Index $p[k]$. The Abolishment Likelihood Index of municipality i in year k is denoted as $p_i[k]$, and is defined as:

Equation 17

$$p_i[k] = \frac{3 \cdot {a_i}^T \cdot x[k]}{({a_i}^T \cdot u) \cdot x_i[k]} + \frac{s^T[k] \cdot u}{N[k] \cdot s_i[k]}$$

where the $N[k] \times 1$ vector $a_i[k]$ denotes the i-th row of the $N[k] \times N[k]$ adjacency matrix $A[k]$. The first term of the Abolishment Likelihood Index in Equation 17 compares the population $x_i[k]$ of the i-th municipality in year k with the average population of its neighbors $\frac{3a_i^T \cdot x[k]}{d_i[k]}$ (with a weight factor 3) in the same year, where $d_i[k] = (a_i^T \cdot u)$ is the degree of municipality i in year k. The second term of the Abolishment Likelihood Index in Equation 17 compares the area $s_i[k]$ of the i-th municipality in year k with the average area $\frac{S[k]}{N[k]}$ (with a weight factor of 1) of all municipalities in the same year, since the area-size of municipalities was also considered a criterion for mergers, especially in the early 19th century (as mentioned in sub-section 3.1.3). Here, the population is weighted with a factor 3 and the area with a factor of 1 after heuristic testing, during which it was discovered that this combination of weight factors gives the model the most accurate municipality merger predictions when compared with the actual set of abolished municipalities in reality for the entire researched time period.

For each year k, the municipalities are ranked according to their Abolishment Likelihood Index values, and the set of abolished municipalities per year $\mathcal{A}[k]$, where $\mathcal{A}[k] = N_a[k]$, is determined as the set of $N_a[k]$ municipalities with the highest Abolishment Likelihood Index value $p[k]$.

4.3 Validation and Predictions

The combination of the population linear correlation model (first modelling step, described in theory in sub-section 2.2.1 and applied to the DMN in section 4.1) and the population migration model (second modelling step, described in 2.2.4) captures and estimates the population dynamics of the DMN throughout the period 1851-2019 with remarkable accuracy using Equation 15. The Abolishment Likelihood Index $p[k]$ (third modelling step, described in section 4.2) estimates the set of abolished municipalities in each year in the model. The Abolishment Likelihood Index $p[k]$ is first validated using real annual sets of active municipalities $\mathcal{N}[k]$ and abolished municipalities $\mathcal{A}[k]$ in sub-section 4.3.1, and subsequently used for estimations and future predictions in the DMN in sub-section 4.3.2.

The model takes as inputs:
1) the population vector $x[1851]$ and the area vector $s[1851]$ of the first year of the continuous population datasets (both with dimensions $N[1851] \times 1 = 1209 \times 1$),
2) the DMN topology defined in the adjacency matrix $A[1851]$ of the first year of the continuous population datasets (with dimension 1209×1209) ,
3) the total population of the Netherlands for each year $X[k]$, where $k \in \{1851, \ldots, 1940,\ 1947,\ 1950,\ 1955,\ 1960, \ldots, 2019\}$
4) the number of abolished municipalities $N_a[k]$ in reality for years $k \in \{1851, \ldots, 1940,\ 1947,\ 1950,\ 1955,\ 1960, \ldots, 2019\}$

The complete 3-step model for the Dutch Municipality Network runs in Matlab iteratively for 153 annual loops, i.e. for years $k \in \{1851,...,1940,\ 1947,\ 1950,\ 1955,\ 1960,...,2019\}$ }. The need for a continuous period of annual population instances for the iterative simulations forces the model to start from year k=1851 instead of 1830, as there is a 21-year gap between population censuses before 1851 (also see Appendix 7.6). A lack of continuous population datasets after WW2 also causes the model to skip these years in the simulations, which in turn causes slight differences in the number of active $N[k]$ and abolished $N_a[k]$ municipalities for the following years:
$k \in \{1941, \ldots, 1946, 1948, 1949, 1951, \ldots, 1954, 1956, \ldots, 1959\}$. During this period, the known number of abolished municipalities in reality is distributed to the closely following and preceding years in the model, which is why in the model some years have a slightly larger number of abolished municipalities. Another reason that causes a slight deviation between the number of active municipalities $N[k]$ in the model and in reality is that newly established municipalities $N_n[k]$ in reality are not taken into account in the model. The above-mentioned differences in $N_a[k]$ and $N[k]$ can be seen in Figure 58.

An output at the end of each year is the Abolishment Likelihood Index of municipalities $p[k]$ in year k. As described in section 4.2, the set of abolished municipalities in each year $\mathcal{A}[k]$ is decided based on which municipalities have the highest $p_i[k]$, while the number of abolished municipalities in the model is the same as the number of abolished municipalities in reality $N_a[k]$, except for the years $k \in \{1941, \ldots, 1946, 1948, 1949, 1951, \ldots, 1954, 1956, \ldots, 1959\}$ when the population datasets are missing. Additionally, the Abolishment Likelihood Index cannot be determined for the municipalities with zero node degree (island municipalities), since the $p_i[k]$ calculation depends on a municipality's neighbors. By convention, an artificial value $p_i[k] = 0$ is adopted for these island municipalities, which eliminates their chance of being abolished in the modelled simulations.

4.3.1 Validation of the Abolishment Likelihood Index $p[k]$

The Abolishment Likelihood Index $p[k]$ can be applied to each annual set of municipalities both in reality and in the model. To validate the Abolishment Likelihood Index $p[k]$ as a metric for the survivability of municipalities, it is firstly applied on the real annual sets of active municipalities $\mathcal{N}[k]$ (for example in the 2019 municipality set in Table 10) and abolished municipalities $\mathcal{A}[k]$.

The correlation between the two terms in the definition of the Abolishment Likelihood Index $p[k]$ of abolished municipalities (Equation 17) is plotted on the left part of Figure 49, where it is obvious that the two terms seem to be independent from each other. The right part of Figure 49 shows that the value distribution of the Abolishment Likelihood Index $p[k]$ for all abolished municipalities in period $k \in \{1851,\ldots,1940,\ 1947,\ 1950,\ 1955,\ 1960,\ldots,2019\}$ is on average higher than the Abolishment Likelihood Index $p[k]$ for municipalities that existed in 2019.

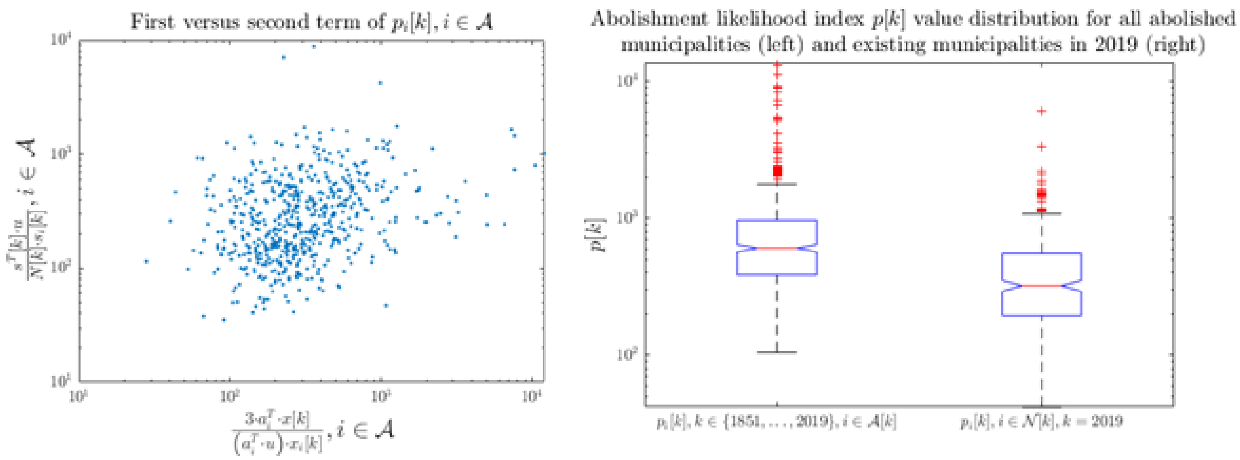


Figure 49 (Left part) The correlation between the first and second term of the Abolishment Likelihood Index $p[k]$ of abolished municipalities in reality in their year of abolishment. (Right part) The value distribution of the Abolishment Likelihood Index $p[k]$ for abolished municipalities in their year of abolishment in reality and for municipalities that existed in 2019 in reality

Figure 50 plots the per year average Abolishment Likelihood Index $p[k]$ for each set of active municipalities $\mathcal{N}[k]$ and each set of abolished municipalities $\mathcal{A}[k]$.

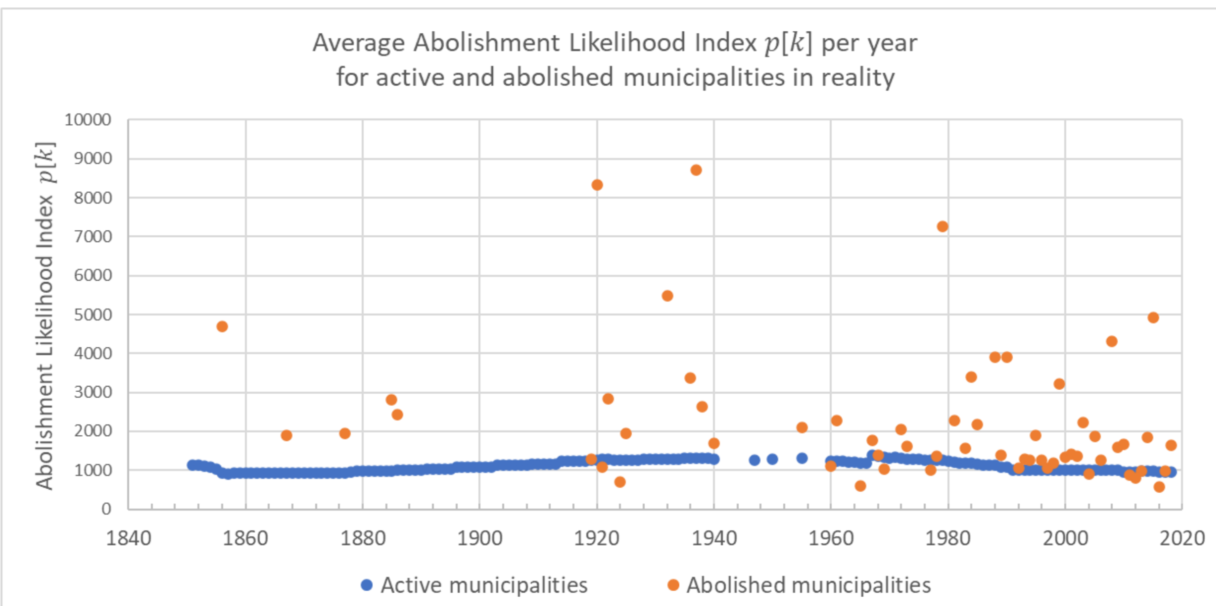


Figure 50 Average Abolishment Likelihood Index p[k] for active municipalities in reality in each year (blue line) and abolished municipalities in reality in each year (orange dots)

Taking into account the network effects regarding municipality mergers at neighbor-level, Figure 51 plots the correlation between the Abolishment Likelihood Index $p_i[k]$ for each abolished municipality (Y-axis) and the average Abolishment Likelihood Index

$p[k]$ for the surviving neighbors of each abolished municipality (X-axis), for the period $k \in \{1851, ..., 1940,\ 1947,\ 1950,\ 1955,\ 1960, ..., 2019\}$. The X-Y coordinate pair position of each dot on the plot is therefore determined by the value $p_i[k]$ of each abolished municipality (Y-coordinate) and the average value of the $p[k]$ for the surviving neighbors of each abolished municipality (X-coordinate). The majority of the $p[k]$ values for the surviving neighbors of abolished municipalities is concentrated below $p[k] < 1000$ on the X-axis, while the values for abolished municipalities are scattered above the diagonal line $y = x$ and are located at higher Y-axis positions ($p[k] > 1000$), indicating that the $p[k]$ of most abolished municipalities was higher than the $p[k]$ of the surviving neighbors of these abolished municipalities.

Figure 52 plots the per year average Abolishment Likelihood Index $p[k]$ per year for all abolished municipalities and their surviving neighbors during the period $k \in \{1851, ..., 1940,\ 1947,\ 1950,\ 1955,\ 1960, ..., 2019\}$. It is evident from the figure that the majority of the $p[k]$ values of abolished municipalities is on average much higher than the $p[k]$ values of the surviving neighbors of the abolished municipalities, thus verifying that the comparison of the population and the area of a municipality with its neighbors (as is the definition of the Abolishment Likelihood Indicator in Equation 17) is indeed an important criterion for determining the likelihood a municipality being merged.

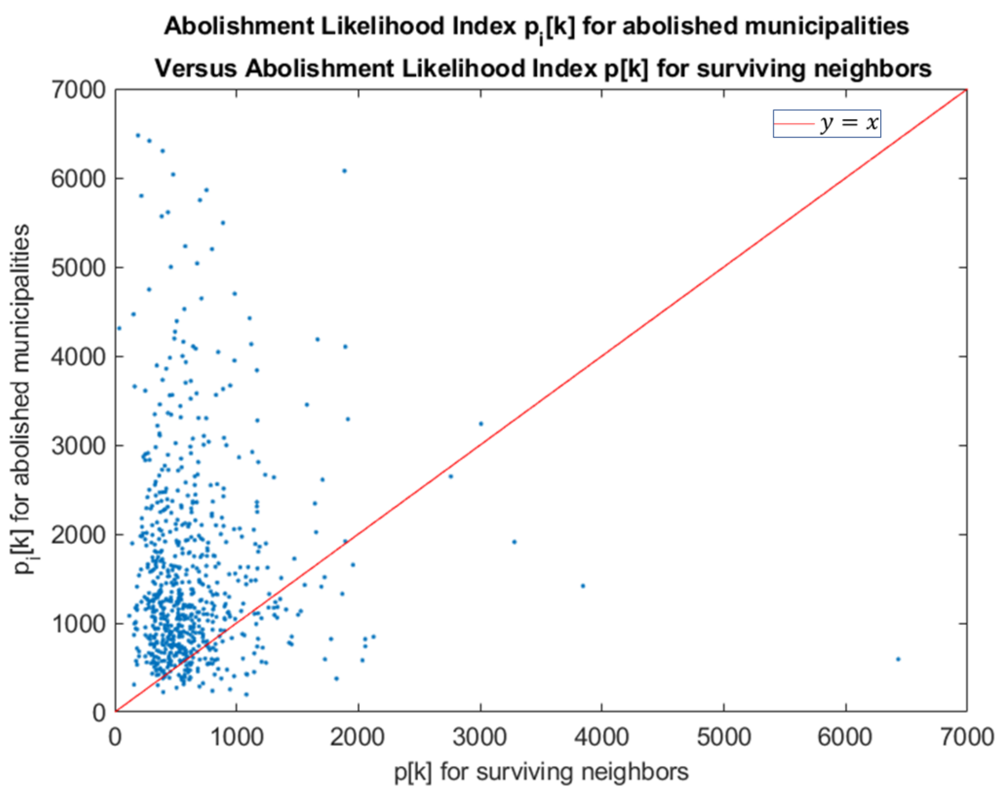


Figure 51 Abolishment Likelihood Index $p_i[k]$ for each abolished municipality (Y-axis) versus Abolishment Likelihood Index $p[k]$ for the surviving neighbors of each abolished municipality (X-axis) in period $k \in \{1851, \ldots, 1940, 1947, 1950, 1955, 1960, \ldots, 2019\}$. The red diagonal like with equation $y = x$ is plotted for correlation comparison purposes between the values on the X-axis and the values on the Y-axis.

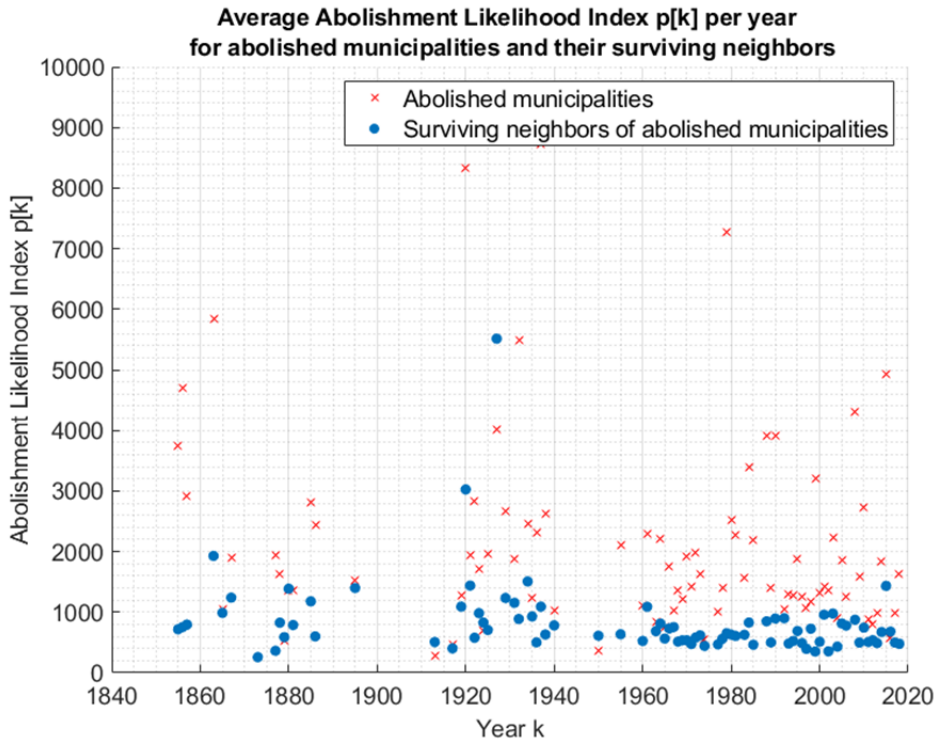


Figure 52 Average Abolishment Likelihood Indicator p[k] per year for abolished municipalities and their surviving neighbors.

Figure 53 plots the Average Abolishment Likelihood Index $p[k]$ for all municipalities per year in period $k \in \{1851, \ldots, 1940, 1947, 1950, 1955, 1960, \ldots, 2019\}$. Since a high value of $p_i[k]$ for the i-th municipality indicates a higher inequality in the population and area-size between municipality i and its neighbors, subsequently by extending the network effect to all municipalities on average in each annual instance k, a higher value of the average $p[k]$ in year k indicates that there are more inequalities among (clusters of) Dutch municipalities in terms of their population and area-size. These inequalities between municipalities were increasing (from lower values of $p[k]$ in 1860 towards the peak value of $p[k]$ in 1967) during the period of industrialisation and urbanisation. Since 1967, the average $p[k]$ values have been declining, possibly indicating that the intensified merging process that occurred in two waves in the 1960s and the 1980s managed to reduce the differences in population and area-size among Dutch municipalities. The sudden decrease in the average $p[k]$ values between 1955 and 1965 is caused by the decrease in the $p[k]$ values of the municipalities within the province of Utrecht during the same years, which can be seen in Figure 54.

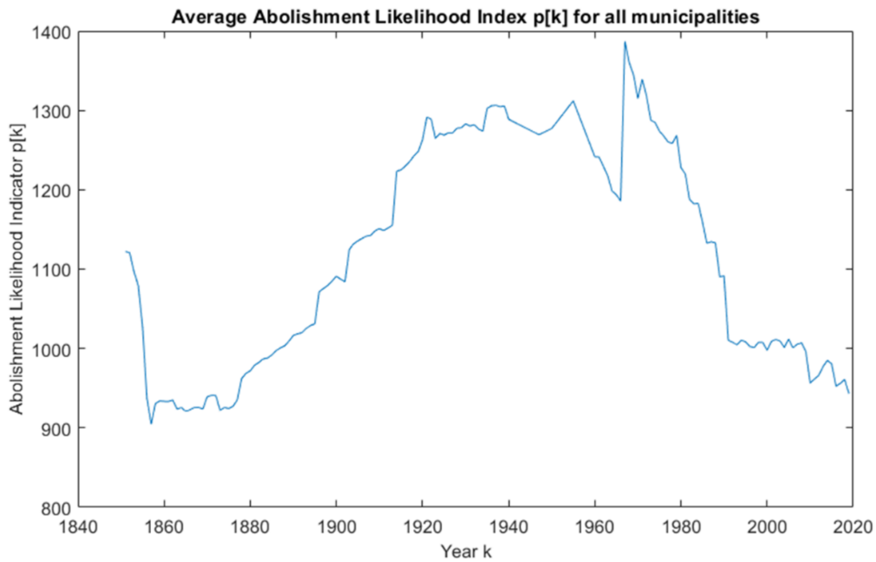
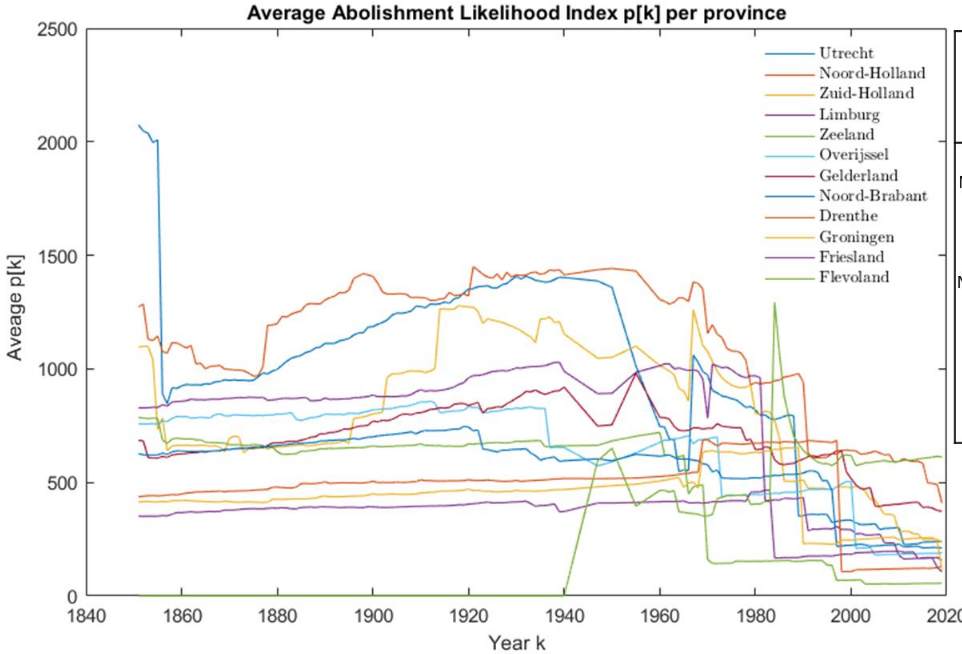


Figure 53 Average Abolishment Likelihood Index p[k] for all active municipalities $N[k]$ *in period* $k \in \{1851, \ldots, 1940, 1947, 1950, 1955, 1960, \ldots, 2019\}$

Note that the trend of the average $p[k]$ presented in Figure 53 is very similar with the trend of the following figures:
1) the variance of the logarithm of the population vector $log(x\,[k])$ (Figure 16),
2) the estimated slope of the population rank-size distribution (Figure 20), and
3) the mirrored curve of the estimated exponent $\tau[k]$ of the power law fit of the population distribution per municipality (Figure 21)

Figure 54 plots the development of the Average Abolishment Likelihood Index $p[k]$ per province and ranks the provinces based on each province's total average $p[k]$ over all years. The mostly rural provinces of Groningen and Friesland have the lowest total average $p[k]$ for the period 1851-2019, possibly indicating that the majority of municipalities within these provinces share similar characteristics in terms of population and area-size. On the contrary, the provinces of Noord-Holland and Utrecht have the highest total average $p[k]$ for the period 1851-2019, likely indicating that these provinces comprise municipalities with larger differences among their municipalities (in terms of population and area-size) than the differences among municipalities in provinces with lower total average $p[k]$. Regarding the $p[k]$ rankings in 2019, it is remarkable that the provinces of Drenthe, Groningen and Friesland maintain the same ranking order in $p[k = 2019]$ as in the $p[k = 1851]$ ranking , as well as in the ranking order of the all-year average $p[k]$ in period 1851-2019.



Province	Average $p[k]$ in 2019	Total average $p[k]$ in 1851-2019
Flevoland	611.59	553.76
Noord-Holland	409.20	1109.02
Gelderland	372.98	686.95
Utrecht	240.68	950.74
Zuid-Holland	235.41	799.32
Noord-Brabant	211.28	570.48
Overijssel	190.61	648.17
Limburg	157.90	760.46
Drenthe	131.72	473.41
Groningen	112.09	432.50
Friesland	106.33	344.58
Zeeland	56.50	480.28

Figure 54 (Plot) Average Abolishment Likelihood Index p[k] per province. (Table) Ranking of provinces based on the total average value of p[k] over all years per province.

Figure 55 shows the results of applying the Abolishment Likelihood Index $p[k]$ on each active set of municipalities $\mathcal{N}[k]$ in the DMN (in reality) per urbanisation degree for $k \in \{2004, \dots, 2019\}$ during which period urbanisation degree statistics per municipality are available. STED 3 municipalities show an increasing Abolishment Likelihood Index $p[k]$ trend after 2014 and have the highest average $p[k]$ in 2019, which can be explained by observing in the right part of Figure 55 that the majority of the neighbors of STED 3 municipalities belong to all the other urbanisation classes but very rarely to the same urbanisation class, making the neighborhood of STED 3 municipalities the most diverse in terms of population (and area) characteristics, thus raising the average $p[k]$ for STED 3 municipalities.
Figure 56 shows the annual number of active municipalities per urbanisation degree and the total number of abolished municipalities per urbanisation degree during period 2004-2019. None STED 1 municipalities and 4 STED 2 municipalities were abolished during 2004-2019, which validates the low Abolishment Likelihood Index $p[k]$ of these municipalities seen in Figure 55. In addition, the STED 5 municipalities is the urbanisation class with the most rapid decline in number of municipalities (Figure 56), as these rural municipalities are merged with larger neighboring municipalities. The 58 STED 5 municipalities that have managed to survive in 2019 are mostly concentrated at the periphery of the country and are neighboring with other STED 5 municipalities, which likely have comparable population and area-size thus leading to an a decreasing trend in $p[k]$ values for municipalities belonging to the STED 5 urbanisation class in Figure 55. In other words, the population and area-size differences in the neighborhood of STED 5 municipalities in 2019 are not as large as the differences in 2004. STED 1, STED 2 and

STED 5 municipalities have the same average $p[k]$ in 2019, which indicates that STED 1 and STED 2 municipalities (mainly located within the Randstad) are neighbors with municipalities that share similar characteristics in terms of population and area size.

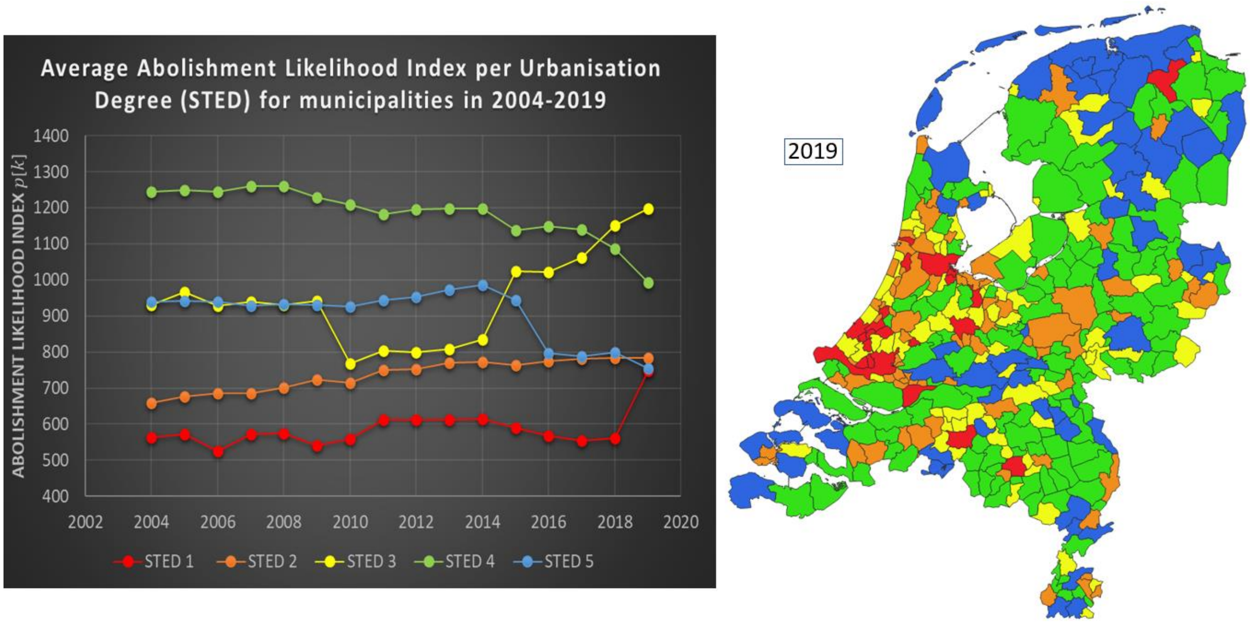


Figure 55 (Left part) Average Abolishment Likelihood Index $p[k]$ per urbanisation degree of municipalities existing in reality in period 2004-2019. (Right part) Urbanisation degree of municipalities in 2019.

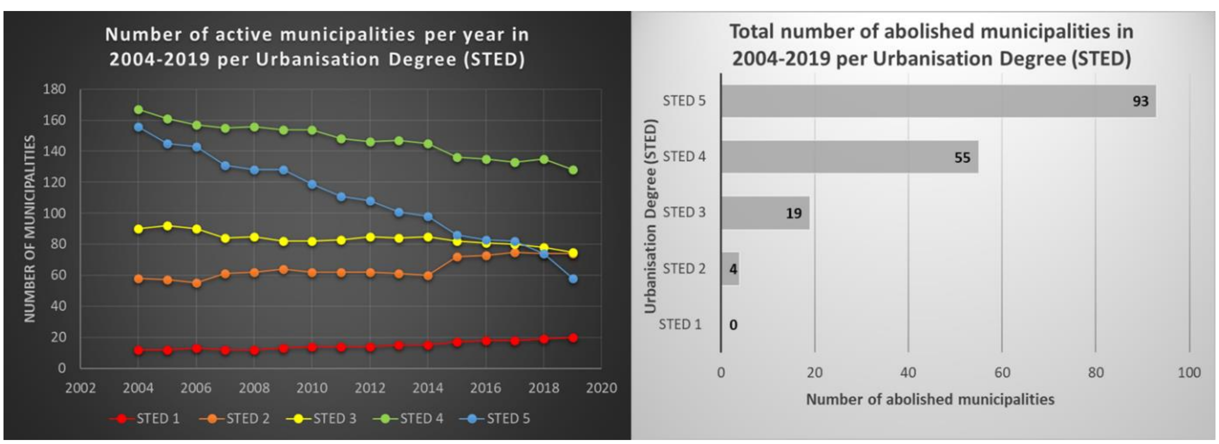
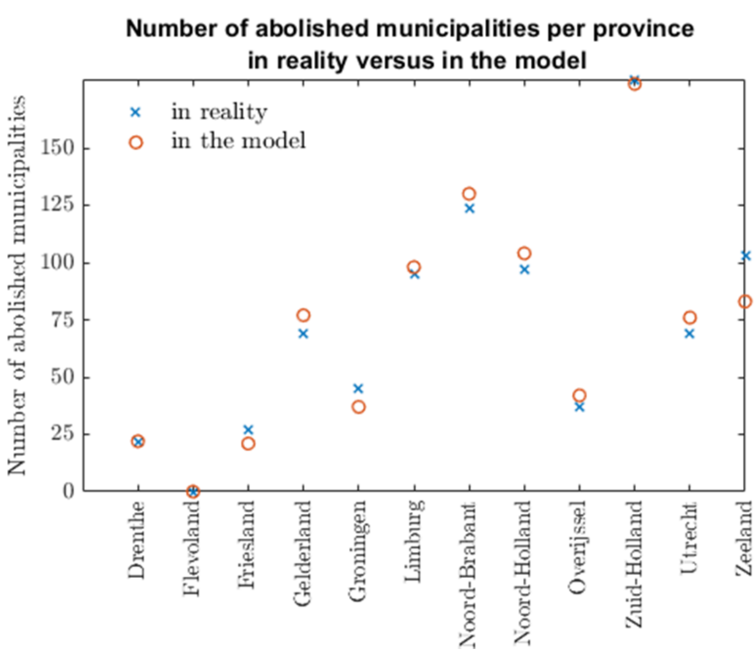


Figure 56 (Left part) Number of active municipalities per year in 2004-2019 per urbanisation degree (STED). (Right part) Total number of abolished municipalities in 2004-2019 per urbanisation degree (STED)

4.3.2 Model Estimations and Predictions

The set of abolished municipalities in the model-based simulations during the time period $k \in \{1851,...,1940,\ 1947,\ 1950,\ 1955,\ 1960,...,2019\}$ overlaps with the set of abolished municipalities in reality during the same time period by 75.3%. However, the predicted years of abolishment in the model are not the same as in reality in many cases.

Figure 57 compares the number of abolished municipalities per province in period $k \in \{1851,...,1940,\ 1947,\ 1950,\ 1955,\ 1960,...,2019\}$ in reality against the model's abolishment predictions. The prediction accuracy is 91.7%, which is achieved without the model being aware of provincial classifications (the province to which municipalities belong is not an input to the model). The largest difference in the predicted number of abolished municipalities between the model and reality is in Zeeland. This happens because Zeeland in 1851 consisted of 6 disconnected municipality clusters, which were eventually connected with each other and with the mainland (the giant graph component). However, the model is unaware of the new municipality connections (in the form of tunnels, bridges and dikes), therefore the abolishment calculations based on the annual Abolishment Likelihood Index $p[k]$ does not take into account the new municipality neighbor connection-pairs that were created in reality in Zeeland during 1851-2019.



Province	Abolished municipalities in reality	Abolished municipalities in the model	Difference
Drenthe	22	22	0
Flevoland	0	0	0
Friesland	27	21	6
Gelderland	69	77	8
Groningen	45	37	8
Limburg	95	98	3
Noord-Brabant	124	130	6
Noord-Holland	97	104	7
Overijssel	37	42	5
Zuid-Holland	180	178	2
Utrecht	69	76	7
Zeeland	103	83	20
Total	868	868	72

Figure 57 Number of abolished municipalities per province in reality and in the model in period $k \in \{1851,\dots,1940, 1947, 1950, 1955, 1960,\dots,2019\}$

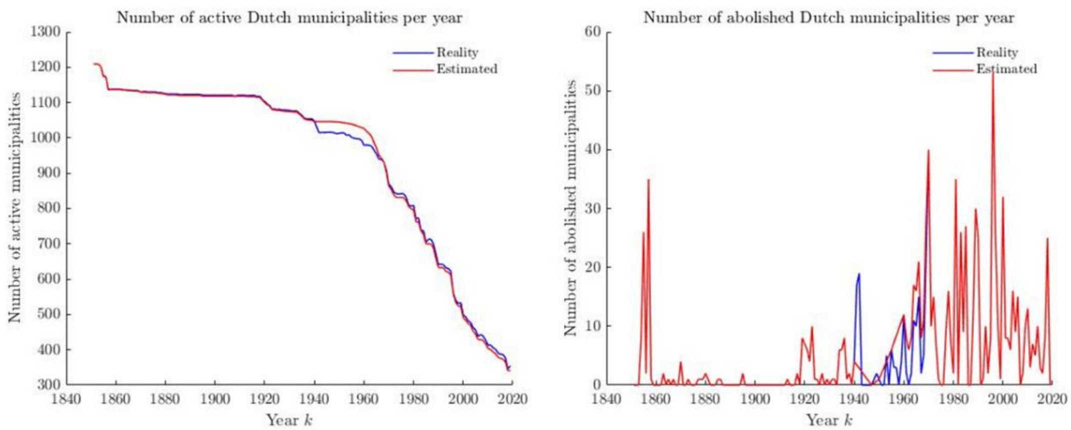


Figure 58 Left part: Number of active (left part) and abolished (right part) Dutch municipalities in reality (blue curves) and estimated in the model (red curves) for period 1851-2019.

In terms of year-on-year predictions, the accuracy is not as precise. Figure 59 plots the year-on-year prediction accuracy of municipality abolishments in the model against reality. Due to the fact that municipality mergers can take years to come into effect, a 20-year prediction depth is also considered in Figure 59; for example, if a municipality was predicted to be abolished in year k but in reality was abolished in year $k + 10$, this is considered a successful prediction. Once again, an abolishment is considered when both the CBS and the Amsterdam code of a municipality are discontinued in the same year k. Note that in many years there were very few abolishments (in many cases in the 19th century only one municipality was abolished per year), therefore almost all the exact-year predictions (blue dots in Figure 59) are zero.

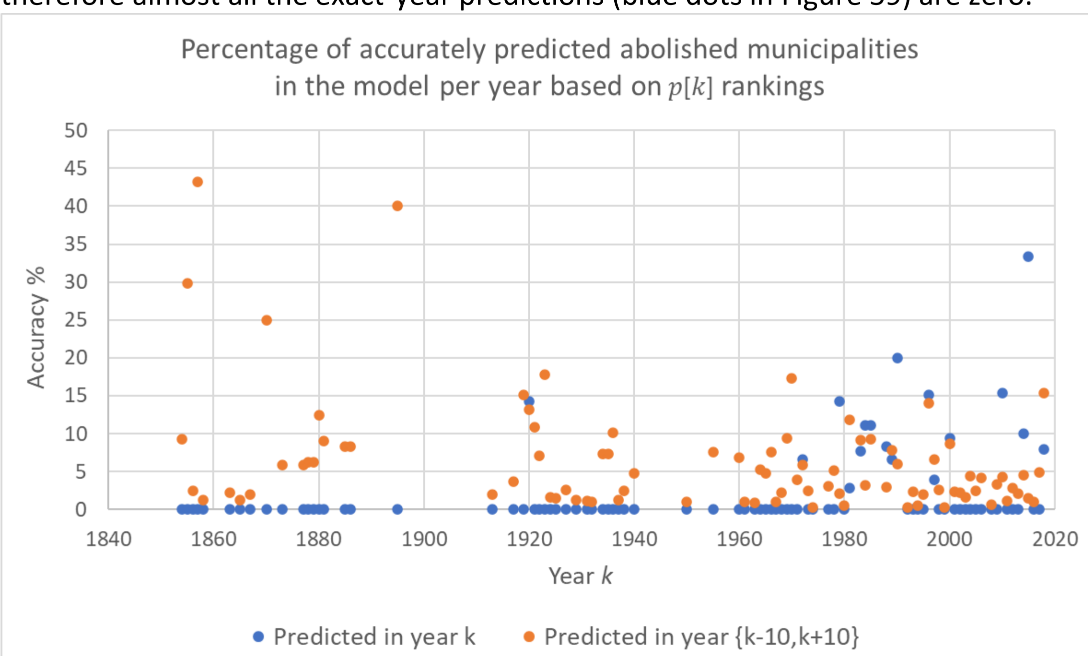


Figure 59 Percentage of accurately predicted abolished municipalities in the model based on $p[k]$ rankings of annual municipality sets i) at the exact year of a municipality's abolishment in reality (blue) and ii) within ten years before or after the municipality's abolishment in reality (orange)

In order to test the model predictions for the future of Dutch municipalities, Table 8 shows the ranking order of the Abolishment Likelihood Index $p[k = 2019]$ of the active municipalities in reality in the DMN in 2019 which were actually abolished during the period 2020-2022 (both their CBS and Amsterdam codes were abolished). There were $N[2019] = 355$ municipalities in 2019, five of which had no neighbors, thus the vector $p[k = 2019]$ has dimensions 350×1. Table 8 ranks the municipalities that were abolished between 2020-2022 according to their Abolishment Likelihood Index in 2019 from highest to lowest, therefore municipalities closer to the top of the ranking are the most likely candidates for abolishment. Indeed, the first four municipalities in Table 8 are within the top 5% of the $p[k = 2019]$ abolishment likelihood ranking order (municipalities with $p[k] > 2400$), indicating a high prediction accuracy of the Abolishment Likelihood Index $p[k]$ regarding future municipality mergers.

Table 8 Abolished municipalities in reality between 2020-2022 and their ranking in the 2019 DMN based on the Abolishment Likelihood Index $p[k = 2019]$.

Abolished Municipality	CBS Code	CBS and AMS Code Abol.	Province	Population in 2019	STED	Abolishment Likelihood Index $p[k]$ in 2019	Municipality ranking in $p[k]$ in 2019
Westvoorne	GM0614	2022	ZH.	14731	4	4979.25	5
Brielle	GM0501	2022	ZH.	17271	4	3753.33	9
Weesp	GM0457	2022	NH.	19738	2	3335.72	12
Loppersum	GM0024	2020	GR.	9537	5	2465.04	17
Beemster	GM0370	2021	NH.	10022	4	1729.00	34
Haaren	GM0788	2020	NB.	14370	5	1622.10	38
Appingedam	GM0003	2020	GR.	11642	3	1218.18	66
Grave	GM0786	2021	NB.	12436	4	1125.20	81
Langedijk	GM0416	2021	NH.	28163	4	1013.58	102
Landerd	GM1685	2021	NB.	15730	5	859.31	130
Sint Anthonis	GM1702	2021	NB.	11664	5	806.99	144
Mill en Sint Hubert	GM0815	2021	NB.	10939	5	773.13	153
Cuijk	GM1684	2021	NB.	25130	4	349.62	277

5 Conclusions and Recommendations for Future Work

This chapter presents this thesis' conclusions and recommendations. Section 5.1 summarises the answers to the research questions. Recommendations for future research are provided in section 5.2. The main results of this research are the linearity observed from the population data over the period 1830-2019 and the realisation of a model that can estimate the population developments and merger dynamics of the Dutch Municipality Network. Furthermore, evident power-law behavior was found in each year of the time-series in the period 1851-2019, when taking the cut-off effect into account for very large and very small municipalities in terms of their population size. When considering for every year k the entire municipality population vector, from the smallest to the largest number of inhabitants, then the population distribution can be qualified as power-law-like.

5.1 Conclusions

RQ1: *How can we characterize the population distribution in different annual sets of Dutch municipalities which have been recorded since 1830?*

The population distribution in Dutch municipalities during the period 1830-2019 seems to follow:
1) a lognormal distribution
2) a Fermi-Dirac distribution
3) a power-law-like distribution

We have tested the assumptions regarding the lognormal and Fermi-Dirac distributions by means of the Anderson-Darling (AD) and Kolmogorov-Smirnov (KS) goodness-of-fit tests. Results derived from both the AD and the KS test are consistent and indicate that the plausibility of the population distribution per municipality following the Fermi-Dirac probability is higher than of the lognormal distribution, over the entire period (1830 - 2019).
From the population vectors, we observed in each year of the researched time series that the exponent value $\tau[k]$ of the probability density function varies between 2 and 3, thus revealing power-law-like behavior and likely placing the Dutch Municipality Network to the class of scale-free networks. The maximum exponent value occurred in 1865 at $\tau[1856] = 2.69$. During the period of industrialization and urbanisation in the Netherlands, the exponent value had a decreasing trend with the lowest value occurring at $\tau[1961] = 2.17$. Year 1961 marked a transition phase, after which the exponent value started increasing and eventually approaching its mid-19th century values during the last decade with values such as $\tau[2013] = 2.62$ and $\tau[2019] = 2.63$. The turning point of the exponent value in 1961 likely marks the beginning of suburbanization in the Netherlands, enabled by mass transportation and daily commuting, thus causing the rate of the population increase of large municipalities to become slower compared to the faster population growth until the 1960. An exponential cut-off function can be applied

to both sides of the logarithmic population scale in the probability density function (for example Figure 22), to exclude the municipalities with the largest population (right-hand side of the population axis) and the municipalities with very low population (left-hand side of the population axis).

RQ2a: *Can we define and derive node survivability as a new metric that indicates the survivability of individual municipalities (against the average node survivability of all municipality nodes in the network and the average node survivability in each province) from time series of geospatial data, population data and sector specific data?*

In terms of population and area, an Abolishment Likelihood Index $p[k]$of each individual municipality can be considered as an indicator for the survivability of municipalities calculated from the data of the period $k \in \{1851,...,1940,\ 1947,\ 1950,\ 1955,\ 1960,...,2019\}$. This index is calculated for every municipality in every year *k* by comparing:

1) the population of each municipality with the population of the municipality's neighbors in year k and
2) the area size of each municipality with the average area size of all existing municipalities in year k.

The population term in Equation 17 has a proposed weight factor of 3, while the area factor has a proposed weight of 1. In the modelled simulations, each year the set of municipalities with the highest Abolishment Likelihood Index is abolished. The set of abolished municipalities in the modelled simulations per year is different than the set of municipalities that was abolished in reality, while the number of abolished municipalities per year is the same both in the modelled simulations and in reality.

In terms of sector-specific data (proximity to facilities dataset, which is available for the period 2006-2018): The Average Neighbor Superiority NS_{av} is calculated on average over three types of facilities:

1) proximities to essential facilities,
2) proximities to education facilities and
3) proximities to entertainment facilities

The Average Neighbor Superiority NS_{av}quantifies how 'superior' are the neighbors of municipalities compared to the municipalities themselves (in terms of the proximities to facilities offered to their citizens). The Average Neighbor Superiority is calculated for three distinct municipality groups:

A) all abolished type A municipalities in period 2006-2018,
B) all abolished type C municipalities in period 2006-2018 and
C) all existing municipalities in 2019.

The Average Neighbor Superiority is calculated for each facility type:
1) on average for all municipalities in each municipality group (Table 4) and
2) per individual municipality (Table 10-12)

RQ2b: *Which approaches can be suitable and which approach is optimal to indicate the node survivability of each individual node in a network such as the Dutch Municipality Network?*

The Abolishment Likelihood Index $p[k]$ is likely more suitable, because it can be consistently calculated over a large period (1851-2019), as opposed to the sector-related Average Neighbor Superiority (which can only be calculated for municipalities in period 2006-2018). In addition, the Abolishment Likelihood Index is based on the government layer λ=0 (related to the area size of municipalities) and the population layer λ=1 (related to the population per municipality) of the DMN, while the Average Neighbor Superiority is based on sector-related layers. An application of both metrics in the 2019 DMN can be found in Table 10 Abolishment Likelihood Index $p[k]$ and Average Neighbor Superiority (NS_{av}) for three types of proximity to sector-related facilities for municipalities existing in 2019.

RQ3a: Which node survivability values, developments and municipality interactions can be observed from the time series of data of each individual municipality node (against the average node survivability of all municipality nodes in the network and the average node survivability in each province)?

The average value of the Abolishment Likelihood Index $p[k]$ for the surviving municipalities in each annual set $N[k]$ tends to be around 1000 for the entire researched time period (1851-2019). In 2019, the lowest non-zero $p[k]$ value was assigned to Rotterdam $p[k] = 59.05$ while the highest $p[k]$ value was observed in Rozendaal ($p[k] = 17504.08$). The 5 Wadden island municipalities have $p[k] = 0$ as there is no network effect caused by the absence of neighboring municipalities in the context of this research construct. As can be observed from Figure 55 and verified in Table 10, highly urbanised municipalities such as Amsterdam and Rotterdam have the lowest values of Abolishment Likelihood Index ($p[k] \leq 600$) an average value. If in general the pi<=1000, the likelihood of survivability is high.

Taking into account the network effects regarding municipality mergers on a neighbor-level, Figure 51 plots the correlation between the Abolishment Likelihood Index $p_i[k]$ for each abolished municipality (Y-axis) and the average Abolishment Likelihood Index $p[k]$ for the surviving neighbors of each abolished municipality (X-axis), for the period $k \in \{1851, \ldots, 1940,\ 1947,\ 1950,\ 1955,\ 1960, \ldots, 2019\}$ .The majority of the $p[k]$ values for the surviving neighbors of abolished municipalities is concentrated below $p[k] < 1000$ on the X-axis, while the values for abolished municipalities are scattered above the diagonal line $y = x$ and are located at higher Y-axis positions ($p[k] > 1000$), indicating that the $p[k]$ of most abolished municipalities was higher than the $p[k]$ of the surviving neighbors of these abolished municipalities. This shows that a neighbor-level analysis on the population and area characteristics of a cluster of neighboring municipalities (as is the definition of the Abolishment Likelihood Indicator in Equation 17) could indicate which municipalities are most likely to survive and which municipalities have a higher likelihood of abolishment.

Figure 52 plots the per year average Abolishment Likelihood Index $p[k]$ for all abolished municipalities and their surviving neighbors during the period $k \in \{1851,...,1940,\ 1947,\ 1950,\ 1955,\ 1960,...,2019\}$. It is evident from the figure that the majority of the $p[k]$ values of abolished municipalities is on average much higher than the $p[k]$ values of the surviving neighbors of the abolished municipalities.

Figure 54 plots the development of the Average Abolishment Likelihood Index $p[k]$ per province and ranks the provinces based on each province's total average $p[k]$ over all years. The mostly rural provinces of Groningen and Friesland have the lowest total average $p[k]$, possibly indicating that the majority of municipalities within these provinces share similar characteristics in terms of population and area-size. On the contrary, the provinces of Noord-Holland and Utrecht have the highest total average $p[k]$, likely indicating that these provinces comprise municipalities with larger differences among their municipalities (in terms of population and area-size) than the differences among municipalities in provinces with lower ranking on the total average $p[k]$ ranking.

Figure 53 plots the Average Abolishment Likelihood Index $p[k]$ for all municipalities per year in period $k \in \{1851, \ldots, 1940, 1947, 1950, 1955, 1960, \ldots, 2019\}$. Since a high value of $p_i[k]$ for the i-th municipality indicates a higher inequality in the population and area-size between municipality i and its neighbors, then by extension to all municipalities on average in each annual instance k, a higher value of the average $p[k]$ in year k indicates that there are more inequalities among (clusters of) Dutch municipalities in terms of their population and area-size. These inequalities between municipalities were increasing (from lower values of $p[k]$ in 1860 towards the peak value of $p[k]$ in 1967) during the period of industrialisation and urbanisation. Since 1967, the average $p[k]$ values have been declining, possibly indicating that the intensified merging process that occurred in two waves in the 1960s and the 1980s managed to reduce to some extent the differences in population and area-size among (neighboring) Dutch municipalities.

RQ3b: *Which factors influence the merging process of municipalities?*

The main factor that influences the merging of municipalities is the population migration. According to the push/pull hypothesis [45] , there is a push factor that drives people away from smaller municipalities, and a pull factor that attracts people to larger municipalities. This is in accordance with the notion of preferential attachment (that characterises scale-free networks) and preferential detachment. Therefore, the migration flow of people is mainly directed from

smaller towards bigger municipalities (in terms of population). As a consequence of this continuous migration process, it is increasingly difficult for municipalities that have a smaller (and in some cases a declining trend in) population to cope with their administrative tasks, which drives them to merge with larger (neighboring) municipalities. A long term consequence of this merging process is the increase of the average area size of Dutch municipalities over time, thus leaving fewer small-area municipalities active in each annual instance of the Dutch Municipality Network. This fact makes the area size of municipalities an additional criterion for mergers, apart from the population size. In the definition of the Abolishment Likelihood Index per municipality, both the population and area size of municipalities are taken into account with different weight factors (the population has a proposed weight factor of 3 based on heuristic testing, while the area has a weight factor of 1), and the average value of the Abolishment Likelihood Index for all the existing municipalities in 2019 is lower than the average Abolishment Likelihood Index of abolished municipalities (right part of Figure 49), thus confirming that municipalities with a high Abolishment Likelihood Index are more likely to be abolished.
Of course, there are many other (non-quantifiable) factors that influence the decisions and the outcomes of municipality mergers, some of which are mentioned in sub-section 3.1.3. However, the main contribution of this thesis' approach is that it reduces the complexity of the merging process analysis by isolating and choosing only two aspects (population and area), which seem to be dominant factors in the complex dynamics of the merging process of municipalities.

RQ4: *Which existing network metrics could indicate the urbanization degree[12] of individual municipality nodes in the Dutch Municipality Network?*

As demonstrated in section 3.9 , the eigenvector centrality displays the highest correlation with the urbanisation degree of municipalities compared all other researched graph metrics. To quantify the correlation, the Pearson correlation coefficient R was calculated for the municipalities in the DMN for the period 2004-2019 during which urbanisation statistics per municipality are available. The correlation coefficient for the eigenvector centrality of municipalities increases from $R = -0.353$ in 2004 to $R = -0.410$ in 2019. The correlation can also be visually observed in Figure 46. Since other researched graph metrics (such as the degree, betweenness centrality, closeness centrality and local clustering coefficient) do not seem to be highly correlated with the urbanisation degree of municipalities, it is concluded that the eigenvector centrality is the most indicative graph metric for the urbanisation degree of municipalities. The node-related metrics mentioned in sub-section 2.2.5 are visually expressed by means of heatmaps in Appendix 7.2

[12] The urbanization degree is not a network metric; it is an indicator reflecting the degree of concentration of human activities (living, working, transacting) in an area, based on the area's local address density [42].

RQ5a: *Which type of model can serve as a mathematical fundament for a research construct that can capture and relate time series of geospatial data, population data and sector specific data (about facilities and establishments) of each individual municipality?*

It is possible to capture the dynamic interactions between different aspects of municipalities through the deployment of a multilayer Discrete-Linear State Space (DLSS) model, which is described in sub-section 2.2.2. The fundamentals for the adaptation of the multilayer DLSS for the Dutch Municipality Network, by interconnecting N DLSS systems to represent municipality nodes and incorporating socioeconomic sectors as different layers of the multilayer DLSS is given in sub-section 2.2.3.

RQ5b: *Which other modelling ways without a layered approach could be suitable as well?*

Due to the limited availability of continuous sector-related datasets for the researched time period (1830-2019), the multilayer DLSS model for the DMN described in sub-section 2.2.3 cannot be realised. Consequently, an alternative non-layered approach was proposed. The proposed model consists of the 3 complementary modeling steps, two of which were described in sub-section 2.2.1 (first step) and 2.2.4 (second step). The third modelling step was introduced in section 4.2 and the entire modeling process was validated in section 4.3.
The combination of the population linear correlation model (first modelling step) and the population migration model (second modelling step) captures and estimates the population dynamics of the DMN throughout the period 1851-2019 with remarkable accuracy, while the Abolishment Likelihood Index $p[k]$ (third modelling step) estimates the set of abolished municipalities in each year in the model. The Abolishment Likelihood Index $p[k]$ ranks each annual set of municipalities with descending order of likelihood of abolishment, by comparing the population and area of each municipality with the population and area of its neighbors. Based on the number of abolished municipalities in each year $N_a[k]$ in reality, the model chooses to abolish the top $N_a[k]$ municipalities in the $p[k]$ municipality ranking table of year k. Note that the Abolishment Likelihood Index $p[k]$ can be used as a metric for the ranking of the survivability of municipalities both in the model and in reality (sub-section 4.3.1 applies and validates $p[k]$ in annual sets of existing $\mathcal{N}[k]$ and abolished $\mathcal{A}[k]$ municipalities in reality).

RQ6a: To what extent are the node survivability values and developments observed from the research construct in line with the statistics about the urbanization degree values of individual Dutch municipalities?
RQ6b: To what extent are the node survivability values, survivability developments and inter-municipal migration developments observed from the research construct in line with the classes of urbanization?

Figure 55 shows the results of applying the Abolishment Likelihood Index $p[k]$ on each active set of municipalities $\mathcal{N}[k]$ in the DMN (in reality) per urbanisation degree for $k \in \{2004, \ldots, 2019\}$ during which period urbanisation degree statistics per municipality are available. STED 3 municipalities show an increasing Abolishment Likelihood Index $p[k]$ trend after 2014 and have the highest average $p[k]$ in 2019, which can be explained by observing in the right part of Figure 55 that the majority of the neighbors of STED 3 municipalities belong to all the other urbanisation classes but very rarely to the same urbanisation class, making the neighborhood of STED 3 municipalities the most diverse in terms of population (and area) characteristics, thus raising the average $p[k]$ for STED 3 municipalities.
Figure 56 shows the annual number of active municipalities per urbanisation degree and the total number of abolished municipalities per urbanisation degree during period 2004-2019. None STED 1 municipalities and 4 STED 2 municipalities were abolished during 2004-2019, which validates the low Abolishment Likelihood Index $p[k]$ of these municipalities seen in Figure 55. In addition, the STED 5 municipalities is the urbanisation class with the most rapid decline in number of municipalities (Figure 56), as these rural municipalities are merged with larger neighboring municipalities. The 58 STED 5 municipalities that have managed to survive in 2019 are mostly concentrated at the periphery of the country and are neighboring with other STED 5 municipalities, which likely have comparable population and area-size thus leading to an a decreasing trend in $p[k]$ values for municipalities belonging to the STED 5 urbanisation class in Figure 55. In other words, the population and area-size differences in the neighborhood of STED 5 municipalities in 2019 are not as large as the differences in 2004. STED 1, STED 2 and STED 5 municipalities have the same average $p[k]$ in 2019, which indicates that STED 1 and STED 2 municipalities (mainly located within the Randstad) are neighbors with municipalities that share similar characteristics in terms of population and area size.

RQ7a: *How did the geographical borders (topology) and names of Dutch municipalities change over time as a consequence of the merging process?*

An example of how the merging process of municipalities affects the topology of the Dutch Municipality Network is shown for two consecutive years in Figure 36. The continuous process of merging municipalities, orchestrated by the Dutch government on the government layer λ=0 of the DMN (ISIC section O), has consequences on the geospatial municipality graph as well as the municipality polygons (area demarcation of municipalities). The area size of the average Dutch municipality $E[s[k]]$ becomes larger over time, as the general tendency is for small-area municipalities to be annexed by larger neighbors (Type A merger) or to form coalitions with other neighboring municipalities to create new larger-sized municipalities (Type C mergers).

During the period 1830-2019, there were 56 administrative adjustments resulting in the name change of 56 municipalities, a process defined as a reclassification Type D (Dutch or Frisian name change) in sub-section 3.1.2. Out of these 56 municipalities, 23 of them still existed in

2019 under a different name (and therefore with a different CBS code, but inherited the same Amsterdam code from their predecessor municipality). The names, population development and urbanisation index of these 23 Type D municipalities can be seen on Table 0. From the 56 municipalities that changed their name, 13 of them belong to Friesland. This is because the Frisian municipalities changed their name spelling from the Dutch to the Frisian language.

RQ7b: *Which patterns can be observed from the network topology change over time?*

While the number of nodes and links in the Dutch Municipality Network has been decreasing from 1228 nodes and 2958 links in 1830 towards 355 nodes and 867 links in 2019, the average network degree remained almost constant at $E[D] \approx 5$. As can be observed in Figure 11, the average area size of Dutch municipalities has increased by a factor 3.6 during the period 1830-2019. A period of intense municipality mergers started from the 1960's, when municipalities were assigned more administrative power and responsibilities, leading to smaller municipalities (both in terms of population and area) to be annexed by larger municipalities (Type A mergers). In more recent decades (1990-2018), the previously dominant Type A (Annexation) merger type occurred less frequently, while Type C (Coalition) mergers became more common. As seen in Figure 14, the average area size of abolished Type C municipalities was almost always larger than Type A abolished municipalities, which could indicate that Type C municipalities were large enough (in terms of area size) to avoid annexation, but they had to form coalitions with other municipalities in order to survive.

In 1830, there were 12 island municipalities (without any road/railway transport connection to the mainland), as well as 191 municipalities belonging to 9 municipality clusters which were disconnected from the giant graph component. In 2019, there remain 5 Wadden island municipalities and there are zero disconnected municipality clusters since the opening of the Westerscheldetunnel on March 2003, which connected the Zeeland municipalities Borsele and Terneuzen.

RQ8a: *Which Dutch municipalities have continuously existed in each annual set of municipalities from 1830 to 2019?*

There are 250 municipalities that have continuously existed during the period 1830-2019. 227 municipalities have kept their original 1830 name until 2019, while 23 municipalities had their name (and therefore their CBS code) changed once during the period 1830-2019 (Type D reclassification). The 250 municipalities are listed in Appendix 0.

RQ8b: Which future municipality mergers can be predicted based on observations from the research construct from the trend and the outcome of RQ8a?

Table 8 lists the municipalities that existed in 2019 but were abolished in reality during 2020-2022, and ranks them from highest to lowest value of Abolishment Likelihood Index $p[k]$, therefore municipalities closer to the top of the ranking are the most likely candidates for abolishment at the end of 2019. Indeed, the first four municipalities listed in Table 8 are within the top 5% of the $p[k = 2019]$ ranking order of the 355 Dutch municipalities existing in 2019, indicating a high prediction accuracy of the Abolishment Likelihood Index $p[k]$ regarding future municipality mergers. All the municipalities that existed in 2019 are ranked from highest to lowest Abolishment Likelihood Index $p[k]$ in Table 10.

5.2 Recommendations for Future Work

A next step in this research is to validate the linear correlation and migration model with statistical data recorded in other countries. A requirement is that lengthy time-series of statistical data are available when comparing the results with the findings from Dutch statistical data presented in this thesis. In addition, the Abolishment Likelihood Index $p[k]$ regarding abolishment of municipalities could be tested in other countries, provided that municipal-level administrative reclassifications occur on a regular basis (as is the case for the Netherlands)

6 References

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7 Appendix

7.1 Municipality Ranking Tables

7.1.1 Municipalities that continuously existed in the period 1830-2019

There are 250 municipalities that have continuously existed during the period 1830-2019. 227 of them have kept their original 1830 name until 2019, while 23 municipalities had their name (and therefore their CBS code) changed once during the period 1830-2019 (Type D reclassification). The 250 municipalities are listed in Table 9.

7.1.2 Abolishment Likelihood Index and Average Neighbor Superiority for municipalities that exist in 2019

Presented in Table 10 Abolishment Likelihood Index $p[k]$ and Average Neighbor Superiority (NS_{av}) for three types of proximity to sector-related facilities for municipalities existing in 2019.

7.1.3 Average Neighbor Superiority for abolished Type A municipalities between 2006-2018

Presented in Table 11 Average Neighbor Superiority (NS_{av}) for three types of proximity to sector-related facilities for abolished Type A municipalities during period 2006-2018.

7.1.4 Average Neighbor Superiority for abolished Type C municipalities between 2006-2018

Presented in Table 12 Average Neighbor Superiority (NS_{av}) for three types of proximity to sector-related facilities for abolished Type C municipalities during period 2006-2018.

Table 9 Ranking Table of 250 municipalities that have continuously existed during period 1830-2019, ranked according to their 2019 population. The urbanisation degree (STED) refers to the 2019 status.

Nr	Municipality	CBS Code GMXXXX	AMS Code	CBS Code Est.	CBS Code Abol.	AMS Code Est.	AMS Code Abol.	Province	Merger Type	STED	Population 1830	Population 2019
1	Amsterdam	GM0363	11150	1830	Exists in 2019	1830	Exists in 2019	Noord-Holland	Exists in 2019	1	202175	872757
2	Rotterdam	GM0599	10345	1830	Exists in 2019	1830	Exists in 2019	Zuid-Holland	Exists in 2019	1	72294	651168
3	's-Gravenhage	GM0518	11434	1830	Exists in 2019	1830	Exists in 2019	Zuid-Holland	Exists in 2019	1	56105	545838
4	Utrecht	GM0344	10722	1830	Exists in 2019	1830	Exists in 2019	Utrecht	Exists in 2019	1	43407	357597
5	Eindhoven	GM0772	11298	1830	Exists in 2019	1830	Exists in 2019	Noord-Brabant	Exists in 2019	1	2996	234394
6	Groningen	GM0014	10426	1830	Exists in 2019	1830	Exists in 2019	Groningen	Exists in 2019	1	30260	232874
7	Tilburg	GM0855	10792	1830	Exists in 2019	1830	Exists in 2019	Noord-Brabant	Exists in 2019	1	11726	219789
8	Breda	GM0758	10154	1830	Exists in 2019	1830	Exists in 2019	Noord-Brabant	Exists in 2019	2	13114	184069
9	Nijmegen	GM0268	11209	1830	Exists in 2019	1830	Exists in 2019	Gelderland	Exists in 2019	2	17734	177659
10	Apeldoorn	GM0200	11075	1830	Exists in 2019	1830	Exists in 2019	Gelderland	Exists in 2019	2	7226	163818
11	Haarlem	GM0392	10357	1830	Exists in 2019	1830	Exists in 2019	Noord-Holland	Exists in 2019	1	21667	162902
12	Arnhem	GM0202	10795	1830	Exists in 2019	1830	Exists in 2019	Gelderland	Exists in 2019	2	14509	161348
13	Enschede	GM0153	10364	1830	Exists in 2019	1830	Exists in 2019	Overijssel	Exists in 2019	2	3253	159640
14	Amersfoort	GM0307	10948	1830	Exists in 2019	1830	Exists in 2019	Utrecht	Exists in 2019	2	11782	157276
15	's-Hertogenbosch	GM0796	10054	1830	Exists in 2019	1830	Exists in 2019	Noord-Brabant	Exists in 2019	2	20489	155111
16	Zwolle	GM0193	10093	1830	Exists in 2019	1830	Exists in 2019	Overijssel	Exists in 2019	2	15640	128840
17	Zoetermeer	GM0637	10766	1830	Exists in 2019	1830	Exists in 2019	Zuid-Holland	Exists in 2019	1	841	125285
18	Leiden	GM0546	10702	1830	Exists in 2019	1830	Exists in 2019	Zuid-Holland	Exists in 2019	1	34564	125099
19	Leeuwarden	GM0080	11228	1830	Exists in 2019	1830	Exists in 2019	Friesland	Exists in 2019	2	20938	124084
20	Maastricht	GM0935	10182	1830	Exists in 2019	1830	Exists in 2019	Limburg	Exists in 2019	2	24444	121575
21	Dordrecht	GM0505	11157	1830	Exists in 2019	1830	Exists in 2019	Zuid-Holland	Exists in 2019	1	19972	119284
22	Ede	GM0228	10743	1830	Exists in 2019	1830	Exists in 2019	Gelderland	Exists in 2019	2	7690	117165

Nr	Municipality	CBS Code GMXXXX	AMS Code	CBS Code Est.	CBS Code Abol.	AMS Code Est.	AMS Code Abol.	Province	Merger Type	STED	Population 1830	Population 2019
23	Alkmaar	GM0361	10527	1830	Exists in 2019	1830	Exists in 2019	Noord-Holland	Exists in 2019	2	9439	109436
24	Emmen	GM0114	11180	1830	Exists in 2019	1830	Exists in 2019	Drenthe	Exists in 2019	4	2120	107048
25	Delft	GM0503	10928	1830	Exists in 2019	1830	Exists in 2019	Zuid-Holland	Exists in 2019	1	15023	103595
26	Venlo	GM0983	10477	1830	Exists in 2019	1830	Exists in 2019	Limburg	Exists in 2019	2	7277	101802
27	Deventer	GM0150	10899	1830	Exists in 2019	1830	Exists in 2019	Overijssel	Exists in 2019	2	13639	100719
28	Helmond	GM0794	10932	1830	Exists in 2019	1830	Exists in 2019	Noord-Brabant	Exists in 2019	2		92423
29	Oss	GM0828	10834	1830	Exists in 2019	1830	Exists in 2019	Noord-Brabant	Exists in 2019	3		91915
30	Nieuwer-Amstel	GM1249	10799	1830	1963	1830	Exists in 2019	Noord-Holland	Type D	2	4430	91675
31	Hilversum	GM0402	11285	1830	Exists in 2019	1830	Exists in 2019	Noord-Holland	Exists in 2019	1	4367	90831
32	Heerlen	GM0917	10902	1830	Exists in 2019	1830	Exists in 2019	Limburg	Exists in 2019	2	4140	87086
33	Purmerend	GM0439	11066	1830	Exists in 2019	1830	Exists in 2019	Noord-Holland	Exists in 2019	2	3061	81249
34	Hengelo (O.)	GM0164	10907	1830	Exists in 2019	1830	Exists in 2019	Overijssel	Exists in 2019	2	3152	81140
35	Schiedam	GM0606	11260	1830	Exists in 2019	1830	Exists in 2019	Zuid-Holland	Exists in 2019	1	11588	78730
36	Gouda	GM0513	10302	1830	Exists in 2019	1830	Exists in 2019	Zuid-Holland	Exists in 2019	1	12878	73427
37	Vlaardingen	GM0622	10811	1830	Exists in 2019	1830	Exists in 2019	Zuid-Holland	Exists in 2019	1	6823	73397
38	Hoorn	GM0405	11392	1830	Exists in 2019	1830	Exists in 2019	Noord-Holland	Exists in 2019	2	7418	73261
39	Velsen	GM0453	10620	1830	Exists in 2019	1830	Exists in 2019	Noord-Holland	Exists in 2019	2	1779	68648
40	Assen	GM0106	10522	1830	Exists in 2019	1830	Exists in 2019	Drenthe	Exists in 2019	2	2184	68599
41	Bergen op Zoom	GM0748	11037	1830	Exists in 2019	1830	Exists in 2019	Noord-Brabant	Exists in 2019	2	7245	67496
42	Capelle aan den Ijssel	GM0502	11248	1830	Exists in 2019	1830	Exists in 2019	Zuid-Holland	Exists in 2019	2	1235	67122
43	Veenendaal	GM0345	11052	1830	Exists in 2019	1830	Exists in 2019	Utrecht	Exists in 2019	2	2682	66493
44	Katwijk	GM0537	10707	1830	Exists in 2019	1830	Exists in 2019	Zuid-Holland	Exists in 2019	2	4000	65753
45	Zeist	GM0355	10324	1830	Exists in 2019	1830	Exists in 2019	Utrecht	Exists in 2019	2	2477	64905
46	Barneveld	GM0203	10906	1830	Exists in 2019	1830	Exists in 2019	Gelderland	Exists in 2019	4	5063	59082
47	Roermond	GM0957	11313	1830	Exists in 2019	1830	Exists in 2019	Limburg	Exists in 2019	2	5397	58260

Nr	Municipality	CBS Code GMXXXX	AMS Code	CBS Code Est.	CBS Code Abol.	AMS Code Est.	AMS Code Abol.	Province	Merger Type	STED	Population 1830	Population 2019
48	Heerhugowaard	GM0398	10752	1830	Exists in 2019	1830	Exists in 2019	Noord-Holland	Exists in 2019	2	819	57587
49	Den Helder	GM0400	10285	1830	Exists in 2019	1830	Exists in 2019	Noord-Holland	Exists in 2019	2	5489	56296
50	Smallingerland	GM0090	10405	1830	Exists in 2019	1830	Exists in 2019	Friesland	Exists in 2019	3	5844	56150
51	Oosterhout	GM0826	11280	1830	Exists in 2019	1830	Exists in 2019	Noord-Brabant	Exists in 2019	2	7287	55982
52	Hoogeveen	GM0118	10839	1830	Exists in 2019	1830	Exists in 2019	Drenthe	Exists in 2019	3	6164	55699
53	Rijswijk (ZH.)	GM0603	11133	1830	Exists in 2019	1830	Exists in 2019	Zuid-Holland	Exists in 2019	1	2132	54450
54	Terneuzen	GM0715	10704	1830	Exists in 2019	1830	Exists in 2019	Zeeland	Exists in 2019	4	1903	54426
55	Kampen	GM0166	10253	1830	Exists in 2019	1830	Exists in 2019	Overijssel	Exists in 2019	3	8882	54319
56	Woerden	GM0632	10974	1830	Exists in 2019	1830	Exists in 2019	Utrecht	Exists in 2019	3	3052	52299
57	Houten	GM0321	10230	1830	Exists in 2019	1830	Exists in 2019	Utrecht	Exists in 2019	2	829	50146
58	Weert	GM0988	11081	1830	Exists in 2019	1830	Exists in 2019	Limburg	Exists in 2019	3	5895	50105
59	Middelburg (Z.)	GM0687	10122	1830	Exists in 2019	1830	Exists in 2019	Zeeland	Exists in 2019	2	14700	48822
60	Waalwijk	GM0867	11359	1830	Exists in 2019	1830	Exists in 2019	Noord-Brabant	Exists in 2019	3		48637
61	Harderwijk	GM0243	10786	1830	Exists in 2019	1830	Exists in 2019	Gelderland	Exists in 2019	2	4829	48414
62	Zutphen	GM0301	10254	1830	Exists in 2019	1830	Exists in 2019	Gelderland	Exists in 2019	2	10204	47934
63	Soest	GM0342	11021	1830	Exists in 2019	1830	Exists in 2019	Utrecht	Exists in 2019	3	2228	46606
64	Bemmel	GM0206	10744	1830	2002	1830	Exists in 2019	Gelderland	Type D	4	3211	46601
65	Schagen	GM0441	10511	1830	Exists in 2019	1830	Exists in 2019	Noord-Holland	Exists in 2019	4	1707	46483
66	Ridderkerk	GM0597	10646	1830	Exists in 2019	1830	Exists in 2019	Zuid-Holland	Exists in 2019	2	3554	46189
67	Kerkrade	GM0928	10313	1830	Exists in 2019	1830	Exists in 2019	Limburg	Exists in 2019	2	3435	45749
68	Medemblik	GM0420	11215	1830	Exists in 2019	1830	Exists in 2019	Noord-Holland	Exists in 2019	4	2541	45101
69	Zwijndrecht	GM0642	10468	1830	Exists in 2019	1830	Exists in 2019	Zuid-Holland	Exists in 2019	2	787	44737
70	Heusden	GM0797	10307	1830	Exists in 2019	1830	Exists in 2019	Noord-Brabant	Exists in 2019	3	1834	44692
71	Vlissingen	GM0718	10270	1830	Exists in 2019	1830	Exists in 2019	Zeeland	Exists in 2019	2	8029	44360
72	Steenwijk	GM0181	10546	1830	2002	1830	Exists in 2019	Overijssel	Type D	4	2882	44126

Nr	Municipality	CBS Code GMXXXX	AMS Code	CBS Code Est.	CBS Code Abol.	AMS Code Est.	AMS Code Abol.	Province	Merger Type	STED	Population 1830	Population 2019
73	Etten en Leur	GM1251	10750	1830	1967	1830	Exists in 2019	Noord-Brabant	Type D	2		43878
74	Rheden	GM0275	11355	1830	Exists in 2019	1830	Exists in 2019	Gelderland	Exists in 2019	3	5189	43761
75	Zevenaar	GM0299	10938	1830	Exists in 2019	1830	Exists in 2019	Gelderland	Exists in 2019	3	2981	43750
76	Venray	GM0984	11222	1830	Exists in 2019	1830	Exists in 2019	Limburg	Exists in 2019	4	4237	43614
77	Noordwijk	GM0575	10769	1830	Exists in 2019	1830	Exists in 2019	Zuid-Holland	Exists in 2019	3	2730	43508
78	Nijkerk	GM0267	10446	1830	Exists in 2019	1830	Exists in 2019	Gelderland	Exists in 2019	3	6230	43171
79	De Bilt	GM0310	10168	1830	Exists in 2019	1830	Exists in 2019	Utrecht	Exists in 2019	3	1172	43137
80	Tiel	GM0281	10027	1830	Exists in 2019	1830	Exists in 2019	Gelderland	Exists in 2019	3	4776	42159
81	Uden	GM0856	11141	1830	Exists in 2019	1830	Exists in 2019	Noord-Brabant	Exists in 2019	3		42119
82	Beverwijk	GM0375	10272	1830	Exists in 2019	1830	Exists in 2019	Noord-Holland	Exists in 2019	1	2092	41626
83	Huizen	GM0406	11170	1830	Exists in 2019	1830	Exists in 2019	Noord-Holland	Exists in 2019	2	2037	41273
84	Wijchen	GM0296	10723	1830	Exists in 2019	1830	Exists in 2019	Gelderland	Exists in 2019	3	2579	41110
85	Hellevoetsluis	GM0530	11078	1830	Exists in 2019	1830	Exists in 2019	Zuid-Holland	Exists in 2019	2	2006	40142
86	Wageningen	GM0289	11010	1830	Exists in 2019	1830	Exists in 2019	Gelderland	Exists in 2019	2	3454	39664
87	Heemskerk	GM0396	10679	1830	Exists in 2019	1830	Exists in 2019	Noord-Holland	Exists in 2019	2	751	39182
88	Rijssen	GM0178	10358	1830	2003	1830	Exists in 2019	Overijssel	Type D	3	2341	38177
89	Goes	GM0664	10674	1830	Exists in 2019	1830	Exists in 2019	Zeeland	Exists in 2019	3	4888	38082
90	Raalte	GM0177	10279	1830	Exists in 2019	1830	Exists in 2019	Overijssel	Exists in 2019	4	4706	37712
91	Zevenbergen	GM0878	10046	1830	1998	1830	Exists in 2019	Noord-Brabant	Type D	4		37129
92	Gorinchem	GM0512	10942	1830	Exists in 2019	1830	Exists in 2019	Zuid-Holland	Exists in 2019	2	6834	37022
93	Edam	GM1315	10884	1830	1974	1830	Exists in 2019	Noord-Holland	Type D	3	3940	36197
94	Castricum	GM0383	11287	1830	Exists in 2019	1830	Exists in 2019	Noord-Holland	Exists in 2019	3	791	35986
95	Hellendoorn	GM0163	10806	1830	Exists in 2019	1830	Exists in 2019	Overijssel	Exists in 2019	4	3069	35916
96	Coevorden	GM0109	10383	1830	Exists in 2019	1830	Exists in 2019	Drenthe	Exists in 2019	4	2666	35297
97	Groesbeek	GM0241	10616	1830	2015	1830	Exists in 2019	Gelderland	Type D	4	2156	34992

Nr	Municipality	CBS Code GMXXXX	AMS Code	CBS Code Est.	CBS Code Abol.	AMS Code Est.	AMS Code Abol.	Province	Merger Type	STED	Population 1830	Population 2019
98	IJsselstein	GM0353	10152	1830	Exists in 2019	1830	Exists in 2019	Utrecht	Exists in 2019	2	3010	34109
99	Meppel	GM0119	11204	1830	Exists in 2019	1830	Exists in 2019	Drenthe	Exists in 2019	3	5682	33920
100	Zuidlaren	GM0136	10002	1830	1999	1830	Exists in 2019	Drenthe	Type D	4	1164	33887
101	Vriezenveen	GM0186	10643	1830	2002	1830	Exists in 2019	Overijssel	Type D	4	2600	33743
102	Lochem	GM0262	11263	1830	Exists in 2019	1830	Exists in 2019	Gelderland	Exists in 2019	4	1788	33729
103	Maassluis	GM0556	10880	1830	Exists in 2019	1830	Exists in 2019	Zuid-Holland	Exists in 2019	2	4434	33213
104	Epe	GM0232	10940	1830	Exists in 2019	1830	Exists in 2019	Gelderland	Exists in 2019	4	5144	33178
105	Papendrecht	GM0590	10427	1830	Exists in 2019	1830	Exists in 2019	Zuid-Holland	Exists in 2019	2	1594	32136
106	Tietjerksteradeel	GM0094	11241	1830	1988	1830	Exists in 2019	Friesland	Type D	5	7346	32052
107	Aalsmeer	GM0358	11264	1830	Exists in 2019	1830	Exists in 2019	Noord-Holland	Exists in 2019	4	2319	31859
108	Oldenzaal	GM0173	11100	1830	Exists in 2019	1830	Exists in 2019	Overijssel	Exists in 2019	3	2529	31836
109	Renkum	GM0274	11325	1830	Exists in 2019	1830	Exists in 2019	Gelderland	Exists in 2019	4	1767	31419
110	Heesch	GM0791	10149	1830	1995	1830	Exists in 2019	Noord-Brabant	Type D	4		31240
111	Hendrik-Ido-Ambacht	GM0531	10416	1830	Exists in 2019	1830	Exists in 2019	Zuid-Holland	Exists in 2019	2	1537	31202
112	Valkenswaard	GM0858	11031	1830	Exists in 2019	1830	Exists in 2019	Noord-Brabant	Exists in 2019	3		31193
113	Boxtel	GM0757	10083	1830	Exists in 2019	1830	Exists in 2019	Noord-Brabant	Exists in 2019	3		30801
114	Diemen	GM0384	11039	1830	Exists in 2019	1830	Exists in 2019	Noord-Holland	Exists in 2019	1	753	30780
115	Leusden	GM0327	10978	1830	Exists in 2019	1830	Exists in 2019	Utrecht	Exists in 2019	3	1338	30401
116	Best	GM0753	10442	1830	Exists in 2019	1830	Exists in 2019	Noord-Brabant	Exists in 2019	3		29988
117	Bergen (NH.)	GM0373	11424	1830	Exists in 2019	1830	Exists in 2019	Noord-Holland	Exists in 2019	4	868	29839
118	Opsterland	GM0086	10005	1830	Exists in 2019	1830	Exists in 2019	Friesland	Exists in 2019	5	9115	29733
119	Groenlo	GM0240	11094	1830	2006	1830	Exists in 2019	Gelderland	Type D	4	2149	29627
120	Krimpen aan den Ijssel	GM0542	10859	1830	Exists in 2019	1830	Exists in 2019	Zuid-Holland	Exists in 2019	2	836	29526
121	Uithoorn	GM0451	11206	1830	Exists in 2019	1830	Exists in 2019	Noord-Holland	Exists in 2019	3	1254	29478

Nr	Municipality	CBS Code GMXXXX	AMS Code	CBS Code Est.	CBS Code Abol.	AMS Code Est.	AMS Code Abol.	Province	Merger Type	STED	Population 1830	Population 2019
122	Boxmeer	GM0756	11227	1830	Exists in 2019	1830	Exists in 2019	Noord-Brabant	Exists in 2019	4		29365
123	Sint-Michielsgestel	GM0845	10496	1830	Exists in 2019	1830	Exists in 2019	Noord-Brabant	Exists in 2019	4		29208
124	Culemborg	GM0216	10342	1830	Exists in 2019	1830	Exists in 2019	Gelderland	Exists in 2019	3	4299	28955
125	Zaltbommel	GM0297	10557	1830	Exists in 2019	1830	Exists in 2019	Gelderland	Exists in 2019	4	3261	28881
126	Winterswijk	GM0294	11119	1830	Exists in 2019	1830	Exists in 2019	Gelderland	Exists in 2019	3	7101	28854
127	Nieuwkoop	GM0569	10728	1830	Exists in 2019	1830	Exists in 2019	Zuid-Holland	Exists in 2019	4	2015	28811
128	Dalfsen	GM0148	11007	1830	Exists in 2019	1830	Exists in 2019	Overijssel	Exists in 2019	4	4238	28587
129	Achtkarspelen	GM0059	10199	1830	Exists in 2019	1830	Exists in 2019	Friesland	Exists in 2019	5	6160	27843
130	Brunssum	GM0899	10533	1830	Exists in 2019	1830	Exists in 2019	Limburg	Exists in 2019	2	1007	27821
131	Hulst	GM0677	11408	1830	Exists in 2019	1830	Exists in 2019	Zeeland	Exists in 2019	4	2124	27556
132	Veendam	GM0047	11292	1830	Exists in 2019	1830	Exists in 2019	Groningen	Exists in 2019	3	6809	27384
133	Heemstede	GM0397	11288	1830	Exists in 2019	1830	Exists in 2019	Noord-Holland	Exists in 2019	2	2227	27234
134	Aalten	GM0197	11046	1830	Exists in 2019	1830	Exists in 2019	Gelderland	Exists in 2019	4	5487	27121
135	Leiderdorp	GM0547	10058	1830	Exists in 2019	1830	Exists in 2019	Zuid-Holland	Exists in 2019	2	1306	27056
136	Ermelo	GM0233	10732	1830	Exists in 2019	1830	Exists in 2019	Gelderland	Exists in 2019	4	3378	27008
137	Buren	GM0214	11286	1830	Exists in 2019	1830	Exists in 2019	Gelderland	Exists in 2019	5	1580	26749
138	Vught	GM0865	11224	1830	Exists in 2019	1830	Exists in 2019	Noord-Brabant	Exists in 2019	3		26558
139	Denekamp	GM0149	10245	1830	2002	1830	Exists in 2019	Overijssel	Type D	5	3820	26461
140	Gilze en Rijen	GM0784	11375	1830	Exists in 2019	1830	Exists in 2019	Noord-Brabant	Exists in 2019	3		26431
141	Wassenaar	GM0629	10164	1830	Exists in 2019	1830	Exists in 2019	Zuid-Holland	Exists in 2019	3	2422	26305
142	Oisterwijk	GM0824	10103	1830	Exists in 2019	1830	Exists in 2019	Noord-Brabant	Exists in 2019	4		26245
143	Dongen	GM0766	11412	1830	Exists in 2019	1830	Exists in 2019	Noord-Brabant	Exists in 2019	3		26222
144	Weststellingwerf	GM0098	11322	1830	Exists in 2019	1830	Exists in 2019	Friesland	Exists in 2019	4	7350	25914
145	Beuningen	GM0209	10417	1830	Exists in 2019	1830	Exists in 2019	Gelderland	Exists in 2019	4	1216	25890
146	Tholen	GM0716	10376	1830	Exists in 2019	1830	Exists in 2019	Zeeland	Exists in 2019	5	2159	25757

Nr	Municipality	CBS Code GMXXXX	AMS Code	CBS Code Est.	CBS Code Abol.	AMS Code Est.	AMS Code Abol.	Province	Merger Type	STED	Population 1830	Population 2019
147	Voorschoten	GM0626	10537	1830	Exists in 2019	1830	Exists in 2019	Zuid-Holland	Exists in 2019	2	1308	25596
148	Ooststellingwerf	GM0085	10836	1830	Exists in 2019	1830	Exists in 2019	Friesland	Exists in 2019	5	3990	25469
149	Sliedrecht	GM0610	11331	1830	Exists in 2019	1830	Exists in 2019	Zuid-Holland	Exists in 2019	2	4028	25220
150	Duiven	GM0226	11028	1830	Exists in 2019	1830	Exists in 2019	Gelderland	Exists in 2019	3	2160	25126
151	Driel	GM1248	10341	1830	1944	1830	Exists in 2019	Gelderland	Type D	5	2546	25030
152	Stein (L.)	GM0971	11319	1830	Exists in 2019	1830	Exists in 2019	Limburg	Exists in 2019	4	1636	25007
153	Baarn	GM0308	11411	1830	Exists in 2019	1830	Exists in 2019	Utrecht	Exists in 2019	2	1593	24868
154	Oegstgeest	GM0579	10287	1830	Exists in 2019	1830	Exists in 2019	Zuid-Holland	Exists in 2019	2	1528	24840
155	Delfzijl	GM0010	10976	1830	Exists in 2019	1830	Exists in 2019	Groningen	Exists in 2019	4	3653	24678
156	Voorst	GM0285	10912	1830	Exists in 2019	1830	Exists in 2019	Gelderland	Exists in 2019	4	6699	24552
157	Wierden	GM0189	10676	1830	Exists in 2019	1830	Exists in 2019	Overijssel	Exists in 2019	4	4175	24446
158	Steenbergen en Kruisland	GM1376	10731	1830	1996	1830	Exists in 2019	Noord-Brabant	Type D	4		24416
159	Kesteren	GM0258	10916	1830	2003	1830	Exists in 2019	Gelderland	Type D	5	1740	24339
160	Haaksbergen	GM0158	11435	1830	Exists in 2019	1830	Exists in 2019	Overijssel	Exists in 2019	3	4327	24311
161	Putten	GM0273	11109	1830	Exists in 2019	1830	Exists in 2019	Gelderland	Exists in 2019	4	2860	24112
162	Heiloo	GM0399	10793	1830	Exists in 2019	1830	Exists in 2019	Noord-Holland	Exists in 2019	3	544	23968
163	Wijk bij Duurstede	GM0352	10760	1830	Exists in 2019	1830	Exists in 2019	Utrecht	Exists in 2019	3	2181	23914
164	Goirle	GM0785	10971	1830	Exists in 2019	1830	Exists in 2019	Noord-Brabant	Exists in 2019	3		23904
165	Oldebroek	GM0269	11106	1830	Exists in 2019	1830	Exists in 2019	Gelderland	Exists in 2019	4	3367	23646
166	Bloemendaal	GM0377	10850	1830	Exists in 2019	1830	Exists in 2019	Noord-Holland	Exists in 2019	3	1748	23571
167	Loon op Zand	GM0809	11259	1830	Exists in 2019	1830	Exists in 2019	Noord-Brabant	Exists in 2019	3		23408
168	Nuenen, Gerwen en Nederwetten	GM0820	10761	1830	Exists in 2019	1830	Exists in 2019	Noord-Brabant	Exists in 2019	3		23383
169	Borne	GM0147	10326	1830	Exists in 2019	1830	Exists in 2019	Overijssel	Exists in 2019	3	3102	23312
170	Elburg	GM0230	11113	1830	Exists in 2019	1830	Exists in 2019	Gelderland	Exists in 2019	4	2174	23161

Nr	Municipality	CBS Code GMXXXX	AMS Code	CBS Code Est.	CBS Code Abol.	AMS Code Est.	AMS Code Abol.	Province	Merger Type	STED	Population 1830	Population 2019
171	Lisse	GM0553	10197	1830	Exists in 2019	1830	Exists in 2019	Zuid-Holland	Exists in 2019	2	1390	22955
172	Rucphen	GM0840	11152	1830	Exists in 2019	1830	Exists in 2019	Noord-Brabant	Exists in 2019	4		22878
173	Losser	GM0168	11166	1830	Exists in 2019	1830	Exists in 2019	Overijssel	Exists in 2019	4	4372	22683
174	Hillegom	GM0534	11236	1830	Exists in 2019	1830	Exists in 2019	Zuid-Holland	Exists in 2019	2		22209
175	Veere	GM0717	10369	1830	Exists in 2019	1830	Exists in 2019	Zeeland	Exists in 2019	5	921	21880
176	Woensdrecht	GM0873	10602	1830	Exists in 2019	1830	Exists in 2019	Noord-Brabant	Exists in 2019	4		21876
177	Bunschoten	GM0313	11343	1830	Exists in 2019	1830	Exists in 2019	Utrecht	Exists in 2019	3	900	21866
178	Zundert	GM0879	11192	1830	Exists in 2019	1830	Exists in 2019	Noord-Brabant	Exists in 2019	4		21829
179	Geertruidenberg	GM0779	10101	1830	Exists in 2019	1830	Exists in 2019	Noord-Brabant	Exists in 2019	3	1558	21544
180	Tubbergen	GM0183	10694	1830	Exists in 2019	1830	Exists in 2019	Overijssel	Exists in 2019	5	4965	21275
181	Budel	GM0759	10219	1830	1998	1830	Exists in 2019	Noord-Brabant	Type D	4		21138
182	Urk	GM0184	10783	1830	Exists in 2019	1830	Exists in 2019	Flevoland	Exists in 2019	3	789	21031
183	Brummen	GM0213	10798	1830	Exists in 2019	1830	Exists in 2019	Gelderland	Exists in 2019	4	4215	20726
184	Melick en Herkenbosch	GM0939	10196	1830	1992	1830	Exists in 2019	Limburg	Type D	5	1157	20574
185	Alblasserdam	GM0482	11327	1830	Exists in 2019	1830	Exists in 2019	Zuid-Holland	Exists in 2019	2	1607	20165
186	Rhenen	GM0340	10309	1830	Exists in 2019	1830	Exists in 2019	Utrecht	Exists in 2019	4	2674	20119
187	Weesp	GM0457	10773	1830	Exists in 2019	1830	Exists in 2019	Noord-Holland	Exists in 2019	2	2898	19738
188	Someren	GM0847	10203	1830	Exists in 2019	1830	Exists in 2019	Noord-Brabant	Exists in 2019	4		19368
189	Wamel	GM0290	10042	1830	1985	1830	Exists in 2019	Gelderland	Type D	5	3118	19324
190	Eersel	GM0770	10741	1830	Exists in 2019	1830	Exists in 2019	Noord-Brabant	Exists in 2019	4		19313
191	Druten	GM0225	10068	1830	Exists in 2019	1830	Exists in 2019	Gelderland	Exists in 2019	4	2804	18926
192	Dantumadeel	GM0065	10650	1830	2008	1830	Exists in 2019	Friesland	Type D	5	5430	18922
193	Meerssen	GM0938	10494	1830	Exists in 2019	1830	Exists in 2019	Limburg	Exists in 2019	4	1738	18828
194	Oirschot	GM0823	10225	1830	Exists in 2019	1830	Exists in 2019	Noord-Brabant	Exists in 2019	4		18714
195	Bergeyk	GM0749	11160	1830	1998	1830	Exists in 2019	Noord-Brabant	Type D	4		18635

Nr	Municipality	CBS Code GMXXXX	AMS Code	CBS Code Est.	CBS Code Abol.	AMS Code Est.	AMS Code Abol.	Province	Merger Type	STED	Population 1830	Population 2019
196	Enkhuizen	GM0388	10729	1830	Exists in 2019	1830	Exists in 2019	Noord-Holland	Exists in 2019	3	5388	18591
197	Heerde	GM0246	10291	1830	Exists in 2019	1830	Exists in 2019	Gelderland	Exists in 2019	4	3385	18589
198	Olst	GM0174	10409	1830	2002	1830	Exists in 2019	Overijssel	Type D	5	3202	18252
199	Waalre	GM0866	10959	1830	Exists in 2019	1830	Exists in 2019	Noord-Brabant	Exists in 2019	4		17456
200	Son en Breugel	GM0848	10549	1830	Exists in 2019	1830	Exists in 2019	Noord-Brabant	Exists in 2019	4		17322
201	Brielle	GM0501	10232	1830	Exists in 2019	1830	Exists in 2019	Zuid-Holland	Exists in 2019	4	4195	17271
202	Staphorst	GM0180	11362	1830	Exists in 2019	1830	Exists in 2019	Overijssel	Exists in 2019	5	3575	17145
203	Zandvoort	GM0473	10910	1830	Exists in 2019	1830	Exists in 2019	Noord-Holland	Exists in 2019	2	897	17116
204	Nederweert	GM0946	10681	1830	Exists in 2019	1830	Exists in 2019	Limburg	Exists in 2019	4	4101	17019
205	Gennep	GM0907	10542	1830	Exists in 2019	1830	Exists in 2019	Limburg	Exists in 2019	4	1042	16921
206	Asten	GM0743	10478	1830	Exists in 2019	1830	Exists in 2019	Noord-Brabant	Exists in 2019	4		16721
207	Heumen	GM0252	10600	1830	Exists in 2019	1830	Exists in 2019	Gelderland	Exists in 2019	4	972	16454
208	Beek (L.)	GM0888	11374	1830	Exists in 2019	1830	Exists in 2019	Limburg	Exists in 2019	4	2343	15865
209	Harlingen	GM0072	10909	1830	Exists in 2019	1830	Exists in 2019	Friesland	Exists in 2019	3	7537	15722
210	Hilvarenbeek	GM0798	11297	1830	Exists in 2019	1830	Exists in 2019	Noord-Brabant	Exists in 2019	4		15518
211	Bunnik	GM0312	10820	1830	Exists in 2019	1830	Exists in 2019	Utrecht	Exists in 2019	4	743	15191
212	Westervoort	GM0293	11085	1830	Exists in 2019	1830	Exists in 2019	Gelderland	Exists in 2019	3	760	14971
213	Lopik	GM0331	10333	1830	Exists in 2019	1830	Exists in 2019	Utrecht	Exists in 2019	5	1080	14467
214	Haaren	GM0788	11155	1830	Exists in 2019	1830	Exists in 2019	Noord-Brabant	Exists in 2019	5		14370
215	Ouder-Amstel	GM0437	10998	1830	Exists in 2019	1830	Exists in 2019	Noord-Holland	Exists in 2019	3	1994	14026
216	Montfoort	GM0335	10033	1830	Exists in 2019	1830	Exists in 2019	Utrecht	Exists in 2019	4	1671	13917
217	Uitgeest	GM0450	11238	1830	Exists in 2019	1830	Exists in 2019	Noord-Holland	Exists in 2019	3	1324	13666
218	Texel	GM0448	10237	1830	Exists in 2019	1830	Exists in 2019	Noord-Holland	Exists in 2019	5	4460	13575
219	Beesel	GM0889	10195	1830	Exists in 2019	1830	Exists in 2019	Limburg	Exists in 2019	4	1237	13482
220	Woudenberg	GM0351	11398	1830	Exists in 2019	1830	Exists in 2019	Utrecht	Exists in 2019	4	1765	13362

Nr	Municipality	CBS Code GMXXXX	AMS Code	CBS Code Est.	CBS Code Abol.	AMS Code Est.	AMS Code Abol.	Province	Merger Type	STED	Population 1830	Population 2019
221	Bergen (L.)	GM0893	11281	1830	Exists in 2019	1830	Exists in 2019	Limburg	Exists in 2019	5	3445	13085
222	Kapelle	GM0678	11223	1830	Exists in 2019	1830	Exists in 2019	Zeeland	Exists in 2019	4	1198	12695
223	Voerendaal	GM0986	11341	1830	Exists in 2019	1830	Exists in 2019	Limburg	Exists in 2019	4	1605	12475
224	Grave	GM0786	10165	1830	Exists in 2019	1830	Exists in 2019	Noord-Brabant	Exists in 2019	4	2833	12436
225	Hattem	GM0244	10673	1830	Exists in 2019	1830	Exists in 2019	Gelderland	Exists in 2019	4	2128	12209
226	Opmeer	GM0432	10609	1830	Exists in 2019	1830	Exists in 2019	Noord-Holland	Exists in 2019	4	371	11836
227	Appingedam	GM0003	10886	1830	Exists in 2019	1830	Exists in 2019	Groningen	Exists in 2019	3	2855	11642
228	Blaricum	GM0376	10493	1830	Exists in 2019	1830	Exists in 2019	Noord-Holland	Exists in 2019	3	687	11540
229	Landsmeer	GM0415	11225	1830	Exists in 2019	1830	Exists in 2019	Noord-Holland	Exists in 2019	3	928	11491
230	Laren (NH.)	GM0417	10649	1830	Exists in 2019	1830	Exists in 2019	Noord-Holland	Exists in 2019	3	1829	11280
231	Doesburg	GM0221	10327	1830	Exists in 2019	1830	Exists in 2019	Gelderland	Exists in 2019	4	3255	11077
232	Mill en Sint Hubert	GM0815	10535	1830	Exists in 2019	1830	Exists in 2019	Noord-Brabant	Exists in 2019	5		10939
233	Boekel	GM0755	10432	1830	Exists in 2019	1830	Exists in 2019	Noord-Brabant	Exists in 2019	4		10785
234	Simpelveld	GM0965	10515	1830	Exists in 2019	1830	Exists in 2019	Limburg	Exists in 2019	4	1083	10555
235	Oudewater	GM0589	10188	1830	Exists in 2019	1830	Exists in 2019	Utrecht	Exists in 2019	4	2002	10230
236	Vaals	GM0981	10007	1830	Exists in 2019	1830	Exists in 2019	Limburg	Exists in 2019	3	2773	10105
237	Beemster	GM0370	10816	1830	Exists in 2019	1830	Exists in 2019	Noord-Holland	Exists in 2019	4	2764	10022
238	Scherpenzeel	GM0279	11146	1830	Exists in 2019	1830	Exists in 2019	Gelderland	Exists in 2019	4	1067	9880
239	Oostzaan	GM0431	11303	1830	Exists in 2019	1830	Exists in 2019	Noord-Holland	Exists in 2019	3	1131	9735
240	Loppersum	GM0024	10934	1830	Exists in 2019	1830	Exists in 2019	Groningen	Exists in 2019	5	1795	9537
241	Eemnes	GM0317	10248	1830	Exists in 2019	1830	Exists in 2019	Utrecht	Exists in 2019	4	1351	9247
242	Zoeterwoude	GM0638	11074	1830	Exists in 2019	1830	Exists in 2019	Zuid-Holland	Exists in 2019	4	2057	8605
243	Mook en Middelaar	GM0944	10271	1830	Exists in 2019	1830	Exists in 2019	Limburg	Exists in 2019	5	920	7847
244	Baarle-Nassau	GM0744	10060	1830	Exists in 2019	1830	Exists in 2019	Noord-Brabant	Exists in 2019	5		6859

Nr	Municipality	CBS Code GMXXXX	AMS Code	CBS Code Est.	CBS Code Abol.	AMS Code Est.	AMS Code Abol.	Province	Merger Type	STED	Population 1830	Population 2019
245	Renswoude	GM0339	10269	1830	Exists in 2019	1830	Exists in 2019	Utrecht	Exists in 2019	5	985	5444
246	Terschelling	GM0093	11210	1830	Exists in 2019	1830	Exists in 2019	Friesland	Exists in 2019	5	2350	4888
247	Ameland	GM0060	11153	1830	Exists in 2019	1830	Exists in 2019	Friesland	Exists in 2019	5	1895	3716
248	Rozendaal	GM0277	10684	1830	Exists in 2019	1830	Exists in 2019	Gelderland	Exists in 2019	4		1704
249	Vlieland	GM0096	10211	1830	Exists in 2019	1830	Exists in 2019	Friesland	Exists in 2019	5	561	1155
250	Schiermonnikoog	GM0088	10355	1830	Exists in 2019	1830	Exists in 2019	Friesland	Exists in 2019	5	930	947

Table 10 Abolishment Likelihood Index $p[k]$ and Average Neighbor Superiority (NS_{av}) for three types of proximity to sector-related facilities for municipalities existing in 2019, ranked according to their Abolishment Likelihood Index $p[k]$

Nr	Municipality	CBS Code GMXXXX	AMS Code	Province	NS_{av} Essential	NS_{av} Education	NS_{av} Entertainment	STED	Population 2019	Population Ranking	Abolishment Likelihood Index $p[k]$ in 2019
1	Rozendaal	GM0277	10684	Gelderland	56.7	34.9	37.9	4	1704	353	17504.08
2	Oostzaan	GM0431	11303	Noord-Holland	61.3	48.1	47.2	3	9735	343	8760.29
3	Ouder-Amstel	GM0437	10998	Noord-Holland	54.8	68.2	48.6	3	14026	315	5942.52
4	Landsmeer	GM0415	11225	Noord-Holland	49	52.3	45.9	3	11491	332	5580.85
5	Westvoorne	GM0614	10009	Zuid-Holland	81.3	85.8	71.2	4	14731	311	4979.25
6	Albrandswaard	GM0613	10124	Zuid-Holland	74	81.3	80.5	3	25590	220	4518.38
7	Waterland	GM0852	10983	Noord-Holland	78.7	85.9	82.5	4	17424	293	4488.65
8	Diemen	GM0384	11039	Noord-Holland	49.8	37.9	40.5	1	30780	177	3834.22
9	Brielle	GM0501	10232	Zuid-Holland	61.1	50	49.8	4	17271	295	3753.33
10	Zoeterwoude	GM0638	11074	Zuid-Holland	60.9	89.2	70	4	8605	346	3698.32
11	Renswoude	GM0339	10269	Utrecht	53.9	80.4	50.7	5	5444	350	3431.97
12	Weesp	GM0457	10773	Noord-Holland	30.7	25.5	30.4	2	19738	275	3335.72
13	Westervoort	GM0293	11085	Gelderland	50.5	60.9	30.2	3	14971	310	3128.68
14	Maassluis	GM0556	10880	Zuid-Holland	54.9	49.9	54.2	2	33213	161	2904.97
15	Blaricum	GM0376	10493	Noord-Holland	49.3	64.6	60.4	3	11540	331	2782.96
16	Midden-Delfland	GM1842	10130	Zuid-Holland	77	76.8	73.4	3	19341	279	2648.47
17	Loppersum	GM0024	10934	Groningen	80.1	89.6	68.8	5	9537	344	2465.04
18	Bunnik	GM0312	10820	Utrecht	45.8	67	51.9	4	15191	309	2420.07
19	Uitgeest	GM0450	11238	Noord-Holland	44.8	49.9	57.4	3	13666	317	2316.85
20	Heemstede	GM0397	11288	Noord-Holland	31.5	41	42.8	2	27234	203	2281.96
21	Oegstgeest	GM0579	10287	Zuid-Holland	59.7	14.5	48.9	2	24840	230	2159.13
22	Wassenaar	GM0629	10164	Zuid-Holland	89.5	82.5	77	3	26305	211	2100.06
23	Montfoort	GM0335	10033	Utrecht	48.8	42	52.2	4	13917	316	2067.82
24	Son en Breugel	GM0848	10549	Noord-Brabant	54.7	64.9	54.9	4	17322	294	1970.24

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25	Alphen-Chaam	GM1723	10710	Noord-Brabant	72	84.7	74.2	5	10203	339	1879.12
26	Doesburg	GM0221	10327	Gelderland	59.7	52.7	43.4	4	11077	334	1877.95
27	Pijnacker-Nootdorp	GM1926	10031	Zuid-Holland	80.1	83.1	73.1	3	55308	78	1870.37
28	Beesel	GM0889	10195	Limburg	45.2	34	49.5	4	13482	319	1848.24
29	Hattem	GM0244	10673	Gelderland	32.6	41.6	28.9	4	12209	326	1793.61
30	Rijswijk (ZH.)	GM0603	11133	Zuid-Holland	42.3	29.4	35.1	1	54450	79	1755.16
31	Voorschoten	GM0626	10537	Zuid-Holland	50.6	60.2	41.1	2	25596	219	1745.23
32	Laren (NH.)	GM0417	10649	Noord-Holland	25.8	24.7	34.7	3	11280	333	1741.53
33	Krimpen aan den Ijssel	GM0542	10859	Zuid-Holland	37.8	8.7	48.9	2	29526	185	1731.13
34	Beemster	GM0370	10816	Noord-Holland	55.6	63.9	49.5	4	10022	341	1729
35	Simpelveld	GM0965	10515	Limburg	46.8	57.1	57.9	4	10555	337	1694.01
36	Harlingen	GM0072	10909	Friesland	26.4	1.9	41.2	3	15722	307	1680.74
37	Waalre	GM0866	10959	Noord-Brabant	35	46.5	46.9	4	17456	292	1624.68
38	Haaren	GM0788	11155	Noord-Brabant	85.8	96.2	81.4	5	14370	313	1622.1
39	Hillegom	GM0534	11236	Zuid-Holland	34.3	18	41.6	2	22209	260	1564.58
40	Alblasserdam	GM0482	11327	Zuid-Holland	38.9	37.4	30.1	2	20165	273	1552.77
41	Enkhuizen	GM0388	10729	Noord-Holland	21.9	11.1	47.4	3	18591	287	1523.55
42	Capelle aan den Ijssel	GM0502	11248	Zuid-Holland	30.3	34.5	37.5	2	67122	56	1514.11
43	Barendrecht	GM0489	10943	Zuid-Holland	64.8	52.2	44.2	2	48714	91	1507.85
44	Scherpenzeel	GM0279	11146	Gelderland	44.9	48	40.6	4	9880	342	1503.48
45	Leiderdorp	GM0547	10058	Zuid-Holland	33.7	16.9	26.1	2	27056	205	1493.05
46	Lisse	GM0553	10197	Zuid-Holland	54.7	19.7	49	2	22955	251	1462.15
47	IJsselstein	GM0353	10152	Utrecht	41	28	27.7	2	34109	155	1443.95
48	Schiedam	GM0606	11260	Zuid-Holland	20.7	28.7	25.7	1	78730	45	1442.43
49	Boekel	GM0755	10432	Noord-Brabant	68.5	80.1	59.2	4	10785	336	1438.54

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50	Ridderkerk	GM0597	10646	Zuid-Holland	58.4	47.3	53.9	2	46189	102	1425.08
51	Mook en Middelaar	GM0944	10271	Limburg	29	33	42.7	5	7847	347	1418.87
52	Urk	GM0184	10783	Flevoland	37.3	26	33.7	3	21031	269	1410.57
53	Papendrecht	GM0590	10427	Zuid-Holland	46	17.7	35.6	2	32136	165	1402.44
54	Noord-Beveland	GM1695	10250	Zeeland	61.3	74.6	75.3	5	7392	348	1383
55	Wormerland	GM0880	10648	Noord-Holland	59.6	58.3	53	3	16270	303	1382.58
56	Sliedrecht	GM0610	11331	Zuid-Holland	26	37	36.8	2	25220	224	1340.27
57	Opmeer	GM0432	10609	Noord-Holland	42.1	69.3	49.3	4	11836	328	1337.3
58	Nuenen, Gerwen en Nederwetten	GM0820	10761	Noord-Brabant	55.6	49.3	50.2	3	23383	247	1333.68
59	Bergen (L.)	GM0893	11281	Limburg	79.5	91	79.2	5	13085	322	1331.7
60	Gooise Meren	GM1942	10281	Noord-Holland	48.3	50.7	47.6	2	58055	68	1309.29
61	Beek (L.)	GM0888	11374	Limburg	41	45.3	26.4	4	15865	305	1283.87
62	Loon op Zand	GM0809	11259	Noord-Brabant	52.7	48.3	41.2	3	23408	246	1282.08
63	Heiloo	GM0399	10793	Noord-Holland	31.6	45.9	36.9	3	23968	240	1250.86
64	Zundert	GM0879	11192	Noord-Brabant	97.7	90.6	78.1	4	21829	264	1230.56
65	Heeze-Leende	GM1658	10462	Noord-Brabant	63.1	72.9	56.9	4	16152	304	1218.61
66	Appingedam	GM0003	10886	Groningen	8.2	5.7	39.9	3	11642	330	1218.18
67	Hendrik-Ido-Ambacht	GM0531	10416	Zuid-Holland	32.9	63.2	45.1	2	31202	174	1186.23
68	Zuidplas	GM1892	10855	Zuid-Holland	63.3	84	59.3	3	43885	114	1181.22
69	Delft	GM0503	10928	Zuid-Holland	16.9	31.6	38	1	103595	30	1178.66
70	Vlaardingen	GM0622	10811	Zuid-Holland	38.8	22	31.5	1	73397	50	1169.71
71	Eersel	GM0770	10741	Noord-Brabant	62.7	53.3	61.8	4	19313	281	1167.4
72	Zeewolde	GM0050	10012	Flevoland	91	69.5	67.3	4	22653	258	1161.18
73	Beverwijk	GM0375	10272	Noord-Holland	16.4	26.9	32.9	1	41626	127	1158.15
74	Bloemendaal	GM0377	10850	Noord-Holland	52.2	43	55.2	3	23571	245	1148.7

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75	Heumen	GM0252	10600	Gelderland	47.8	60.9	38.8	4	16454	301	1146.98
76	Brunssum	GM0899	10533	Limburg	35.4	23.3	33.6	2	27821	198	1146.74
77	Hilvarenbeek	GM0798	11297	Noord-Brabant	62.6	80.5	50.7	4	15518	308	1140.38
78	Gilze en Rijen	GM0784	11375	Noord-Brabant	55.8	73.6	62.8	3	26431	210	1134.48
79	Bunschoten	GM0313	11343	Utrecht	66.7	32.1	72.3	3	21866	263	1125.27
80	Lansingerland	GM1621	10139	Zuid-Holland	66.4	50.5	64.1	3	62373	63	1125.23
81	Grave	GM0786	10165	Noord-Brabant	57.5	6.9	42.9	4	12436	325	1125.2
82	Oudewater	GM0589	10188	Utrecht	58.6	67.7	49.3	4	10230	338	1123.02
83	Rhenen	GM0340	10309	Utrecht	58	43.8	46.5	4	20119	274	1119.42
84	Oldenzaal	GM0173	11100	Overijssel	18.7	6.5	30.9	3	31836	168	1105.91
85	Voerendaal	GM0986	11341	Limburg	30.3	42.6	43	4	12475	324	1102.85
86	Pekela	GM0765	10848	Groningen	32.3	46.1	51.5	4	12196	327	1101.11
87	Hardinxveld-Giessendam	GM0523	10167	Zuid-Holland	39.3	47.6	55.9	4	18295	289	1090.68
88	Woudenberg	GM0351	11398	Utrecht	43.8	51.7	48.5	4	13362	320	1088.88
89	Dongen	GM0766	11412	Noord-Brabant	54.7	33.8	50.8	3	26222	213	1086.91
90	Renkum	GM0274	11325	Gelderland	61.9	53.3	53.6	4	31419	171	1083.04
91	Goirle	GM0785	10971	Noord-Brabant	35.8	17.9	23	3	23904	243	1080.99
92	Haaksbergen	GM0158	11435	Overijssel	53.3	46	55.9	3	24311	238	1079.46
93	Duiven	GM0226	11028	Gelderland	52.2	30.5	57.3	3	25126	226	1076.77
94	De Ronde Venen	GM0736	11379	Utrecht	75.9	63.8	61.8	4	44456	110	1074.52
95	Losser	GM0168	11166	Overijssel	56.1	67.6	45.8	4	22683	257	1059.98
96	Best	GM0753	10442	Noord-Brabant	30.9	21.5	24.9	3	29988	181	1046.63
97	Meerssen	GM0938	10494	Limburg	36.1	56.4	58.7	4	18828	284	1041.16
98	Beuningen	GM0209	10417	Gelderland	40.6	75.5	34.4	4	25890	215	1037.15
99	Olst-Wijhe	GM1773	10409	Overijssel	69	90.6	68.2	5	18252	290	1024.71
100	Aalsmeer	GM0358	11264	Noord-Holland	47.1	53.1	58.6	4	31859	167	1022.72

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101	Stede Broec	GM0532	11337	Noord-Holland	33.6	19.3	34.8	3	21726	265	1018.69
102	Langedijk	GM0416	10955	Noord-Holland	46.1	48.4	42.2	4	28163	195	1013.58
103	Waddinxveen	GM0627	10081	Zuid-Holland	29.6	20.9	30.8	2	29291	188	1012.27
104	Borne	GM0147	10326	Overijssel	31.5	24.3	16.9	3	23312	248	987.62
105	Nieuwegein	GM0356	10374	Utrecht	31	28.7	44.4	2	63462	61	974.55
106	Baarn	GM0308	11411	Utrecht	33.8	47.4	40.1	2	24868	229	970.59
107	Valkenburg aan de Geul	GM0994	11077	Limburg	54.8	38.1	26.7	4	16367	302	966.46
108	Uithoorn	GM0451	11206	Noord-Holland	46.5	16.6	28.9	3	29478	186	964.9
109	Oirschot	GM0823	10225	Noord-Brabant	77.4	82.4	65.7	4	18714	285	958.64
110	Maasdriel	GM0263	10341	Gelderland	59.3	59.9	49.1	5	25030	227	943.21
111	Stein (L.)	GM0971	11319	Limburg	71.8	20.7	45.7	4	25007	228	941.76
112	Laarbeek	GM1659	10173	Noord-Brabant	40.4	48	41.4	4	22523	259	934.21
113	Huizen	GM0406	11170	Noord-Holland	75.7	35.4	65.2	2	41273	129	932.32
114	Brummen	GM0213	10798	Gelderland	71.3	75.4	76.3	4	20726	270	931.91
115	Staphorst	GM0180	11362	Overijssel	68.1	58.4	47	5	17145	296	931.3
116	Geertruidenberg	GM0779	10101	Noord-Brabant	58.3	19.7	37.2	3	21544	266	929.55
117	Zwartewaterland	GM1896	10746	Overijssel	41.8	45	54.3	4	22685	256	921.62
118	Kapelle	GM0678	11223	Zeeland	16.7	34.1	30	4	12695	323	917.93
119	Vught	GM0865	11224	Noord-Brabant	15.9	14.6	35.4	3	26558	208	904.22
120	Voorst	GM0285	10912	Gelderland	61.7	55.3	55	4	24552	232	900.93
121	Geldrop-Mierlo	GM1771	10529	Noord-Brabant	26.3	39.7	20.8	3	39726	132	897.36
122	Leusden	GM0327	10978	Utrecht	51.7	67.3	52.4	3	30401	179	894.6
123	Zandvoort	GM0473	10910	Noord-Holland	30.1	58	29.9	2	17116	297	880.69
124	Eemnes	GM0317	10248	Utrecht	60.6	88.1	46	4	9247	345	878.24
125	Drechterland	GM0498	10642	Noord-Holland	73.5	75.6	58.3	5	19719	276	876.38
126	De Bilt	GM0310	10168	Utrecht	57.6	58.2	60.6	3	43137	123	874.49

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127	Asten	GM0743	10478	Noord-Brabant	55.6	46.8	50.1	4	16721	300	873.05
128	Woensdrecht	GM0873	10602	Noord-Brabant	49.3	62	56	4	21876	262	873.01
129	Drimmelen	GM1719	10258	Noord-Brabant	46.3	53.6	47.9	4	27272	202	863.07
130	Landerd	GM1685	10276	Noord-Brabant	44.7	83.4	67.9	5	15730	306	859.31
131	Kerkrade	GM0928	10313	Limburg	27.3	52.7	46.1	2	45749	104	854.4
132	Amstelveen	GM0362	10799	Noord-Holland	21	22.4	32.3	2	91675	36	850.56
133	Zwijndrecht	GM0642	10468	Zuid-Holland	21.5	4.4	46.7	2	44737	108	845.2
134	Leidschendam-Voorburg	GM1916	11103	Zuid-Holland	25.7	23.3	42.7	1	76534	48	837.09
135	Oisterwijk	GM0824	10103	Noord-Brabant	18.4	32	23.2	4	26245	212	835.7
136	Vaals	GM0981	10007	Limburg	51.9	57.3	52.4	3	10105	340	834.24
137	Sint-Michielsgestel	GM0845	10496	Noord-Brabant	57.1	55.1	40.7	4	29208	189	833.92
138	Ermelo	GM0233	10732	Gelderland	45.6	38.1	44.1	4	27008	206	833.55
139	Heemskerk	GM0396	10679	Noord-Holland	43.4	43.8	38.1	2	39182	135	830.75
140	Landgraaf	GM0882	11335	Limburg	48	66.9	49.8	3	37445	140	829.69
141	Westland	GM1783	11418	Zuid-Holland	74.6	78.1	63.6	3	110375	27	827.36
142	Nissewaard	GM1930	10735	Zuid-Holland	28.8	46.2	46.8	2	85219	41	823.43
143	Tynaarlo	GM1730	10002	Drenthe	59.7	66.4	53.5	4	33887	157	808.72
144	Sint Anthonis	GM1702	11415	Noord-Brabant	63.4	79.1	75.8	5	11664	329	806.99
145	Lingewaard	GM1705	10744	Gelderland	67.8	78.4	59.3	4	46601	100	806.03
146	Wijdemeren	GM1696	10534	Noord-Holland	73.3	89.8	65.7	4	24358	235	802.58
147	Kaag en Braassem	GM1884	10349	Zuid-Holland	72.7	72.4	73.1	4	27297	201	800.17
148	Culemborg	GM0216	10342	Gelderland	25.3	3.1	38.8	3	28955	190	795.99
149	Gorinchem	GM0512	10942	Zuid-Holland	9.4	0	25.8	2	37022	143	793.43
150	Teylingen	GM1525	10017	Zuid-Holland	29	42.9	37.8	3	37440	141	788.34
151	Veldhoven	GM0861	10071	Noord-Brabant	29.4	29.3	32.1	2	45466	105	787.92
152	Bernheze	GM1721	10149	Noord-Brabant	54.3	62.8	42.2	4	31240	173	773.94

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153	Mill en Sint Hubert	GM0815	10535	Noord-Brabant	81.6	68.5	56.1	5	10939	335	773.13
154	Koggenland	GM1598	10354	Noord-Holland	58.2	54	46	5	22749	253	765.63
155	Houten	GM0321	10230	Utrecht	67.8	67.7	54.2	2	50146	86	752.72
156	Soest	GM0342	11021	Utrecht	34	76.9	52.2	3	46606	99	742.85
157	Sluis (2)	GM1714	10895	Zeeland	77.7	97.4	65.8	5	23210	249	738.37
158	Rucphen	GM0840	11152	Noord-Brabant	46.4	64	53	4	22878	252	721.18
159	Lopik	GM0331	10333	Utrecht	91.3	77.9	82.3	5	14467	312	719.07
160	Veenendaal	GM0345	11052	Utrecht	10.8	0.3	33	2	66493	57	717.8
161	Noordenveld	GM1699	10699	Drenthe	56.8	51.5	51.3	4	31253	172	716.06
162	Eijsden-Margraten	GM1903	11243	Limburg	47	75.9	66.4	5	25768	216	715.78
163	Nunspeet	GM0302	10512	Gelderland	69.8	76.1	62.7	4	27851	196	713.46
164	Gouda	GM0513	10302	Zuid-Holland	3	0.3	16.4	1	73427	49	713.33
165	Ommen	GM0175	11069	Overijssel	81.6	56.4	63.5	5	18009	291	710.31
166	Dinkelland	GM1774	10245	Overijssel	83.9	86.8	81.9	5	26461	209	698.12
167	Druten	GM0225	10068	Gelderland	49.4	18.4	47.6	4	18926	282	688.81
168	Wijk bij Duurstede	GM0352	10760	Utrecht	54.7	21.4	60.4	3	23914	242	676.55
169	Wageningen	GM0289	11010	Gelderland	25.4	1.6	16.3	2	39664	133	670.32
170	Dantumadiel	GM1891	10650	Friesland	22.4	40.7	37.3	5	18922	283	668.46
171	Roerdalen	GM1669	10196	Limburg	45.8	72.9	60.4	5	20574	271	664.59
172	Putten	GM0273	11109	Gelderland	77.1	62.4	37.1	4	24112	239	651.86
173	Steenbergen	GM0851	10731	Noord-Brabant	62.5	68.1	48.5	4	24416	234	650.18
174	Someren	GM0847	10203	Noord-Brabant	71.8	42.6	61.5	4	19368	278	645.75
175	Nederweert	GM0946	10681	Limburg	49.7	37.1	48.1	4	17019	298	645.39
176	Heusden	GM0797	10307	Noord-Brabant	60.4	51	43.5	3	44692	109	643.16
177	Hulst	GM0677	11408	Zeeland	84.6	41	69.2	4	27556	199	640.88
178	Wierden	GM0189	10676	Overijssel	51.1	69	52.7	4	24446	233	633.63

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179	Moerdijk	GM1709	10046	Noord-Brabant	82.8	65.7	73.3	4	37129	142	632.74
180	Nieuwkoop	GM0569	10728	Zuid-Holland	76.9	89.5	72.5	4	28811	193	629.53
181	Maasgouw	GM1641	10964	Limburg	39	57.1	36.6	5	23965	241	627.95
182	Woerden	GM0632	10974	Utrecht	22.2	29.5	47.8	3	52299	82	626.97
183	Velsen	GM0453	10620	Noord-Holland	45.8	48.8	43.7	2	68648	53	619.38
184	Tubbergen	GM0183	10694	Overijssel	76.1	70.4	71.7	5	21275	267	619.15
185	Dalfsen	GM0148	11007	Overijssel	57.3	71.6	52.9	4	28587	194	610.61
186	Katwijk	GM0537	10707	Zuid-Holland	35.7	41.9	47	2	65753	58	610.26
187	Zoetermeer	GM0637	10766	Zuid-Holland	46.4	29.9	30.4	1	125285	20	610.1
188	Borsele	GM0654	10043	Zeeland	84.3	91.5	73.9	5	22739	254	592.7
189	Hoorn	GM0405	11392	Noord-Holland	2	0.4	4.6	2	73261	51	592.5
190	Bergen (NH.)	GM0373	11424	Noord-Holland	52.9	61.1	54.2	4	29839	182	589.63
191	Zeist	GM0355	10324	Utrecht	43.8	23.3	40.5	2	64905	60	582.09
192	Etten-Leur	GM0777	10750	Noord-Brabant	22.7	21.4	28.7	2	43878	115	581.7
193	Neder-Betuwe	GM1740	10916	Gelderland	55.8	56.9	64	5	24339	236	579.83
194	Baarle-Nassau	GM0744	10060	Noord-Brabant	91.9	48.5	67	5	6859	349	575.78
195	Berg en Dal	GM1945	10616	Gelderland	63.8	82.3	57.8	4	34992	153	575.05
196	Gennep	GM0907	10542	Limburg	48.5	35.5	41	4	16921	299	573.97
197	Overbetuwe	GM1734	11188	Gelderland	60.6	44.5	63.4	4	47906	96	573.53
198	Tytsjerksteradiel	GM0737	11241	Friesland	65.2	55.3	42.3	5	32052	166	570.82
199	Westerveld	GM1701	10186	Drenthe	73.5	81.6	57.5	5	19460	277	569.32
200	Zaltbommel	GM0297	10557	Gelderland	27.6	30.8	36.7	4	28881	191	568.44
201	Wijchen	GM0296	10723	Gelderland	59.3	47.5	50.1	3	41110	130	567.92
202	Borger-Odoorn	GM1681	10448	Drenthe	64.6	86.3	47.4	5	25559	221	564.24
203	Elburg	GM0230	11113	Gelderland	43.5	9.7	48.1	4	23161	250	563.43
204	Achtkarspelen	GM0059	10199	Friesland	51.1	47.9	44.5	5	27843	197	559.81

Nr	Municipality	CBS Code GMXXXX	AMS Code	Province	NS_{av} Essential	NS_{av} Education	NS_{av} Entertainment	STED	Population 2019	Population Ranking	Abolishment Likelihood Index $p[k]$ in 2019
205	Hellevoetsluis	GM0530	11078	Zuid-Holland	26.8	23.7	34.2	2	40142	131	548.31
206	West Maas en Waal	GM0668	10042	Gelderland	64.7	83.4	53.6	5	19324	280	540.57
207	Castricum	GM0383	11287	Noord-Holland	40.7	26.7	32.7	3	35986	147	539.18
208	Halderberge	GM1655	10397	Noord-Brabant	30.4	40.1	46.9	4	30284	180	538.61
209	Nijkerk	GM0267	10446	Gelderland	32.7	37.3	45.4	3	43171	122	537.51
210	Reusel-De Mierden	GM1667	10162	Noord-Brabant	67.8	33.3	72.6	4	13112	321	536.39
211	Westerwolde	GM1950	11249	Groningen	82	80	77.5	5	25733	218	535.81
212	Veere	GM0717	10369	Zeeland	56.4	62.1	58.3	5	21880	261	534.32
213	Bergeijk	GM1724	11160	Noord-Brabant	77.9	91.7	61.6	4	18635	286	527.96
214	Echt-Susteren	GM1711	10941	Limburg	71.1	39.2	50.4	4	31610	170	527.76
215	Tholen	GM0716	10376	Zeeland	56.3	71	52.3	5	25757	217	525.77
216	Tiel	GM0281	10027	Gelderland	13.1	16	33.8	3	42159	125	520.65
217	Bodegraven-Reeuwijk	GM1901	11091	Zuid-Holland	49.3	70.5	45.7	3	34872	154	516
218	Leiden	GM0546	10702	Zuid-Holland	13.3	10.7	11.9	1	125099	21	512.14
219	Stichtse Vecht	GM1904	10191	Utrecht	62.8	53.7	62.8	3	64931	59	509.54
220	Reimerswaal	GM0703	10077	Zeeland	73.5	44.5	81.9	4	22730	255	509.31
221	De Wolden	GM1690	10262	Drenthe	61.2	81.8	65.5	5	24330	237	505.24
222	Aa en Hunze	GM1680	10787	Drenthe	61.5	66.9	60.9	5	25445	223	501.72
223	Opsterland	GM0086	10005	Friesland	52.1	71	51.4	5	29733	183	500.87
224	Deurne	GM0762	10379	Noord-Brabant	33.9	50.7	50.2	4	32471	164	498.21
225	Lochem	GM0262	11263	Gelderland	59.8	73.8	58.9	4	33729	160	492.92
226	Het Hogeland	GM1966	10246	Groningen	50	56.7	45	5	47801	97	491.77
227	Gemert-Bakel	GM1652	10277	Noord-Brabant	51.1	39	50.1	4	30723	178	491.16
228	Cranendonck	GM1706	10219	Noord-Brabant	43.5	73.7	51.8	4	21138	268	490.79
229	Vlissingen	GM0718	10270	Zeeland	12.1	12	24.9	2	44360	111	489.74
230	Weststellingwerf	GM0098	11322	Friesland	58.5	45.2	54.9	4	25914	214	485.74

Nr	Municipality	CBS Code GMXXXX	AMS Code	Province	NS_{av} Essential	NS_{av} Education	NS_{av} Entertainment	STED	Population 2019	Population Ranking	Abolishment Likelihood Index $p[k]$ in 2019
231	Montferland	GM1955	10350	Gelderland	44.3	72.6	33.6	4	36011	146	484.58
232	Veendam	GM0047	11292	Groningen	39.8	16.7	31.4	3	27384	200	481.99
233	Waadhoeke	GM1949	10404	Friesland	67.5	70.8	49	5	46090	103	481.75
234	Delfzijl	GM0010	10976	Groningen	44.1	39.6	50.7	4	24678	231	480.98
235	Heerhugowaard	GM0398	10752	Noord-Holland	18.7	7.4	26.2	2	57587	70	478.96
236	Raalte	GM0177	10279	Overijssel	61.9	60.4	69	4	37712	139	476.12
237	Heerde	GM0246	10291	Gelderland	51	32.2	57.4	4	18589	288	475.02
238	Purmerend	GM0439	11066	Noord-Holland	18.2	15.9	29.3	2	81249	42	469.77
239	Coevorden	GM0109	10383	Drenthe	52.8	53.5	55.8	4	35297	151	469.1
240	Boxtel	GM0757	10083	Noord-Brabant	37.8	18.5	55.1	3	30801	176	467.21
241	Aalten	GM0197	11046	Gelderland	58.4	35.2	68.9	4	27121	204	462.66
242	Den Helder	GM0400	10285	Noord-Holland	1.5	0	31.1	2	56296	73	461.22
243	Oldebroek	GM0269	11106	Gelderland	53.8	56.8	52.9	4	23646	244	459.49
244	Rijssen-Holten	GM1742	10358	Overijssel	28.7	10.7	34.5	3	38177	137	455.08
245	Gulpen-Wittem	GM1729	11032	Limburg	73.2	52.5	70.7	5	14171	314	453.4
246	Rheden	GM0275	11355	Gelderland	27.4	29.2	49.2	3	43761	116	451.08
247	Epe	GM0232	10940	Gelderland	53.7	58.2	43.2	4	33178	163	450.13
248	Beekdaelen	GM1954	10104	Limburg	65.7	76.2	61.9	5	35938	148	448.92
249	Edam-Volendam	GM0385	10884	Noord-Holland	41.1	19.8	39.9	3	36197	144	444.96
250	Oost Gelre	GM1586	11094	Gelderland	38.1	30.5	42.1	4	29627	184	444.21
251	Buren	GM0214	11286	Gelderland	69.5	86.6	66.5	5	26749	207	443.05
252	Horst aan de Maas	GM1507	11108	Limburg	68.9	54.7	59.4	4	42429	124	442.69
253	Oosterhout	GM0826	11280	Noord-Brabant	35.1	35.2	34.7	2	55982	75	441.21
254	Twenterand	GM1700	10643	Overijssel	40.4	37.9	50.8	4	33743	159	437.67
255	Haarlem	GM0392	10357	Noord-Holland	5	0	7	1	162902	12	434.69
256	Zaanstad	GM0479	11044	Noord-Holland	35.8	37	56.1	2	156794	16	420.1

Nr	Municipality	CBS Code GMXXXX	AMS Code	Province	NS_{av} Essential	NS_{av} Education	NS_{av} Entertainment	STED	Population 2019	Population Ranking	Abolishment Likelihood Index $p[k]$ in 2019
257	Zutphen	GM0301	10254	Gelderland	3.3	1.3	10.9	2	47934	95	418.94
258	Ooststellingwerf	GM0085	10836	Friesland	53.5	48.1	52.6	5	25469	222	416.78
259	Harderwijk	GM0243	10786	Gelderland	8.4	2.6	14.1	2	48414	94	413.58
260	Hof van Twente	GM1735	10076	Overijssel	72.1	64.8	68.2	4	35017	152	412.09
261	Meppel	GM0119	11204	Drenthe	3.1	1.5	23.3	3	33920	156	405.55
262	De Fryske Marren	GM1940	10022	Friesland	58.8	54.2	48.6	4	51564	83	393.96
263	Middelburg (Z.)	GM0687	10122	Zeeland	23.2	17.5	28.1	2	48822	90	393.78
264	Noordwijk	GM0575	10769	Zuid-Holland	48.5	16.9	49.2	3	43508	120	383.68
265	Leudal	GM1640	10840	Limburg	60.8	77.6	64.3	5	35879	150	382.29
266	Bladel	GM1728	11006	Noord-Brabant	38.3	10.5	49.9	4	20390	272	381.63
267	Smallingerland	GM0090	10405	Friesland	24.4	12.3	28.5	3	56150	74	369.97
268	Noardeast-Fryslân	GM1970	10198	Friesland	78.6	59.5	65.5	5	45228	106	366.99
269	Winterswijk	GM0294	11119	Gelderland	31.3	37.1	35.4	3	28854	192	366.19
270	Midden-Drenthe	GM1731	10520	Drenthe	65	68.4	69.2	5	33185	162	365.93
271	Heerenveen	GM0074	10680	Friesland	29.2	16.4	35.5	3	50493	85	359.72
272	Hengelo (O.)	GM0164	10907	Overijssel	12.9	20.1	13.3	2	81140	44	358.53
273	Barneveld	GM0203	10906	Gelderland	70.2	68.3	76.1	4	59082	66	356.34
274	Oude IJsselstreek	GM1509	10260	Gelderland	56.6	43.2	52.9	4	39388	134	356.2
275	Dronten	GM0303	10210	Flevoland	56.2	82.2	50.4	4	41555	128	355.52
276	Bronckhorst	GM1876	11159	Gelderland	73.6	88.5	64.9	5	36055	145	354.06
277	Cuijk	GM1684	10023	Noord-Brabant	39.3	28.2	41.8	4	25130	225	349.62
278	Westerkwartier	GM1969	10604	Groningen	54.3	52.4	45.2	5	63329	62	345.45
279	Hollands Kroon	GM1911	10344	Noord-Holland	92.9	85.1	73.4	5	48432	93	343.67
280	Valkenswaard	GM0858	11031	Noord-Brabant	41.1	7.7	26.7	3	31193	175	342.35
281	Schagen	GM0441	10511	Noord-Holland	44.3	39.1	46.7	4	46483	101	341.8
282	Uden	GM0856	11141	Noord-Brabant	23.3	0.9	18.9	3	42119	126	338.08

Nr	Municipality	CBS Code GMXXXX	AMS Code	Province	NS_{av} Essential	NS_{av} Education	NS_{av} Entertainment	STED	Population 2019	Population Ranking	Abolishment Likelihood Index $p[k]$ in 2019
283	Boxmeer	GM0756	11227	Noord-Brabant	32.9	43.6	47.4	4	29365	187	335.37
284	Hellendoorn	GM0163	10806	Overijssel	34.4	25.2	31.1	4	35916	149	325.16
285	Doetinchem	GM0222	10396	Gelderland	17.5	6.1	32.8	3	58001	69	324.73
286	Waalwijk	GM0867	11359	Noord-Brabant	20.2	42.5	52.1	3	48637	92	324.72
287	Zevenaar	GM0299	10938	Gelderland	30.8	39.8	43.6	3	43750	117	321.14
288	Kampen	GM0166	10253	Overijssel	51.6	23.8	40.2	3	54319	81	320.37
289	Lelystad	GM0995	11110	Flevoland	35.1	48.4	38.1	3	78598	46	319.89
290	Peel en Maas	GM1894	10205	Limburg	66.8	53.6	44.3	4	43425	121	317.64
291	Heerlen	GM0917	10902	Limburg	22.1	8.7	22	2	87086	40	314.64
292	Vijfheerenlanden	GM1961	10685	Utrecht	55	54.2	39.6	4	56811	71	311.91
293	Hilversum	GM0402	11285	Noord-Holland	15.5	10.2	24.9	1	90831	37	309.87
294	Goeree-Overflakkee	GM1924	11067	Zuid-Holland	56.6	50.5	67.1	4	50049	88	306.24
295	Stadskanaal	GM0037	10610	Groningen	35.1	17.6	36.3	4	31686	169	302.64
296	Noordoostpolder	GM0171	10144	Flevoland	65.7	64	77.6	4	47291	98	290.92
297	Haarlemmermeer	GM0394	11387	Noord-Holland	70.6	65.3	66.6	2	156002	17	290.64
298	Molenlanden	GM1978	10451	Zuid-Holland	71.4	81	58.3	5	43909	113	286.58
299	Goes	GM0664	10674	Zeeland	35.8	19.4	33.3	3	38082	138	284.98
300	Medemblik	GM0420	11215	Noord-Holland	54.6	50	57.3	4	45101	107	283.84
301	Oldambt	GM1895	10453	Groningen	37.1	30.3	30.1	4	38209	136	283.31
302	Schouwen-Duiveland	GM1676	10843	Zeeland	53.4	44.1	53.1	5	33839	158	274.66
303	Krimpenerwaard	GM1931	10050	Zuid-Holland	72.6	58.6	62.4	4	56319	72	269.4
304	Hoeksche Waard	GM1963	10222	Zuid-Holland	58	73.3	40	4	87401	39	268.73
305	Helmond	GM0794	10932	Noord-Brabant	5.2	3.8	33.6	2	92423	34	266.2
306	West Betuwe	GM1960	10881	Gelderland	82.9	71.4	60.7	5	51128	84	264.82
307	Hoogeveen	GM0118	10839	Drenthe	8.6	3.1	18	3	55699	77	263.04
308	Midden-Groningen	GM1952	10410	Groningen	50	39.6	39.7	4	60797	65	261.41

Nr	Municipality	CBS Code GMXXXX	AMS Code	Province	NS_{av} Essential	NS_{av} Education	NS_{av} Entertainment	STED	Population 2019	Population Ranking	Abolishment Likelihood Index $p[k]$ in 2019
309	Roermond	GM0957	11313	Limburg	8.4	17.1	29.4	2	58260	67	259.95
310	Bergen op Zoom	GM0748	11037	Noord-Brabant	12.8	4	13.9	2	67496	55	259.02
311	Berkelland	GM1859	10436	Gelderland	56.1	42.2	52.9	4	43747	118	255.68
312	Almelo	GM0141	11053	Overijssel	3.2	7	25.6	2	73107	52	255.45
313	Utrechtse Heuvelrug	GM1581	10777	Utrecht	53	51.2	55.6	4	49580	89	254.79
314	Assen	GM0106	10522	Drenthe	1	0	20.7	2	68599	54	253.73
315	Venray	GM0984	11222	Limburg	35.4	19.9	47.8	4	43614	119	243.01
316	Steenwijkerland	GM1708	10546	Overijssel	43.1	54	48.3	4	44126	112	242.44
317	Weert	GM0988	11081	Limburg	8.9	12	34.8	3	50105	87	241.39
318	Amersfoort	GM0307	10948	Utrecht		14.2	6.7	21	2		15
319	Nijmegen	GM0268	11209	Gelderland	1.4	0.4	15.1	2	177659	10	231.37
320	Oss	GM0828	10834	Noord-Brabant	24.5	30	34.2	3	91915	35	224.67
321	Roosendaal	GM1674	10407	Noord-Brabant	26.7	16.9	29.7	2	77251	47	221.87
322	Maastricht	GM0935	10182	Limburg	9.3	1.9	27.1	2	121575	23	214.52
323	Altena	GM1959	10078	Noord-Brabant	78	76.7	68.3	4	55967	76	214.49
324	Dordrecht	GM0505	11157	Zuid-Holland	17.1	29.6	28.3	1	119284	24	214.18
325	Sittard-Geleen	GM1883	11230	Limburg	14.4	14.1	27.8	3	92429	33	210.6
326	Sûdwest Fryslân	GM1900	11421	Friesland	40	55.3	47.1	4	89987	38	207.82
327	Ede	GM0228	10743	Gelderland	51.2	60.9	56.2	2	117165	25	206.2
328	Arnhem	GM0202	10795	Gelderland	11.6	8.6	25.8	2	161348	13	199.04
329	Alkmaar	GM0361	10527	Noord-Holland	14.6	6.1	25.5	2	109436	28	192.49
330	Alphen aan den Rijn	GM0484	10517	Zuid-Holland	27	10.9	36.1	2	111897	26	189.99
331	Hardenberg	GM0160	10174	Overijssel	41.3	38.2	51.5	4	60948	64	180.8
332	Terneuzen	GM0715	10704	Zeeland	21.1	18.8	30.1	4	54426	80	172.92
333	Leeuwarden	GM0080	11228	Friesland	2.4	3.4	9.9	2	124084	22	166.99
334	Deventer	GM0150	10899	Overijssel	3.8	12.9	13.6	2	100719	32	164.35

Nr	Municipality	CBS Code GMXXXX	AMS Code	Province	NS_{av} Essential	NS_{av} Education	NS_{av} Entertainment	STED	Population 2019	Population Ranking	Abolishment Likelihood Index $p[k]$ in 2019
335	's-Hertogenbosch	GM0796	10054	Noord-Brabant	7.5	8.5	22.4	2	155111	18	164.01
336	Venlo	GM0983	10477	Limburg	7.1	12.2	19.1	2	101802	31	159.42
337	's-Gravenhage	GM0518	11434	Zuid-Holland	9.6	3.9	19.3	1	545838	3	158.84
338	Meierijstad	GM1948	10985	Noord-Brabant	70	56.1	46.4	4	81194	43	152.31
339	Zwolle	GM0193	10093	Overijssel	6.6	4.8	20.4	2	128840	19	146.28
340	Eindhoven	GM0772	11298	Noord-Brabant	7	1.3	23.4	1	234394	5	143.48
341	Enschede	GM0153	10364	Overijssel	17.8	14	28.5	2	159640	14	139.3
342	Utrecht	GM0344	10722	Utrecht	6	2.7	12	1	357597	4	137.07
343	Almere	GM0034	10018	Flevoland	26.9	11.3	49.8	2	211893	8	131.44
344	Breda	GM0758	10154	Noord-Brabant	7.8	1	18.4	2	184069	9	128.64
345	Apeldoorn	GM0200	11075	Gelderland	19.3	17.2	23.7	2	163818	11	125.13
346	Tilburg	GM0855	10792	Noord-Brabant	2.2	4.3	20.2	1	219789	7	117.9
347	Emmen	GM0114	11180	Drenthe	9.1	6.5	30.5	4	107048	29	109.43
348	Groningen	GM0014	10426	Groningen	5	2	5.3	1	232874	6	102.87
349	Amsterdam	GM0363	11150	Noord-Holland	5.4	2.4	11.9	1	872757	1	69.33
350	Rotterdam	GM0599	10345	Zuid-Holland	8	4.1	18.5	1	651168	2	59.05
351	Texel	GM0448	10237	Noord-Holland				5	13575	318	0
352	Terschelling	GM0093	11210	Friesland				5	4888	351	0
353	Ameland	GM0060	11153	Friesland				5	3716	352	0
354	Vlieland	GM0096	10211	Friesland				5	1155	354	0
355	Schiermonnikoog	GM0088	10355	Friesland				5	947	355	0

Table 11 Average Neighbor Superiority (NS_{av}) for three types of proximity to sector-related facilities for abolished Type A municipalities during period 2006-2018

Nr	Name	CBS Code GMXXXX	AMS Code	CBS Code Est.	CBS Code Abol.	AMS Code Est.	AMS Code Abol.	Province	NS_{av} Essential	NS_{av} Education	NS_{av} Entertainment	STED	Population
1	Haren	GM0017	11058	1830	2018	1830	2018	Groningen	46.7	41.1	49.2	4	20191
2	Rijnwoude	GM1672	11257	1993	2013	1830	2013	Zuid-Holland	44.2	67.4	60.9	4	18484
3	Noordwijkerhout	GM0576	11134	1830	2018	1830	2018	Zuid-Holland	59.9	83.8	57.1	3	16685
4	Harenkarspel	GM0395	10963	1830	2012	1830	2012	Noord-Holland	57.4	64.4	56.9	5	16122
5	Boskoop	GM0499	10419	1830	2013	1830	2013	Zuid-Holland	75.8	59.5	52.2	4	15177
6	Rozenburg	GM0600	11314	1830	2010	1830	2010	Zuid-Holland	83.3	73.3	75.0	3	12494
7	Zijpe	GM0476	10004	1830	2012	1830	2012	Noord-Holland	71.3	83.6	76.0	5	11519
8	Maasdonk	GM1671	10370	1993	2014	1830	2014	Noord-Brabant	50.6	86.8	71.8	5	11348
9	Ambt Montfort	GM1679	10456	1995	2006	1830	2006	Limburg		100.0	33.3	5	10909
10	Rijnwaarden	GM0196	10819	1985	2017	1830	2017	Gelderland	87.0	76.7	70.5	5	10810
11	Noorder-Koggenland	GM0529	10924	1979	2006	1830	2006	Noord-Holland		80.0	40.0	5	10596
12	Leeuwarderadeel	GM0081	10851	1830	2017	1830	2017	Friesland	33.6	60.5	31.8	4	10079
13	Ubbergen	GM0282	10408	1830	2014	1830	2014	Gelderland	53.6	61.1	54.4	5	9416
14	's-Gravendeel	GM0517	10052	1830	2006	1830	2006	Zuid-Holland		50.0	22.2	4	9035
15	Ter Aar	GM0480	11104	1830	2006	1830	2006	Zuid-Holland		90.0	53.3	5	8964
16	Abcoude	GM0305	10712	1942	2010	1830	2010	Utrecht	53.2	61.1	57.2	4	8791
17	Swalmen	GM0975	10474	1830	2006	1830	2006	Limburg		41.7	44.4	4	8790
18	Wervershoof	GM0459	11270	1830	2010	1830	2010	Noord-Holland	65.7	76.6	55.6	5	8746
19	Arcen en Velden	GM0885	10202	1830	2009	1830	2009	Limburg	67.5	50.0	41.7	5	8668
20	Wognum	GM0466	10818	1830	2006	1830	2006	Noord-Holland		25.0	40.0	5	8229
21	Meerlo-Wanssum	GM0993	11416	1970	2009	1830	2009	Limburg	72.9	60.4	51.0	5	7813
22	Sevenum	GM0964	10045	1837	2009	1837	2009	Limburg	56.7	63.3	65.4	5	7730

Nr	Name	CBS Code GMXXXX	AMS Code	CBS Code Est.	CBS Code Abol.	AMS Code Est.	AMS Code Abol.	Province	NS_{av} Essential	NS_{av} Education	NS_{av} Entertainment	STED	Population
23	Ten Boer	GM0009	10891	1830	2018	1830	2018	Groningen	60.2	58.0	58.1	5	7289
24	Liemeer	GM1673	10487	1994	2006	1830	2006	Zuid-Holland		75.0	75.0	5	6961
25	Lith	GM0808	11219	1830	2010	1830	2010	Noord-Brabant	91.1	100.0	94.8	5	6685
26	Andijk	GM0364	10822	1830	2010	1830	2010	Noord-Holland	75.0	81.1	72.0	5	6518
27	Graft-De Rijp	GM0365	11417	1971	2014	1830	2014	Noord-Holland	79.5	83.5	78.7	5	6406
28	Zeevang	GM0478	11121	1971	2015	1830	2015	Noord-Holland	68.9	81.7	75.2	5	6241
29	Haarlemmerliede en Spaarnwoude	GM0393	10508	1858	2018	1830	2018	Noord-Holland	80.4	83.5	80.3	4	6167
30	Millingen aan de Rijn	GM0265	10072	1954	2014	1830	2014	Gelderland	50.0	50.0	66.7	4	5879
31	Schermer	GM0458	10308	1971	2014	1830	2014	Noord-Holland	81.6	87.7	81.0	5	5452
32	Bennebroek	GM0372	10734	1830	2008	1830	2008	Noord-Holland	36.3	45.8	41.7	4	5185

Table 12 Average Neighbor Superiority (NS_{av}) for three types of proximity to sector-related facilities for abolished Type C municipalities during period 2006-2018

Nr	Municipality	CBS Code GMXXXX	AMS Code	CBS Code Est.	CBS Code Abol.	AMS Code Est.	AMS Code Abol.	Province	NS_{av} Eessential	NS_{av} Education	NS_{av} Entertainment	STED	Population
1	Spijkenisse	GM0612	10735	1830	2014	1830	Exists still	Zuid-Holland	16.6	43.5	50	2	72740
2	Maarssen	GM0333	10191	1830	2010	1830	Exists still	Utrecht	39.4	24.4	33.2	2	39752
3	Veghel	GM0860	10985	1830	2016	1830	Exists still	Noord-Brabant	48.5	46.7	44.6	3	38255
4	Hoogezand-Sappemeer	GM0018	10410	1950	2017	1830	Exists still	Groningen	37.9	26.9	31.8	3	34158
5	Sneek	GM0091	11421	1830	2010	1830	Exists still	Friesland	5.0	8.3	7.8	3	33573
6	Bussum	GM0381	10281	1830	2015	1830	Exists still	Noord-Holland	13.5	12.6	18.1	2	33097
7	Molenwaard	GM1927	10451	2013	2018	1830	Exists still	Zuid-Holland	73.9	77.8	70.6	5	29318
8	Binnenmaas	GM0585	10222	1984	2018	1830	Exists still	Zuid-Holland	49.7	63.5	51.5	4	29292
9	Skarsterlân	GM0051	10022	1986	2013	1830	Exists still	Friesland	39.8	44.8	32.2	4	27501
10	Werkendam	GM0870	10078	1830	2018	1830	Exists still	Noord-Brabant	44.0	78.2	59.9	4	27295
11	Geldermalsen	GM0236	10881	1830	2018	1830	Exists still	Gelderland	60.7	52.3	54.1	4	27036
12	Dongeradeel	GM0058	10198	1984	2018	1830	Exists still	Friesland	42.4	55.7	71.3	4	23845
13	Nieuwerkerk aan den IJssel	GM0567	10855	1830	2009	1830	Exists still	Zuid-Holland	62.0	41.7	53.8	3	21604
14	Leerdam	GM0545	10685	1830	2018	1830	Exists still	Zuid-Holland	35.4	20.1	37.6	3	21248
15	Berkel en Rodenrijs	GM0493	10139	1830	2006	1830	Exists still	Zuid-Holland		100.0	60.0	4	20856
16	Franekeradeel	GM0070	10404	1830	2017	1830	Exists still	Friesland	58.0	27.0	40.3	4	20213
17	Leek	GM0022	10604	1830	2018	1830	Exists still	Groningen	47.9	28.0	52.2	4	19732
18	Helden	GM0918	10205	1830	2009	1830	Exists still	Limburg	87.8	23.6	45.8	4	19654
19	Bodegraven	GM0497	11091	1830	2010	1830	Exists still	Zuid-Holland	24.3	34.4	37.4	3	19432
20	Winschoten	GM0052	10453	1830	2009	1830	Exists still	Groningen	8.3	0.0	19.8	3	18271
21	Middelharnis	GM0559	11067	1830	2012	1830	Exists still	Zuid-Holland	47.8	15.8	48.9	4	18070
22	Vlagtwedde	GM0048	11249	1830	2017	1830	Exists still	Groningen	76.6	58.0	72.4	5	15868

Nr	Municipality	CBS Code GMXXXX	AMS Code	CBS Code Est.	CBS Code Abol.	AMS Code Est.	AMS Code Abol.	Province	NS_{av} Eessential	NS_{av} Education	NS_{av} Entertainment	STED	Population
23	Eemsmond	GM1651	10246	1992	2018	1830	Exists still	Groningen	50.3	47.3	70.9	5	15411
24	Nuth	GM0951	10104	1830	2018	1830	Exists still	Limburg	75.4	79.8	55.2	4	15187
25	Alkemade	GM0483	10349	1830	2008	1830	Exists still	Zuid-Holland	80.0	76.4	79.2	4	14628
26	Anna Paulowna	GM0366	10344	1871	2011	1871	Exists still	Noord-Holland	59.1	69.0	60.0	5	14304
27	Wester-Koggenland	GM0558	10354	1979	2006	1830	Exists still	Noord-Holland		81.3	37.5	5	14294
28	Nederlek	GM0643	10050	1985	2014	1830	Exists still	Zuid-Holland	41.4	29.1	38.8	4	14143
29	Maasbracht	GM0933	10964	1830	2006	1830	Exists still	Limburg		62.5	58.3	5	13587
30	Margraten	GM0936	11243	1830	2010	1830	Exists still	Limburg	66.9	76.9	54.7	5	13375
31	Heythuysen	GM0920	10840	1830	2006	1830	Exists still	Limburg		37.5	50.0	5	12257
32	Graafstroom	GM0693	10451	1986	2012	1830	Exists still	Zuid-Holland	83.6	67.8	76.9	5	9894
33	Oud-Beijerland	GM0584	11301	1830	2018	1830	2018	Zuid-Holland	41.8	5.8	23.7	3	24403
34	Vianen	GM0620	10887	1830	2018	1830	2018	Utrecht	65.9	66.4	50.7	4	20444
35	Zuidhorn	GM0056	10021	1830	2018	1830	2018	Groningen	36.2	46.8	48.5	5	19066
36	Woudrichem	GM0874	10282	1830	2018	1830	2018	Noord-Brabant	58.5	51.3	65.2	5	14770
37	Giessenlanden	GM0689	10255	1986	2018	1830	2018	Zuid-Holland	52.9	56.7	51.8	5	14540
38	Zederik	GM0707	10618	1986	2018	1830	2018	Zuid-Holland	64.1	92.1	68.9	5	14020
39	Winsum	GM0053	11135	1830	2018	1830	2018	Groningen	56.5	39.6	61.4	5	13505
40	Aalburg	GM0738	11084	1973	2018	1830	2018	Noord-Brabant	77.4	42.4	57.7	5	13321
41	Cromstrijen	GM0611	11346	1984	2018	1830	2018	Zuid-Holland	33.7	43.3	40.2	4	12916
42	Kollumerland en Nieuwkruisland	GM0079	10984	1830	2018	1830	2018	Friesland	74.5	30.9	54.5	5	12761
43	Schinnen	GM0962	10132	1830	2018	1830	2018	Limburg	52.7	51.4	57.8	5	12758
44	Neerijnen	GM0304	10125	1978	2018	1830	2018	Gelderland	83.6	84.1	68.8	5	12468
45	Grootegast	GM0015	11080	1830	2018	1830	2018	Groningen	74.8	46.1	74.7	5	12191
46	Korendijk	GM0588	10914	1984	2018	1830	2018	Zuid-Holland	86.1	89.1	86.2	5	11269
47	Lingewaal	GM0733	11376	1988	2018	1830	2018	Gelderland	54.0	60.8	66.4	5	11193
48	Bedum	GM0005	10425	1830	2018	1830	2018	Groningen	24.4	36.5	23.6	4	10493

Nr	Municipality	CBS Code GMXXXX	AMS Code	CBS Code Est.	CBS Code Abol.	AMS Code Est.	AMS Code Abol.	Province	NS_{av} Eessential	NS_{av} Education	NS_{av} Entertainment	STED	Population
49	Marum	GM0025	11431	1830	2018	1830	2018	Groningen	60.6	75.2	50.8	5	10484
50	De Marne	GM1663	10180	1992	2018	1830	2018	Groningen	63.7	96.4	48.0	5	10037
51	Strijen	GM0617	10558	1830	2018	1830	2018	Zuid-Holland	72.0	92.6	65.2	4	8776
52	Ferwerderadiel	GM1722	11284	1999	2018	1830	2018	Friesland	52.8	53.3	74.8	5	8575
53	Onderbanken	GM0881	10492	1982	2018	1830	2018	Limburg	85.4	72.4	76.2	5	7782
54	Slochteren	GM0040	10747	1830	2017	1830	2017	Groningen	69.7	70.6	57.7	5	14782
55	Menameradiel	GM1908	11144	2011	2017	1830	2017	Friesland	40.0	44.3	57.9	5	13450
56	Menterwolde	GM1987	11282	1992	2017	1830	2017	Groningen	46.9	58.4	53.1	5	12013
57	het Bildt	GM0063	10128	1830	2017	1830	2017	Friesland	62.3	34.7	50.8	5	10560
58	Bellingwedde	GM0007	10340	1969	2017	1830	2017	Groningen	75.2	79.6	76.4	5	8816
59	Schijndel	GM0844	11178	1830	2016	1830	2016	Noord-Brabant	34.8	3.6	37.4	3	23722
60	Sint-Oedenrode	GM0846	10399	1830	2016	1830	2016	Noord-Brabant	88.8	74.7	71.4	4	17892
61	Naarden	GM0425	10187	1830	2015	1830	2015	Noord-Holland	55.7	56.5	52.6	3	17397
62	Muiden	GM0424	10958	1830	2015	1830	2015	Noord-Holland	68.4	76.0	81.5	5	6202
63	Bernisse	GM0568	10316	1980	2014	1830	2014	Zuid-Holland	66.1	65.6	58.9	5	12381
64	Schoonhoven	GM0608	10980	1830	2014	1830	2014	Zuid-Holland	42.1	0.0	40.7	3	11898
65	Bergambacht	GM0491	10962	1830	2014	1830	2014	Zuid-Holland	84.3	81.7	66.8	4	10186
66	Vlist	GM0623	11174	1830	2014	1830	2014	Zuid-Holland	32.1	65.3	45.4	5	9740
67	Ouderkerk	GM0644	10095	1985	2014	1830	2014	Zuid-Holland	63.1	64.9	65.9	4	8241
68	Lemsterland	GM0082	10142	1830	2013	1830	2013	Friesland	38.4	14.4	44.0	4	13524
69	Gaasterlân-Sleat	GM0653	10036	1986	2013	1830	2013	Friesland	79.8	60.1	68.2	5	10186
70	Goedereede	GM0511	10981	1830	2012	1830	2012	Zuid-Holland	55.3	74.6	48.3	5	11329
71	Oostflakkee	GM0580	10714	1966	2012	1830	2012	Zuid-Holland	60.6	74.9	71.7	5	10334
72	Liesveld	GM0694	11205	1986	2012	1830	2012	Zuid-Holland	60.5	37.0	40.4	5	9770
73	Nieuw-Lekkerland	GM0571	10547	1830	2012	1830	2012	Zuid-Holland	36.2	72.7	36.7	4	9526
74	Dirksland	GM0504	11344	1830	2012	1830	2012	Zuid-Holland	43.3	51.2	63.3	5	8526

Nr	Municipality	CBS Code GMXXXX	AMS Code	CBS Code Est.	CBS Code Abol.	AMS Code Est.	AMS Code Abol.	Province	NS_{av} Eessential	NS_{av} Education	NS_{av} Entertainment	STED	Population
75	Wieringermeer	GM0463	10239	1938	2011	1938	2011	Noord-Holland	80.3	46.3	54.2	5	12565
76	Niedorp	GM0412	10923	1971	2011	1830	2011	Noord-Holland	69.0	68.7	59.8	5	12272
77	Wieringen	GM0462	11277	1830	2011	1830	2011	Noord-Holland	36.7	39.8	67.4	5	8562
78	Wymbritseradiel	GM0683	11427	1986	2010	1830	2010	Friesland	47.9	65.3	51.9	5	16078
79	Breukelen	GM0311	10807	1949	2010	1830	2010	Utrecht	78.3	68.7	63.0	4	14736
80	Reeuwijk	GM0595	10485	1830	2010	1830	2010	Zuid-Holland	53.6	69.4	53.8	4	13296
81	Wûnseradiel	GM0710	10454	1987	2010	1830	2010	Friesland	77.5	81.4	58.4	5	11849
82	Eijsden	GM0905	10314	1830	2010	1830	2010	Limburg	48.3	41.7	72.5	4	11565
83	Nijefurd	GM0104	10768	1984	2010	1830	2010	Friesland	40.0	42.6	66.1	5	10971
84	Bolsward	GM0064	10865	1830	2010	1830	2010	Friesland	25.0	0.0	28.3	4	9974
85	Loenen	GM0329	11202	1830	2010	1830	2010	Utrecht	55.2	72.2	79.1	5	8562
86	Scheemda	GM0039	10711	1830	2009	1830	2009	Groningen	59.2	44.4	47.6	5	14252
87	Maasbree	GM0934	11352	1830	2009	1830	2009	Limburg	25.4	62.5	47.9	4	13094
88	Zevenhuizen-Moerkapelle	GM1666	11377	1993	2009	1830	2009	Zuid-Holland	62.2	91.4	80.6	4	10531
89	Moordrecht	GM0563	10120	1830	2009	1830	2009	Zuid-Holland	31.3	43.3	31.7	4	8275
90	Reiderland	GM1661	11043	1992	2009	1830	2009	Groningen	66.3	100.0	59.9	5	6963
91	Meijel	GM0941	10925	1830	2009	1830	2009	Limburg	52.0	67.6	52.6	5	6047
92	Kessel	GM0929	10890	1830	2009	1830	2009	Limburg	46.7	31.9	47.9	5	4263
93	Jacobswoude	GM0645	10461	1991	2008	1830	2008	Zuid-Holland	73.8	64.6	69.8	5	10784
94	Bergschenhoek	GM0492	10445	1830	2006	1830	2006	Zuid-Holland		56.3	58.3	3	16694
95	Bleiswijk	GM0495	10994	1830	2006	1830	2006	Zuid-Holland		20.0	60.0	4	10377
96	Haelen	GM0914	10321	1830	2006	1830	2006	Limburg		45.0	46.7	5	9905
97	Roggel en Neer	GM1670	10505	1993	2006	1830	2006	Limburg		85.0	40.0	5	8463
98	Heel	GM1937	11208	1991	2006	1830	2006	Limburg		40.0	33.3	5	8326
99	Obdam	GM0429	11338	1830	2006	1830	2006	Noord-Holland		33.3	55.6	5	6920
100	Hunsel	GM0925	10784	1830	2006	1830	2006	Limburg		85.0	80.0	5	6193

Nr	Municipality	CBS Code GMXXXX	AMS Code	CBS Code Est.	CBS Code Abol.	AMS Code Est.	AMS Code Abol.	Province	NS_{av} Eessential	NS_{av} Education	NS_{av} Entertainment	STED	Population
101	Thorn	GM0977	11195	1830	2006	1830	2006	Limburg		62.5	50.0	5	2584

7.2 Graph Metric Heatmaps

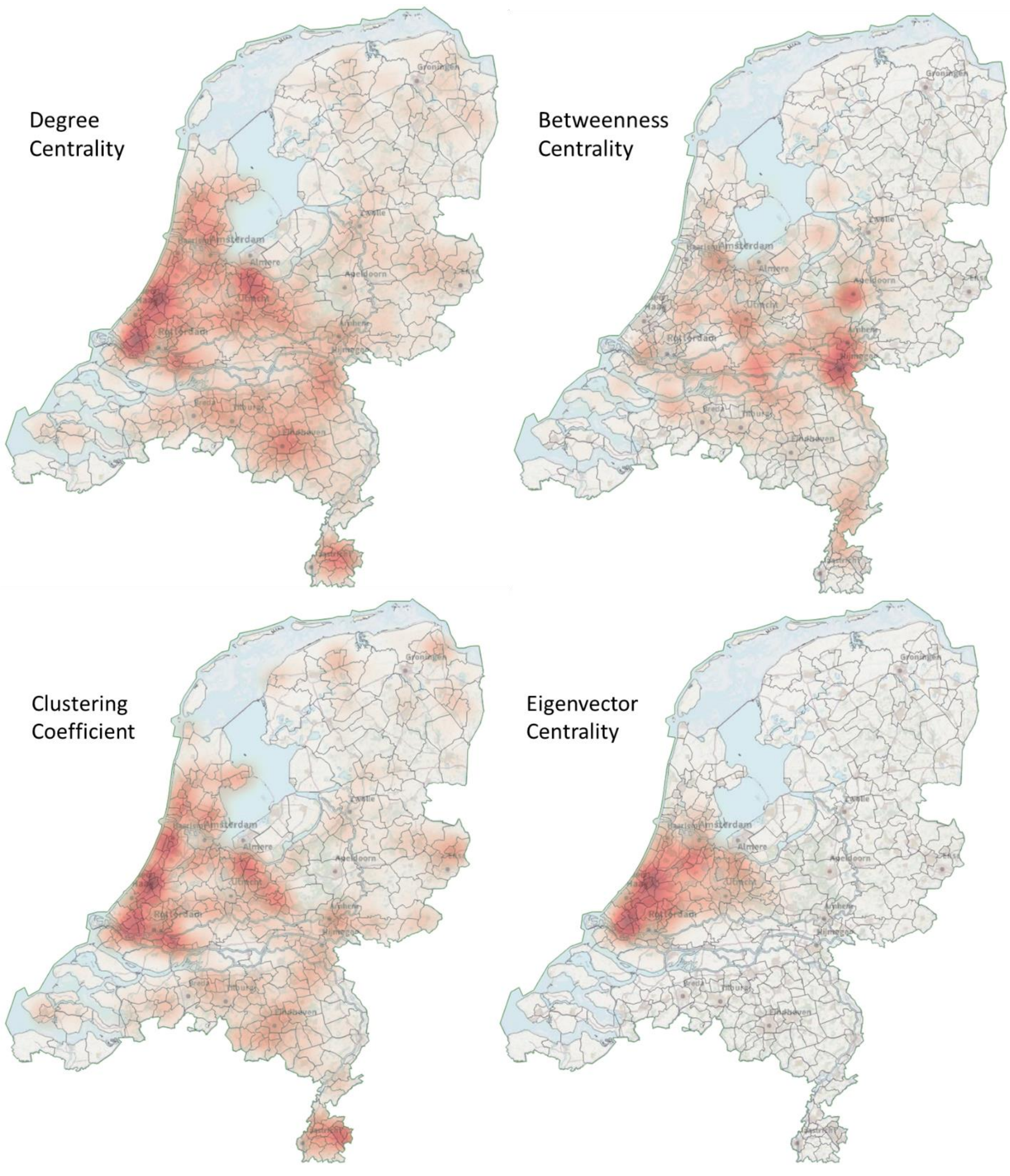

Figure 60 Heatmap of graph metrics upon the 2019 municipality polygons. A darker red color indicates higher metric value.

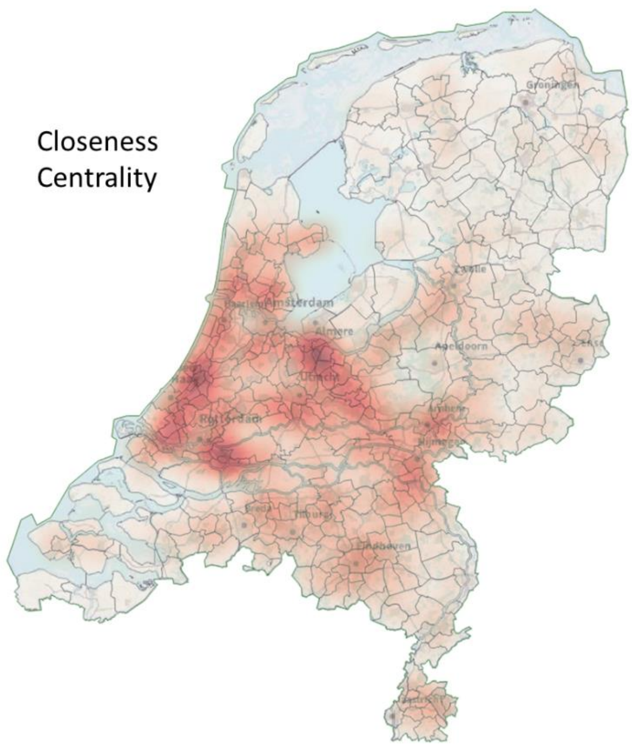

Figure 61 Heatmap of closeness centrality upon the 2019 municipality polygons. A darker red color indicates higher metric value

7.3 Official Classifications

7.3.1 CBS Code and Amsterdam Code

In this research, two different code schemes are used to identify municipalities, namely the four-digit Central Bureau of Statistics code (CBS code) and the five-digit Amsterdam code (AMS code). CBS codes describe municipalities that existed after 1830, while Amsterdam codes can be traced back to Dutch municipalities that existed from 1812. The CBS code identifies specific administrative entities (municipality names), while the Amsterdam code identifies the underlying geographical areas on which municipalities are/were located.

Whenever an annual administrative reorganization leads to a municipality name change or municipality merger (either Type A or Type C, in the case of an existing municipality absorbing one or more municipalities or in the case of forming a new municipality after the merger of two or more municipalities, respectively), a new CBS code is generated and assigned to the new municipality. However, the new municipality is given an existing Amsterdam code that belonged to one of the municipalities that were involved in the merging process, to ensure the historical continuity of the geographical area. The municipality with the largest population before the merger inherits its Amsterdam code to the newly formed municipality (in the case of a Type C merger, Figure 62), while all CBS codes involved in the merger are abolished in that case. When a municipality absorbs another municipality (Type A merger) , the Amsterdam code of the absorber municipality is preserved while the code of the absorbed is abolished, while the same thing happens with their CBS codes in that case.

The CBS code can be considered a unique identifier for a municipality, because it uniquely specifies a municipal entity that exists or has existed for a certain time period. The Amsterdam code, however, is not a unique municipality identifier; It has been designed in such a way that, with the exception of municipalities that have been established on land reclaimed from water (such as Wieringermeer) or have been annexed from neighboring countries (such as Elten from Germany), all Dutch municipalities possess an Amsterdam code that can be traced back to an Amsterdam code of a Dutch municipality that existed in 1812. [28]

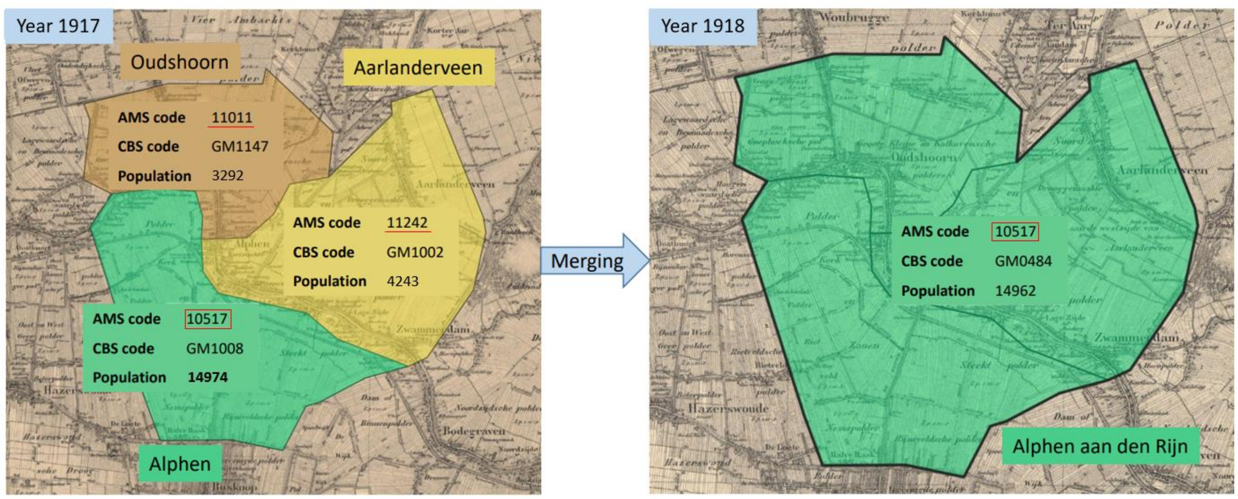

Figure 62 Merger Type C (Coalition) example: the municipality with the largest population among the three merger constituents before the merger (Alphen) inherits its Amsterdam code (AMS code) to the newly formed municipality (Alphen aan den Rihn), which receives a completely new CBS code

Usually, the exact dates of municipal reclassifications officially occur on 1st January of a year. For example, If a municipality is established on $01/01/k+1$ we record year $k+1$ as the establishment year of the municipality. On the contrary, if a municipality is abolished on $01/01/k+1$, it means that the municipality's CBS code was active until $31/12/k$, therefore in the DMN we record year k as the abolishment year of the municipality. However, in some cases, the official dates of administrative changes do not coincide with the first day of the year. For example, the CBS code of Kesteren in Gelderland was abolished due to name-change on 01/04/2003, and the new municipality Neder-Betuwe was formed with a different CBS code on 01/04/2003. For simplicity, in the DMN we record that Kesteren was abolished at the end of year $k=2003$, and that Neder-Betuwe was established in the beginning of year $k+1=2004$, since in the municipality listings of year $k=2003$Kesteren was still listed, but in the listings of year $k+1=2004$ only Neder-Betuwe was listed. As a general rule, if a municipality was officially established between $02/01/k$ and $31/12/k$, we record that it was established in year $k+1$. Likewise, if a municipality was abolished between $02/01/k$ and $31/12/k$, we record that it was abolished in year k.

7.3.2 International Standard Industrial Classification

In this thesis' research the sector layers in the research construct are compliant with the United Nations International Standard Industrial Classification of All Economic Activities (ISIC) and the Dutch *Standaard Bedrijven Indeling* (SBI) that is derived from the UN ISIC. The most recent version of the ISIC classification system is revision 4, published in 2008. The structure of the ISIC rev. 4 classification contains 21 sections. ISIC's comprehensive framework is designed for economic analysis, decision-taking and policy-making.
The mapping of 21 ISIC sections to 20 sectors is given on the table below [15] , as well as a connection between vital sectors (marked with green) and the related layers of the research construct.

Sectors		**Sections (ISIC rev. 4)**	**Vital sectors defined in the Dutch BVI-report**	**(Partially) Used in a layer of the Research Construct**
1.	Administrative activities	section N and class S9601	-	No
2.	Agriculture & Fishing	section A	-	No
3.	Care	section Q and divisions S94, S96	healthcare	Yes
4.	Communications	section J	telecommunications/ICT	Yes
5.	Construction	section F	-	No
6.	Education	section P	-	Yes
7.	Energy	section D	energy	No
8.	Entertainment	section R	-	Yes
9.	Environmental care	divisions E38 and E39	removal of waste products[13]	No
10.	Finance	section K	finance	No
11.	Government	section O	public administration, public order and safety	Yes

13 'Removal of waste products' is defined in [18], among other products/services, as a 'boundary condition' for all vital sectors, i.e. essential for all (vital) sectors to continue functioning [15].

12.	Hotel, Restaurant, Café	section I	food[14]	Yes
13.	Households	section T	-	Yes
14.	Manufacturing	section C	manufacture of chemical and nuclear products	No
15.	Mining	section B	-	No
16.	Professional activities	section M	legal order	No
17.	Real estate	section L	-	Yes
18.	Trade	section G and division S95	-	Yes
19.	Transport	section H	transport	Yes
20.	Water	section E excluding divisions E38, E39	drinking water, managing surface water	No

ISIC Sections:
A. Agriculture, forestry and fishing
B. Mining and quarrying
C. Manufacturing
D. Electricity, gas, steam and air conditioning supply
E. Water supply; sewerage, waste management and remediation activities
F. Construction
G. Wholesale and retail trade; repair of motor vehicles and motorcycles
H. Transportation and storage*
I. Accommodation and food service activities * in research construct
J. Information and communication*
K. Financial and insurance activities
L. Real estate activities
M. Professional, scientific and technical activities
N. Administrative and support service activities
O. Public administration and defence; compulsory social security
P. Education *
Q. Human health and social work activities *
R. Arts, entertainment and recreation
S. Other service activities

14 Accommodation is not considered a vital sector. According to Ministry of the Interior and Kingdom Relations, food supply and safety is defined as a vital service. Therefore, ISIC Section I-56 (Food and beverage service activities) can be classified as a vital sector. In the recent COVID-19 pandemic, only a subset of the services that are listed in ISIC Section I-56 were deemed vital and remained open throughout the crisis, i.e. food delivery/takeaway services [17], [18], [58]

T. Activities of households as employers; undifferentiated goods- and services-producing *, activities of households for own use
U. Activities of extraterritorial organizations and bodies

7.4 Municipalities transferred to other provinces

During the course of 190 years, some municipalities were transferred to other provinces. The provinces of the municipalities of Leimuiden, Noordoostpolder, Oudewater, Terschelling, Urk (2x), Vianen, Vlieland and Woerden have been changed. Below is the list of provincial changes since 1830: [32]

Year of transfer	Municipality of transfer	Original Province	Destination Province	Comments
1864	Leimuiden	Noord-Holland	Zuid-Holland	Type C merger in 1990
1942	Terschelling	Noord-Holland	Fryslân	Exists still
1942	Vlieland	Noord-Holland	Fryslân	Exists still
1950	Urk	Noord-Holland	Overijssel	Exists still, transferred twice
1970	Oudewater	Zuid-Holland	Utrecht	Exists still , on 1-9-1970 added Hoenkoop from Utrecht
1986	Urk	Overijssel	Flevoland	Exists still, Flevoland established in 1986
1986	Noordoostpolder	Overijssel	Flevoland	Exists still, Flevoland established in 1986
1989	Woerden	Zuid-Holland	Utrecht	Exists still , on 1-1-1989 added Zegveld , on 1-1-1989 added Kamerik
2002	Vianen	Zuid-Holland	Utrecht	Type C merger in 2018

7.5 Additional Figures

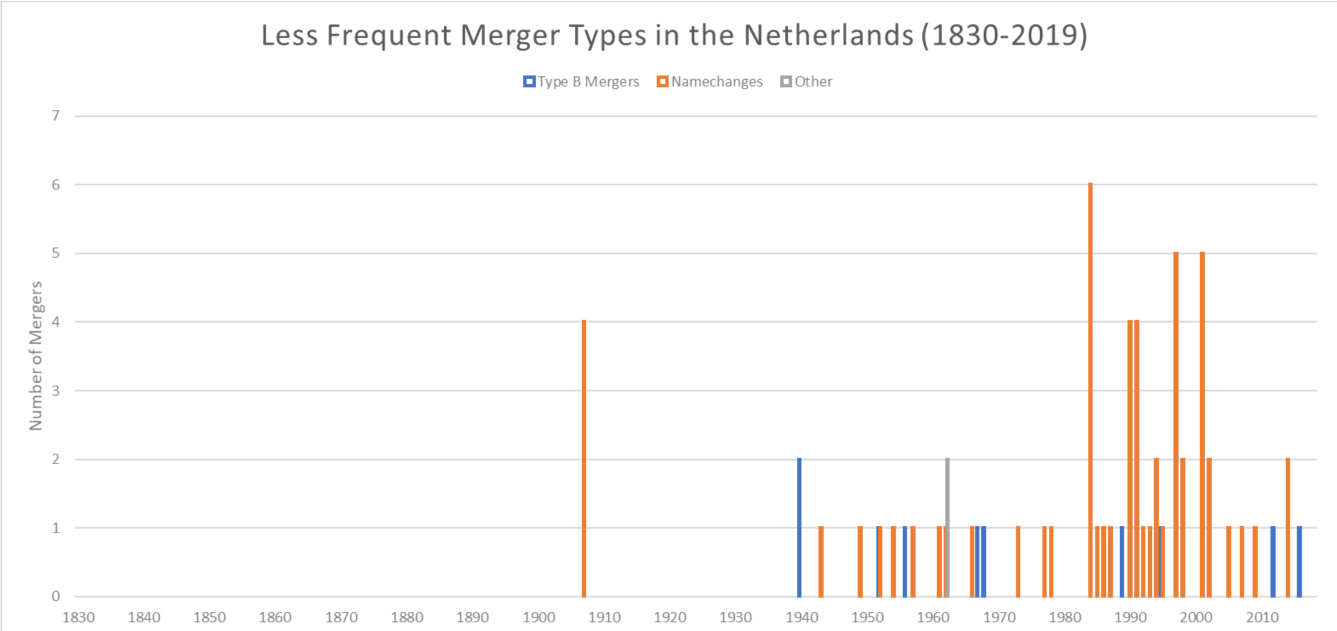

Figure 63 Histogram of the total Type B mergers, Name-changes (Type D) and Other (Type E) (municipalities transferred abroad).

7.6 Datasets used in this research

The main data sources and data sets used in this thesis are shown in the figure below, while a more detailed list is presented in the following table.

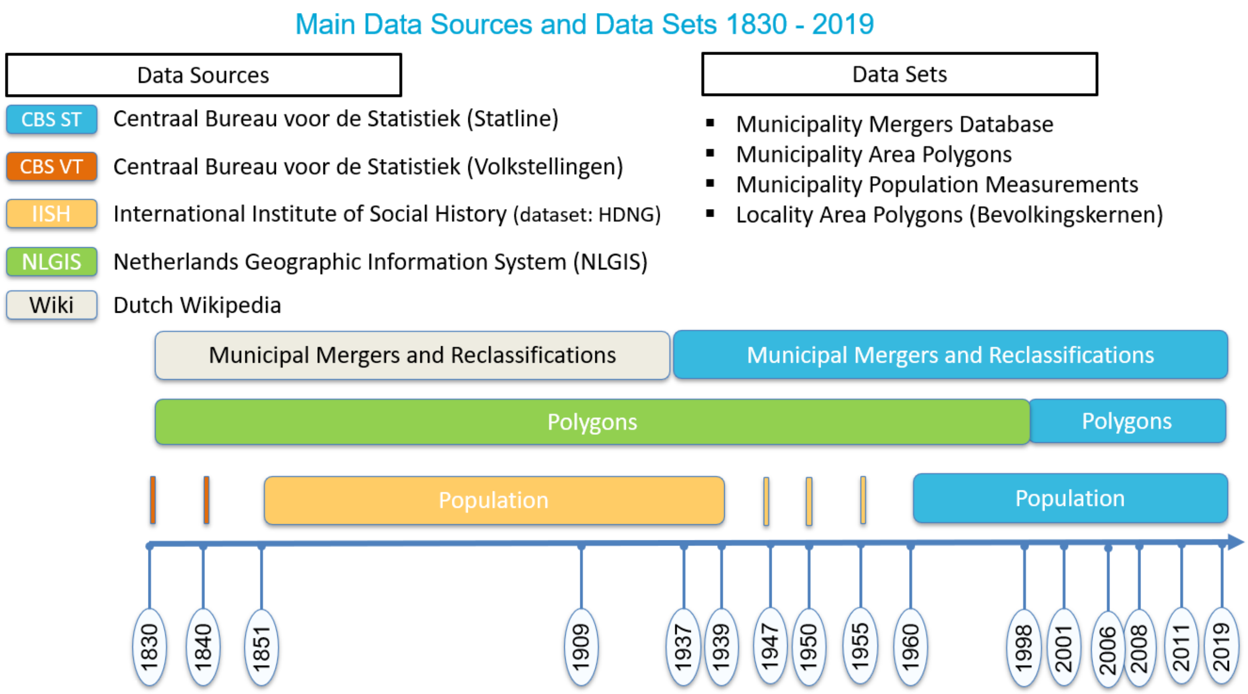

Figure 64 Time coverage of the main datasets used in the research construct

Dataset	Period	Source
Population dynamics; birth, death and migration Bevolkingsontwikkeling; levend geborenen, overledenen en migratie	1960-2019	CBS
Population from HDNG (Historische Database Nederlandse Gemeenten)	1809, 1829, 1851-1939, 1947, 1950, 1955	IISH HDNG
Population from Dutch Censuses Nederlandse Volkstellingen	1830, 1840	CBS Volkstellingen
Inter-municipal migration relocated persons; within/between municipalities Verhuisde personen; binnen/tussen gemeenten	1988-2019	CBS

Time series of municipal reclassifications *Hulpbestanden tijdreeksen*	1960-2019	CBS
	1830-1959	Wikipedia
Proximity to facilities Nabijheid voorzieningen; afstand locatie	2006-2019	CBS
Municipality Polygons	2003-2019	CBS
	1998-2002	Nationaal georegister
	1830-1997	NLGIS
Train Stations	Current 2021	ESRI Nederland
	Closed between 1891-2006	Hidden Places
Schools (locations and number of students, also newly opened and closed schools)	Current School Locations 2021 New and Closed Schools from 1996	DUO

7.7 Abbreviations

Abbreviation	Meaning in Dutch Meaning in English
CBS	Centraal Bureau voor de Statistiek Statistics Netherlands
COROP	Coördinatie Commissie Regionaal OnderzoeksProgramma Coordination Commission of Regional Research Programme
GIS	Geographic Information System
ISIC	International Standard Industrial Classification of All Economic Activities
LLC	Linear Log Correlation

DLSS	Discrete-time Linear State Space
DMN	Dutch Municipality Network
OAD	Omgevingsadressendichtheid
	Local address density
STED	Stedelijkheidsklasse
	Urbanisation Class
SBI	Standaard Bedrijven Indeling
	Standard Business Classification

7.8 Notations

Notation	Explanation
k	Integer number denoting a specific calendar year k
$N[k]$	Number of active municipalities in year k
$N_a[k]$	Number of abolished municipalities in year k
$N_n[k]$	Number of newly established municipalities in year k
$\mathcal{N}[k]$	Set of active municipalities in year k
$\mathcal{A}[k]$	Set of abolished municipalities in year k
$L[k]$	Number of links in the DMN in year k
$\mathcal{L}[k]$	Set of links in the DMN in year k
$A[k]$	Adjacency matrix of the DMN in year k
$a_{ij}[k]$	The ij-th element of A[k]
$Y[k]$	Migration matrix of the DMN in year k
$E[X[k]]$	Expected value of the national total population in year k
$x[k]$	$N[k] \times 1$ vector of population per municipality in year k
$x_i[k]$	Population of municipality i in year k
$X[k]$	Total population of the Netherlands in year k
$G\{\mathcal{N}[k], \mathcal{L}[k]\}$	Graph of the Dutch Municipality Network in year k
$G_\lambda\{\mathcal{N}[k], \mathcal{L}[k]\}$	Graph of the layer λ of the multilayer Dutch Municipality Network
λ	The λ-th layer of the multilayer DMN
Λ	Number of layers in the multilayer DMN
α	Forward migration rate
δ	Backward migration rate
$p_i[k]$	Abolishment Likelihood Index of municipality i in year k
$p[k]$	Abolishment Likelihood Index of municipalities in year k
$c_1[k]$	Estimated slope of the population development in year k
$c_2[k]$	Estimated additive constant of the population development in year k
μ_l	Shape parameter of the lognormal distribution model

σ_l	Scale parameter of the lognormal distribution model
μ_f	Shape parameter of the Fermi-Dirac distribution model
σ_f	Scale parameter of the Fermi-Dirac distribution model
σ	Standard deviation of a random variable
μ	Arithmetic mean (average) of a random variable
$\tau[k]$	Estimated exponent of the power law distribution fit in year k
d_i	Degree of a node i
$E[D]$	Expected degree of a graph
B_i	Betweenness centrality of a node i
c_i	Local clustering coefficient of a node i
C_i	Closeness centrality of a node i
E_i	Eigenvector centrality of a node i
r	Degree assortativity of a graph; Pearson's correlation coefficient
$\sigma_{jm}(i)$	Number of shortest paths between nodes j and m that pass through i
σ_{jm}	Number of shortest paths between nodes j and m
$H_{i\rightarrow}H_j$	Number of hops in the shortest path between nodes i and j
q_i	Number of links between the neighbors of node i
g	Constant
X, Y	Random variables
c, γ, a	Positive constants
K, Π, Γ, K_e	DLSS model parameters
$\varphi[k]$	DLSS system state vector
$\psi[k]$	DLSS system input vector
$\omega[k]$	DLSS system output vector
NS_{av}	Average Neighbor Superiority of municipalities