GIMA

Geographical Information Management and Applications

A GIS approach to monitor accessibility of public urban space for the elderly

MSc Thesis v2.5

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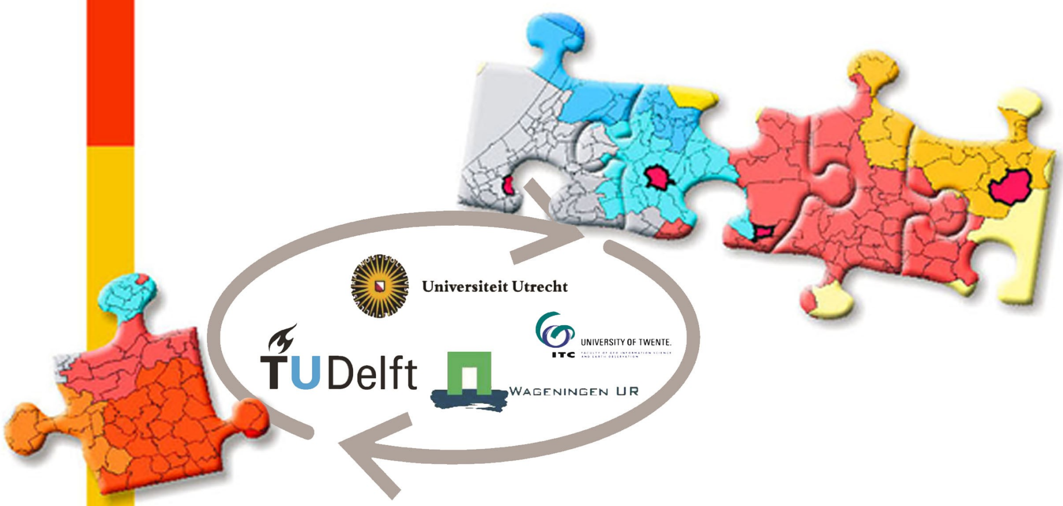

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Preface

I would like to thank the following people who contributed to this report by helping me gather the right information and gain insight in the methodology. Without you, it would have been impossible for me to complete this research!

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- Prof. dr. Maarten van Ham MSc, PhD, FHEA
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1.Introduction

The Dutch population is ageing rapidly. Besides the Netherlands, many other western and eastern countries need to cope with an ageing population *(Caley, M. & Sidhu, K. 2010, Denton, F.T. & Spencer, B.G., 1999 and Martini, E., 2007, Norman, R.A. & Henderson, J.N., 2003*). The generation born after the Second World War, known as the baby boomers, is reaching retirement age. Driven by the desire to maintain higher life standards, couples choose to bear fewer children and at an older age *(Macunovich, D.J., 2000*). This results in a lag in the renewal of the population. Also, with progress in medical technology, people become older and older *(Neyer et al., 2012, Vaupel, J.W. & Kistowski, K.G.V., 2008, Rosenzweig, M.R. & Stark, O., 1997, de Jong & van Duin, 2010, statline CBS*). These developments make the population age shift from green to grey.

One of the biggest concerns of an ageing population is an expected rise in costs for retirement funds, health care and social care (*Lee, R. & Skinner, J., 1999, Todd, W. et al., 2006, Commission of the European Communities, 2008*). This concern is even more urgent since the start of the financial crisis in 2008 where multiple banks on the verge of bankruptcy needed to be saved by government funding. This blew a big hole in both government budget and retirement funds.

Governments, including the Dutch, are now taking precautions to limit the financial damage by increasing retirement age, and cutting costs on public services, including health care and social care. Since fewer funds are available, the government needs to search for innovative approaches that yield the most out of the taxpayer’s money.

One of these approaches is to equip urban areas with facilities that fit the present and future population of all ages and make these facilities as broadly accessible as possible *(SEV, 2012)*. One of the benefits of this approach is that mobility increases when facilities become better accessible. And past research shows that an increase in mobility proves to have significant health benefits (*King, C. et al., 2011*). Increased mobility also stimulates independent living (*Yong, V. et al., 2010)*. Staying mobile makes people less dependent on social care which in its turn decreases social care costs. The Dutch municipality of Rotterdam also follows this approach. Therefore, Rotterdam functions as a test case for this thesis study.

The build-up of a country's population determines which facilities are needed, how public space must be arranged, which forms of transport should be available, what kind of care should be provided, etc. Therefore, when a country's population ages gradually, these conditions change as well. The government must prepare itself to be able to react to these changes. To be prepared means to gain insight in the challenge at hand. And to gain insight, a thorough understanding and analysis of the work area is necessary. This thesis aims to develop a methodology that can support the government in the analysis of urban areas so that well informed decisions can be made on how to support an ageing population in these areas.

Since the government operates in a spatial environment, the technology from Geographic Information Systems (GIS) can assist in providing insight and understanding in how the conditions for an ageing population can be met in urban areas. Because this thesis is part of the MSc Geographical Information Management and Applications, it will examine the spatial conditions that need to be met in public urban spaces to be able to cope with an ageing population. Based on literature study, this thesis will describe the most important facilities for elderly people and which factors influence accessibility of these facilities.

This thesis implements this information into a methodology that makes accessibility and availability of services for elderly people measurable. This methodology uses GIS techniques to analyse if a city has the necessary services available and how well these services are spatially accessibility by elderly people. The goal was to make the methodology as universally applicable as possible, by using registrations that are broadly available in the Netherlands. This way the methodology can easily be implemented in different Dutch municipalities.

However, before diving too deeply into technical details, the upcoming paragraphs describe the substantive context on which this thesis research was based.

This thesis begins with describing the problem definition and the reason for the study. The second chapter describes the background of the research project. Next, the methodology is explained describing the different parameters influencing accessibility of services for elderly people with physical limitation. The results of the implementation of this methodology are described in chapter 4. Finally, the thesis ends with drawn conclusions and discussions. A summary of the research can be found in chapter 7.

1.1 Problem definition

Independent living by the elderly can be explained as such that the elderly can live in their own home for as long as possible without the need for personal assistance whether in social or health care. In the Netherlands, independent living is operationalised by the concept “Living Service Areas”. This policy is a regional approach of the planning of services for living, care and welfare for people of all ages *(SEV, 2012).* Both the accessibility of dwellings and public space are found to be important.

Mobility is an important factor in independent living that largely depends on the accessibility of relevant services (*Yong, V. et al., 2010)*. Accessibility is determined by the urban design of public space (*Clarke, P.J. et al., 2011*). Also the location of relevant services for the target group (elderly people) and how far people have to travel to reach them influence mobility (*SEV, 2012*).

Municipalities are made responsible for implementing the policy of independent living for elderly people. Therefore, to be able to make well informed decisions, policy makers and city planners need insight in the location of relevant services for elderly people including the design of public space in relation to the accessibility of these services. Thus, to make this implementation successful, it is necessary to be able to monitor the factors that determine independent living.

Current monitoring tools aim at accessibility of dwellings and public buildings, based on interior conditions (*SEV, 2012*). However, to the knowledge of the author, no monitoring instrument exists to verify the accessibility of public space for elderly people in relation to relevant services. To make a manual inventory of all public space and services would be inefficient and expensive. Therefore, it would be valuable if this inventory could be (largely) automated.

Hence the problem definition of this thesis is:
Policy makers and city planners must be able to monitor the design of public space for a whole city in relation to independent living by elderly people.

GIS (Geographical Information System) techniques have the potential to analyse large areas at once, using different variables as input, such as the distance to destinations taking into account ways of transport and possible obstacles along the way. Therefore, this thesis aims to develop a methodology that uses GIS techniques to give insight into the accessibility of relevant services for elderly people in relation with urban design of public space.

1.2 Purpose of the study

The purpose of this study is to create a methodology that provides insight in the suitability of a city's public space in relation to independent living of elderly. This study focuses on the availability and accessibility by foot of services relevant to elderly people.

1.3 Significance of the study

A well designed city promotes mobility, which promotes health (*Yong, V. et al., 2010)*. Since healthy people are able to live independently for a longer period, it is important to test how well the city is suited for stimulation of mobility.

The currently available methods only monitor accessibility of buildings based on interior conditions. The methodology developed during this study will complement these methods by adding insight into the urban design of public space in relation to independent living. This additional insight can help policy makers and city planners make better decisions about the composition, location and road accessibility of services.

Since this methodology combines GIS techniques and broadly available registers, it becomes possible to analyse large areas simultaneously. This will be more efficient and more objective than manual field work. Also by using registers that are broadly available in the Netherlands, the methodology can be easily implemented in other Dutch cities.

1.4 Research questions

The main objective of this research project is:
"To gain insight in how to model the spatial characteristics of public urban Rotterdam and their influence on accessibility to relevant services for elderly people by foot using GIS techniques"

The main research objective is supported by answering the following (sub-)questions:

1. Which spatial characteristics support accessibility of the public space for elderly people with physical limitations? (based on literature study)
2. How can these characteristics be translated to measurable parameters using GIS techniques?
3. Where do elderly people live independently in Rotterdam and which of the spatial characteristics found in the literature research are present there?
4. Which parts of the public space have good or poor access to services for the elderly, taking into account:
    a. Access to desired destinations of a certain category by foot or walking device (wheel chair, walker)
    b. Availability of desired destinations
5. When taking related spatial characteristics into account; which composition of services will make areas with limited accessibility to services more suitable for the elderly?

2. Background

The Netherlands faces an ageing population. In and out of the Netherlands however, an ageing population brings along challenges. These challenges relate to health, fertility, finance, longevity and involve the so called 'baby boomers'. To be able to handle these challenges, concepts such as independent living and smart cities are developed. Those concepts are highly influenced by the positive relationship between mobility and health. To successfully develop policy based on these concepts, it is important that their effects on mobility and therefore the health of elderly people can be measured. This chapter describes the main challenges related to population ageing and the way that the Netherlands and other countries are trying to turn them around.

2.1 The Dutch are getting old

The Dutch population is ageing rapidly. The Central Bureau of Statistics of the Netherlands (CBS) prognoses that the percentage of people of 65 years and older will be 17,7% in 2015, 23.7% in 2030 and 25.5% in 2045. However, an ageing population is not typical for the Netherlands. Europe is currently the continent with the oldest average population (*Vaupel, J.W. & Kistowski, K.G.V., 2008*). However, America, Canada, Japan, China and India also show signs of an ageing population (*Caley, M. & Sidhu, K. 2010, Denton, F.T. & Spencer, B.G., 1999 and Martini, E., 2007, Norman, R.A. & Henderson, J.N., 2003*). This increase in the average age is caused by a combination of factors.

First, the birthrate expanded significantly after World War II in the period between 1946 and 1969. People born in this period are known as the “baby boomers”. Currently, these baby boomers are heading for retirement age. The figure below shows the prognosis of the age composition of the population in the Netherlands and the municipality of Rotterdam (*Hoppesteyn, M., 2012*). The pyramids show that from 2012 to 2030 the baby boomers push the average age upwards as they become older. They also show that Rotterdam is relatively young, compared to the rest of the Netherlands. However, there is still a clear shift visible in the number of older people, showing that relatively, the population of Rotterdam is also ageing.

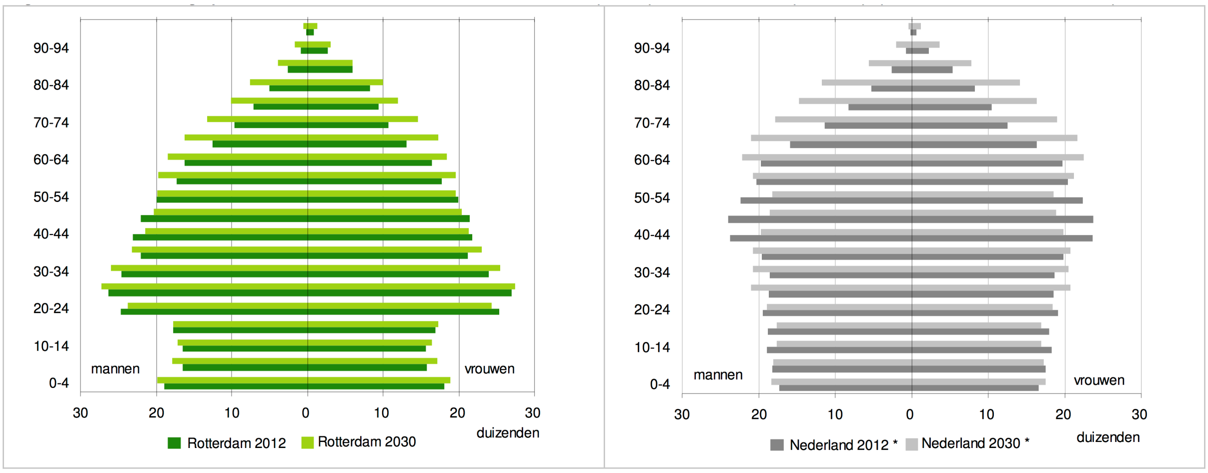

Figure 2.1: Population pyramids of 2012 and 2030 of Rotterdam (left) and the Netherlands (right) (source: Hoppesteyn, M., 2012)

The second factor in population ageing is that life expectancy rises and is expected to continue to rise by approximately 2,5 years per decade. This increase in life expectancy results from the development of better techniques and methods for the prevention, diagnostics and treatment of illnesses (*Neyer et al., 2012, Vaupel, J.W. & Kistowski, K.G.V., 2008, Rosenzweig, M.R. & Stark, O., 1997, de Jong & van Duin, 2010, statline CBS*). By 2060 women are expected to have a life expectancy of 89 years while men are expected to live up to 84 years of age (*Neyer, G. et al., 2012*).

Lastly, the fertility rate in western countries lowers gradually, meaning that women bear less children during their lifetime. In Europe, the fertility rate is reported to be around 1.45 children per woman. The US shows similar fertility rates – between 1.3 and 1.6 children per woman *(Vaupel, J.W. & Kistowski, K.G.V., 2008*). The drop in fertility rate is often attributed to the fact that women delay bearing a child until they are in their thirties *(Neyer, G. et al., 2012*). This delay can be explained by their wish to maintain a certain living standard *(Macunovich, D.J., 2000*). This development is of concern, since the fertility rate stays below the replacement level of the population *(Neyer, G. et al., 2012*). In other words, the population will gradually become older in the short term and smaller in the long term.

<u>Ageing in relation to dependency:</u>
The old-age dependency ratio shows the relationship between the number of people of 65 years and older (retired) and the number of people between 20 and 64 years of age (labour force). This ratio forms an indicator for the financial pressure on the labour force. When the ratio rises (relative high number of retired people) so does the financial pressure on the labour force. The young-age dependency ratio shows the relationship between the number of people between 0 and 19 years old (youth) compared to the number of people between 20 and 64 years old (labour force). The old-age dependency ratio plus the young-age dependency ratio form the total dependency ratio.

The figure below (*Beets, G. & Nimwegen, N., 2000)* shows these ratios for the Netherlands, including a prognosis until 2050. It shows that, although the old-age dependency began rising since 1920, the total dependency gradually lowered until about 2010. This is the result of less children being born, causing the young-age dependency to drop. Nonetheless, starting from 2010, the old-age dependency and the total dependency has been rising significantly. This would mean that in the near future, the financial pressure on the labour force will become stronger.

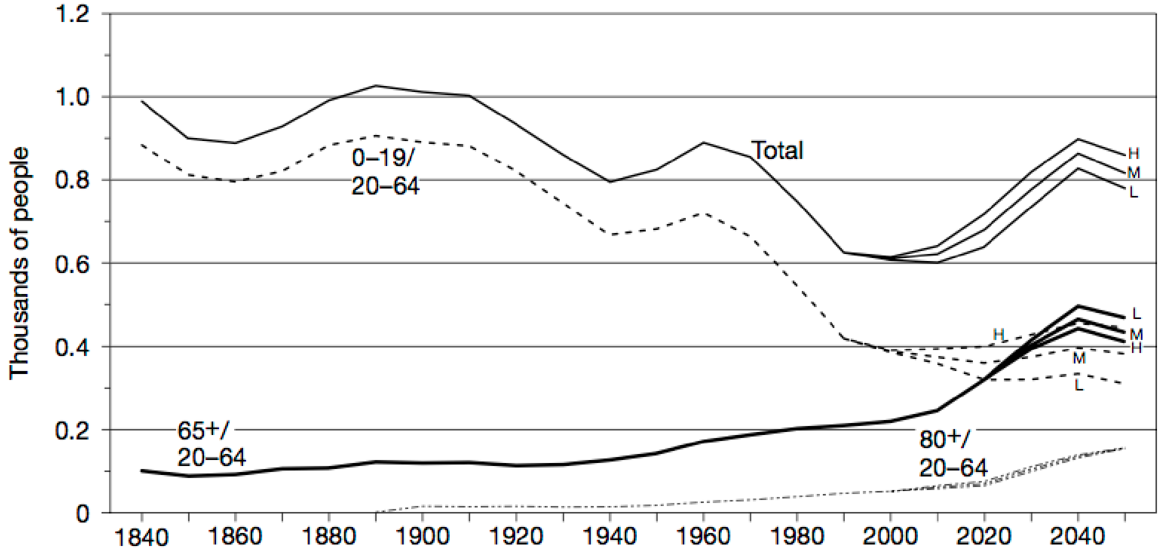

Figure 2.2: Dependency ratio of the Dutch population aged 0–19, 65+, and 80+, per person aged 20–64 years, 1840–2050, including forecasts for 1996–2050 (source: Beets, G. & Nimwegen, N., 2000)

However, Healy J., (2004) points out that the dependency rate is a crude measure. For example, the productivity of people is expected to rise in the future. This would mean that less working staff is needed to realize the same level of productivity of today. Also, many people of working age who are not working would like to do so. In other words, the potential work force is larger than which is deployed currently. Added to that, retired people often still wish to continue to work. More and more women are contributing to the workforce and women who work part-time are willing to work more hours if practically possible.

The reasons as stated by Healy J. (2004) might soften the dependency burden on the workforce. The fact remains that the Dutch population is ageing rapidly and an ageing population brings certain challenges to the table. The next paragraphs will further explain these challenges.

2.2 Financial consequences of an ageing population

An ageing population causes major financial challenges in Europe and other continents in the world (*Commission of the European Communities, 2008*). Different studies show that three factors drive up costs related to ageing, namely: general health care, long term care (disability) and retirement (*Lee, R. & Skinner, J., 1999, Todd, W. et al., 2006, Commission of the European Communities, 2008*). Trying to predict the long term effects of these factors is difficult since they depend on many variables, such as fertility rate, employment, labour force and migration flows (*Foot, D.K., 1989, Commission of the European Communities, 2008*). A drop in fertility will result in a relative decrease in the younger population and increase in the older population. When less people are employed or the available labour force becomes smaller, the overall population becomes financially more dependent on the working population.

In general, employment and labour force are the key predictors for the financial consequences of an ageing population. After all, when less people are working or if people work less hours per week, income to finance pensions and health care will also be lower compared to more people who work more hours (*Beetsma, R. et al., 2003, Commission of the European Communities, 2008*).

The first baby boomers are heading for or just started to enjoy their retirement (*Ewijk, C. et al., 2006)*. This means that a larger portion of the population will retire each year in the upcoming decades (*White, J., 2004*). Retirement forms the largest burden on government finances (*Reinhardt, U.E., 2003*). The economic crisis also left a dent in the pension funds. In the Netherlands, the pension funds reached a funded ration of 90-95%, well under the minimum of 105% (*Kune, J.B., 2009*). Retirement age has increased from 65 to 67 years of age, to supplement the pension funds for future retirees. However, this measure alone will not be enough to cover all future costs (*TNO, 2011*).

Parallel to ageing, the demand in health care is expected to increase and therefore the costs for health care are expected to rise *(Caley, M. & Sidhu, K. 2010, Denton, F.T. & Spencer, B.G., 1999, Martini, E., 2007 et.al.)*. Medical advances and a healthier lifestyle are expected to contribute to limit health care expenses (*Lee, R. & Skinner, J., 1999*). However, health care might become more expensive, because with an ageing population less workers will be available. This may also result in higher labour prices. Thus, the challenge lays less in financing and more in delivering health care. Therefore, it is important to know the health care needs of elderly people and to determine how the supply of these services should be organized (*White, J., 2004*).

This thesis does not directly offer solutions for the financial challenges connected to ageing. However indirectly, it will give insight in the most important services for elderly people and how their locations can be optimized for delivering health care. Optimizing the location and composition of services can help reduce costs in the long term.

2.3 Dutch policy promotes independent living

The expected increase in health care costs brings about a different approach to providing health care. Therefore, the Dutch policy for the elderly promotes independent living. The idea behind this policy is that self-sustaining elderly people need less health care, which is expected to result in fewer costs. Living independently in this thesis can be described as that elderly people can live in their own home for as long as possible with the needed facilities within reach but without need for personal assistance by health care providers.

Research performed by Smets (2012) shows that elderly people prefer to live among various age groups in the centre of their town with access to family and friends. They want to stay independent and have the freedom to do what they want in their own privacy. This means that clusters of elderly or ‘senior’ cities are undesirable. Therefore, to make independent living possible, public authorities stimulate the realization of care services near the living locations of elderly people (Smets, A.J.H., 2012).

The Dutch policy describes this approach as ‘Woonservicegebieden’, which can be translated as ‘Living service areas’. This policy describes a regional approach to the planning of services in the area of living, care and welfare *(SEV, 2012)*.

This policy does not only focus on areas for elderly people, but for people of all ages. In a 'Living service area', vulnerable people such as elderly people or people with physical limitations, can live independently for as long as possible (*KCWZ, 2013*). Physical limitations in this thesis are defined as limitations that make it difficult to walk and perform daily tasks. These ‘living service areas’ have access to services, shops, recreation areas, etc. (*Hunter, R.H. et al., 2011, Phillipson, C., 2012*). For elderly people, easy access to care services and transportation is important (*Phillipson, C., 2012*). The influence of accessibility and mobility on health is further described in 2.4.

The concept of 'Living service areas' (*KCWZ, 2013)* overlaps with 'Smart Growth' (*Hunter, R.H. et al., 2011*) and 'Age friendly cities' (*Phillipson, C., 2012*), where neighbourhoods designed for all ages are key. These concepts describe neighbourhoods as an attractive environment with high walkability and mixed usage sites. Neighbourhoods must be safe, have enough transportation choices and affordable housing that is also accessible for people with mobility limitations. Pedestrian traffic signals take slow walkers into account, places are well lit and there are enough benches to take a rest along the way. Also, relevant services are accessible and within walking distance.

This thesis aims to develop a methodology that includes the philosophy of 'living service areas'. It does this by providing insight in the availability of and the accessibility to services of prime importance to elderly people. The methodology will however be limited to parameters that can be measured, based on available literature. This includes the nearness, expressed in walking distance and the accessibility of pavement, expressed in pavement width and presence of barrier objects. Subjective parameters, such as how 'well' a place is lit or if there are 'enough' benches, are difficult to measure since no solid threshold values are available. Annexes 1 and 2 show which objective and subjective parameters were found in literature.

2.4 Health effects of mobility

To live independently, it is important to stay mobile (*Yong, V. et al., 2010)*. After all, research shows that there is a strong positive relationship between health and mobility.

Being mobile includes being able to perform tasks such as: going to bed, walking, stair climbing, carrying objects and getting in and out of transportation (*Montero-Odasso, M. et al., 2009*). Not being able to perform these tasks prevents people from going outside. Therefore, it becomes difficult to carry out daily activities such as shopping, banking or going out to receive medical care. Meeting friends and relatives becomes more and more difficult. Eventually, low mobility may result in social isolation (*Clarke, P.J. et al., 2011, Hunter, R.H. et al., 2011*). A study performed by *Chung, W.T. et.al* (*2011*) even shows a significant relationship between walkability of neighbourhoods and the risk of hunger. This can be explained by the fact that when it becomes difficult to go outside, it can also become more difficult to gain access to food.

Going outside daily has a positive effect on the health of the elderly and even prolongs life. How often one goes out even proves to be a predictor to the health and functioning of elderly after 7 years (*Jacobs, M. et al., 2008)*. The figure below shows the percentage of people who survived over a period of 12 years, comparing men and women who go outside daily to men and women who do not go out.

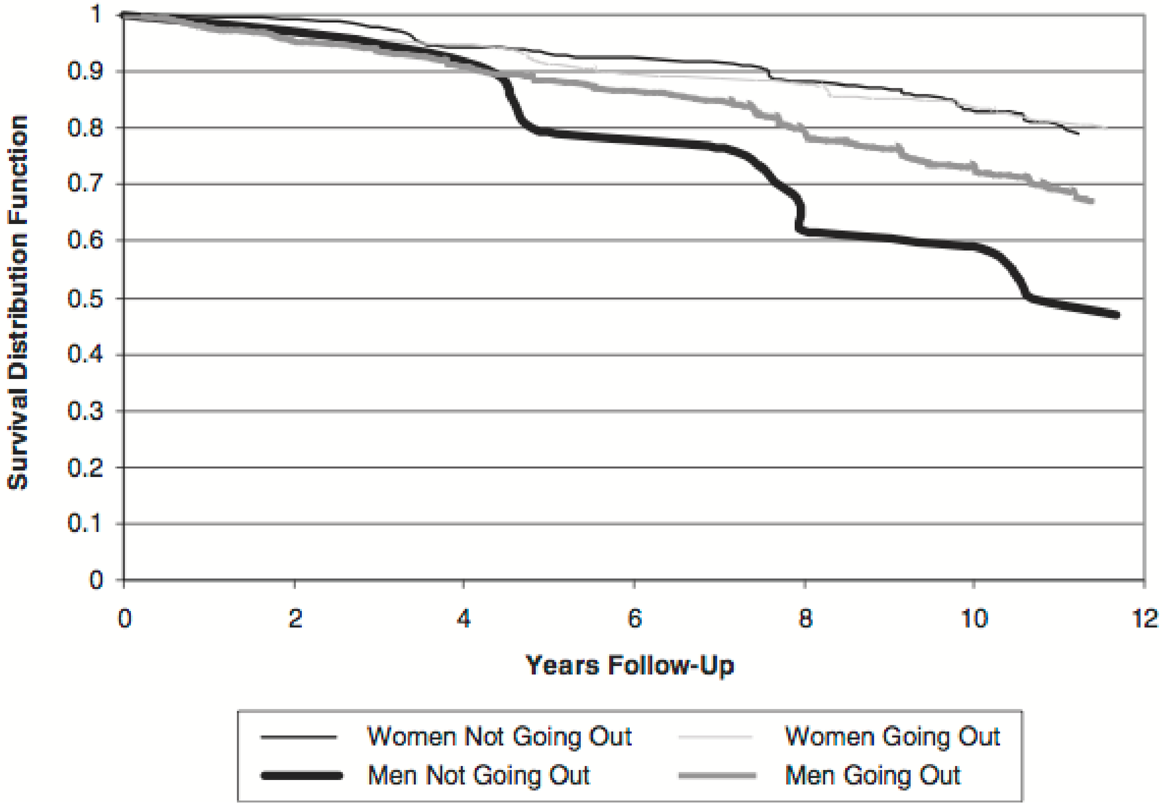

Figure 2.3: Kaplan-Meier Survival Curves for 12 Years of Follow-Up, According to Frequency of Going Out and Gender (source: Jacobs, M. et al., 2008)

The risk for the need to be placed in a nursing home and mortality increase when mobility decreases (*Montero-Odasso, M. et al., 2009, Jacobs, M. et al., 2008, Clarke, P.J. et al., 2011*). Also, relationships exist between depression and the ability to carry objects, climb, run, squat and simply walk. Rehabilitation on these areas improves disability and decreases depression (*Lee, C. et al., 2012*). This means that stimulating mobility decreases the chance of depression in the elderly. Mobility is a good indicator for the need for home-based health care. When people become less mobile, they need to make use of this kind of health care, which is more expensive than when they can go out to receive health care (*Taylor, D.H. Jr. & Hoenig, H., 2006*).

Mobility decreases with age:
Mobility limitations are strongly related to ageing (*Ahacic, K. et al., 2007*). Becoming less mobile relates to functional decline, disability and a higher need for assistance (*Yong, V. et al., 2010*). In other words, people who become less mobile, become more dependent. In 2004 the Central Statistics Bureau of the Netherlands did research on the limitation in physical mobility of the elderly between 1989 and 2002 (*CBS 2004*). The results of this research show that the number of people experiencing physical limitations increases from the age of 55 and up. The relationship between a decrease in mobility and ageing is confirmed in other studies such as *Valdemarsson et al., 2005*.

In summary, mobility has a positive effect on life expectancy, can prevent depression and hunger and improves health in general. Therefore, Yong et al. (2010) suggests an infrastructure that enables the elderly to stay mobile in the city. This is supported by King, C. et al. (2011) who shows a relationship between the walkability of neighbourhoods and the risk of inactivity, overweight and obesity. Also, the elderly living in walkable areas tend to be more mobile than those who live in less walkable areas, even when they are mobility impaired (*King, C. et al., 2011*).

Since mobility is such an important factor in relation to accessibility, health and mortality, it is chosen to implement mobility in this thesis research. In this thesis mobility will be implemented as the accessibility of relevant services for elderly in relation with their living locations. Because mobility is promoted by the walkability of a neighbourhood, this thesis will concentrate on the accessibility of services by foot.

2.5 The effect of urban design on mobility of the elderly

The design of neighbourhoods has a big influence on the mobility of the elderly and people with mobility limitations in general. Even simple changes to the urban design may stimulate persons of all ages to become more mobile. Therefore the build environment is getting increased attention in relation to mobility (*Clarke, P.J. et al., 2011*).

When neighbourhoods have a higher walkability, mobility among elderly people automatically increases. Therefore, the walkability of a neighbourhood forms a significant predictor for walking activity of elderly people (*Sugiyama, T., 2007*).

One of the factors influencing mobility is the perceived walking distance. Accessibility of services cannot be expressed in terms of distance, but depends on how ‘near’ the service ‘feels’ to a person (*SEV, 2012*). Per example, if a public transport stop is a short walk away, people are more eager to use public transport than when people have to walk further (*Baldwin Hess, D., 2012*). In general, elderly people who live on a block with accessible sidewalks and near a public transit stop are much more mobile than people who live on locations where these characteristics are absent (*Clarke, P. 2013*).

In practice, this means that a pavement is accessible when it is wide enough and free from obstructions, when slippery surfaces are appropriately managed and signage is well placed, public transit stops are available, etc. (*SEV, 2012, Philips, J. et.al., 2013*). Therefore, it can be concluded that organisation of public space is important for the (feeling of) accessibility to services and the mobility of elderly people in relation to accessibility.

The developed methodology in this thesis implements perceived walking distance as a gravitation function, which will be described in more detail in paragraph 3.2.1.

Mobility barriers:
High levels of motorized traffic have a negative impact on the mobility of elderly people (*Clarke, P.J. et al., 2011)*. Also, residential security, or the feeling of being

safe, influences the choice of people with mobility limitations to go outside or not. Especially elderly people with mobility limitations tend to stay inside when they do not feel secure outdoors (*Clarke, P.J. et al., 2011, Chung, W.T., et.al, 2011, Hunter, R.H. et al., 2011*). In addition, barriers, such as advertising signs on the pavement, have negative effects on mobility (*Baldwin Hess, D., 2012*). Uneven sidewalks and obstacles are the main causes of outdoor falls by elderly people (*Hunter, R.H. et al., 2011, Clarke, P.J. et al., 2011*). Therefore, bad maintenance of outdoor space can negatively influence the accessibility of urban public space.

<u>Stimulating mobility using good urban design:</u>
Well designed urban space may promote walkability (*Chung, W.T., et.al, 2011*). The urban environment can contribute to good health by providing places where people can meet socially and by offering aesthetically pleasant surroundings (*Clarke, P.J. et al., 2011*). Other factors which can positively influence walkability are: access to relevant services within walking distance, a mix of different land uses, connectivity of streets, a clean environment, good quality of pavement, low traffic, green spaces, seats to take a rest, safe intersections, etc. (*Sugiyama, T., 2007, Hunter, R.H. et al., 2011, WHO, 2007*).

This thesis will give more insight in the objective and subjective barriers that elderly people face when they move outdoors into the city. It will also show the accessibility by foot of services important to the elderly in relation to the living locations of these elderly people. The maintenance state of public space is excluded from this study. The reason is because problems with the maintenance state are only registered for recovery purposes. This means that the available registrations only contain maintenance problems that are either solved already or that will be solved shortly. Therefore, this data does not provide information about locations with insufficient maintenance.

2.6 Municipalities need monitoring tools to support policy implementation

According to the Dutch law on public health, municipalities are responsible for implementing independent living. To be able to implement independent living, they need reliable information about the current and desired accessibility of services relevant to elderly people. This is difficult to achieve without monitoring tools.

Several programs aim at the suitability of dwellings so that the elderly can live independently. These programs aim at monitoring the suitability of dwellings for independent living based on the interior and accessibility of the building (*SEV, 2012*). However, to the knowledge of the author, no monitoring tools exist to test the suitability of public space for the elderly who live independently.

GIS-techniques can reveal the relationship between objects and people within a certain area. Therefore, GIS-supported spatial analysis can provide better insight into the challenges that need to be conquered related to accessibility of services and suitability of transport networks in public urban space. As a result, this thesis aims to develop a methodology that makes monitoring of these challenges possible.

3. Methodology

To determine the methodology of this research project, the research questions were converted into actions. Firstly, the focus group and spatial boundary of the project were determined. Next, a thorough literature study was performed to find out which spatial characteristics influence the accessibility of a city for elderly people with physical limitations. It was also investigated which facilities in a city are most relevant to be accessible by elderly people with physical limitations.

The characteristics found from literature were then translated into measurable parameters using GIS techniques. Thirdly, necessary datasets were either collected or derived from broadly available registers. The datasets and parameters were transformed into a methodology that analyses accessibility of services by elderly people with physical limitations. Using this methodology, it was possible to locate where relevant facilities in the city are well or less accessible for elderly people with physical limitations.

The impact of the accessibility was modelled by comparing the living locations of the elderly with the accessibility of relevant services from those locations. To conclude, it was analysed which parts of the city could be made more accessible to the elderly with physical limitations.

The steps described above are specified in more detail below.

3.1 Focus group and spatial boundary of the research project

This thesis focuses on elderly people with physical limitations in the municipality of Rotterdam. Physical limitations are here defined as limitations that make it difficult to walk and perform daily tasks.

In this study, elderly people are defined as people from the age of 50 and older. The minimum age of 50 years was chosen to get an indication of the living locations of the elderly in the future since most people tend to stay where they live as long as possible (*Smets, 2012*). This means that the locations where people of 50 years in age currently live show an estimate of where people of 65 years in age will live in the future.

To the knowledge of the author, no registration that specifically contains the location of elderly people who live independently exists. Therefore, it was assumed that all elderly people could potentially experience physical limitations currently or in the future. As a result, the living locations of all elderly people of 50 years or older were taken into account in this research project.

The methodology developed in this project was tested on to the public space of the municipality of Rotterdam. This area is chosen for multiple reasons. The first consideration was the size of the city. Because of its size, the municipality of Rotterdam can be easily compared with other larger Dutch cities. Added to that, the municipality of Rotterdam contains multiple smaller and more isolated urban areas such as Hoek van Holland and Rozenburg. Because these areas are isolated, they can be compared with smaller cities as well. A last practical reason to choose Rotterdam was because the information was easily accessible since the author is an employee of the municipality.

3.2 Spatial characteristics influencing accessibility

An important part of the methodology being formed in this research project is the accessibility of public facilities by elderly people with physical limitations. To be able to implement accessibility in the methodology, it is necessary to determine which factors influence accessibility. Also, it was necessary to find out how these factors can be transformed into measurable parameters.

The factors that determine accessibility as described in literature, are:

- The distance that one has to travel to reach a certain destination
- The chosen form of transport
- The usability of the route, or in other words: how easy it is to take a certain route
- The attractiveness of a route, or in other words: how a route is perceived

These factors were extracted from literature and are described in more detail in the following paragraphs.

3.2.1. Distance to destination

The threshold in choosing to go to a certain location is for a large part determined by the travel distance. The longer the travel distance, the less likely it is that one is willing to take the journey. Walk Score (2011) and TNO (2004) described a distance decay or gravitation function based on travel surveys. TNO based its distance gravitation function on the feedback it received from the elderly in the Netherlands. Although the decay function by Walk Score is based on people in general, both TNO and Walk Score showed similar results.

Walk Score is validated by multiple studies as a reliable method for the estimation of walkability of amenities (*Lucas J. et al. 2010, Duncan, T. et al. 2011 & 2012*).

However, although the two gravitation functions are similar, the most probable walking distance travelled by elderly people as described by TNO, is shorter than the overall average as described by Walk Score. This means that, in average, elderly people are willing to walk shorter distances than younger people. Because the gravitation function of Walk Score would show a too optimistic estimation of the probable walking distance by the elderly, it is chosen to use the distance gravitation function of TNO in this research. The figure below shows a comparison of both functions. The gravitation function of TNO was normalised to be able to make the comparison with the function of Walk Score.

The gravitation score can be explained as the willingness to walk a certain distance. For example: approximately 95% of elderly people is willing to walk a distance of 250 metres (m), according to the gravitation function of TNO.

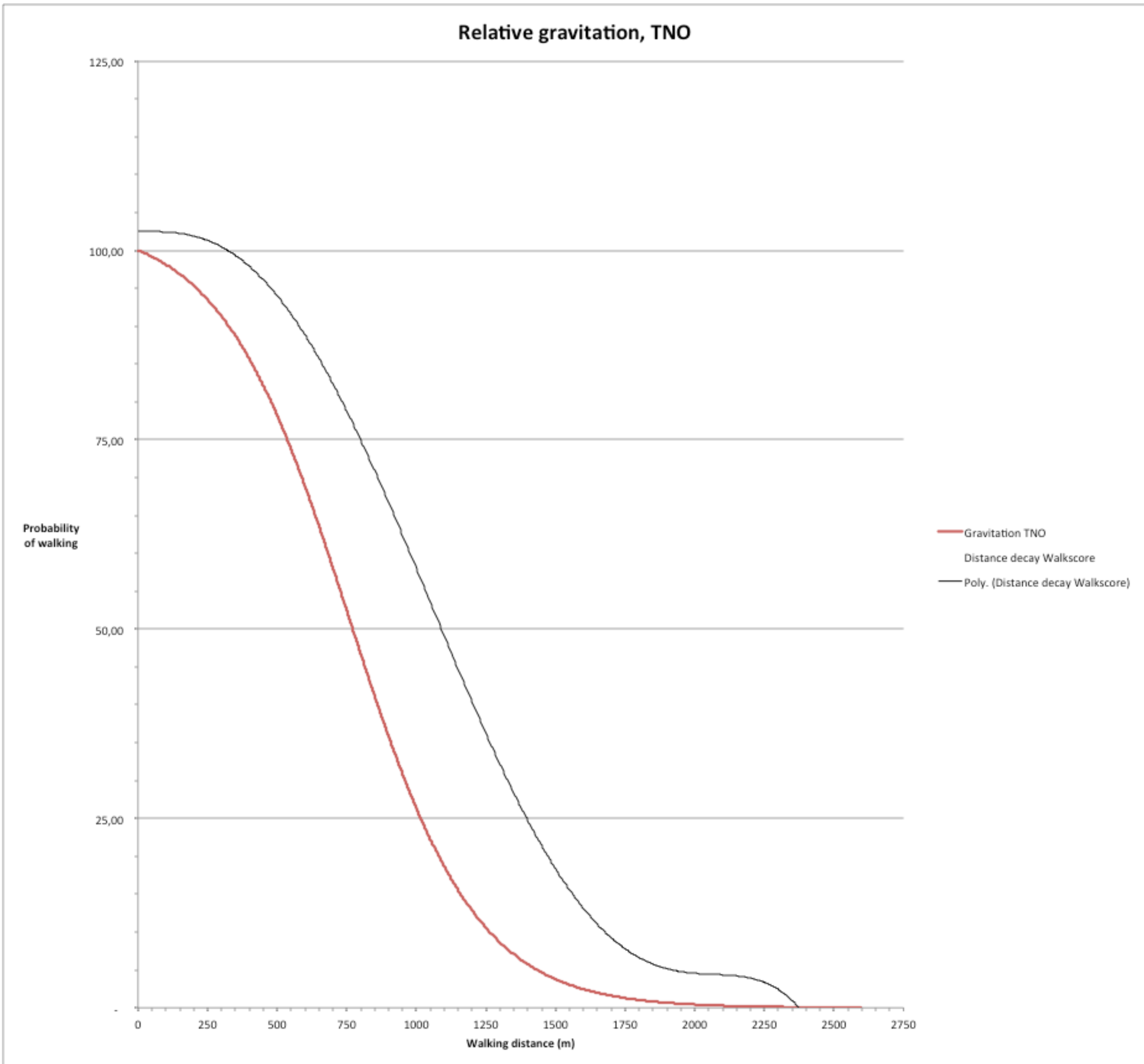

Figure 3.1: Normalised distance gravitation function by Walk Score ™ (2011) and TNO (2004)

The absolute gravitation function of TNO (2004) can be calculated using the following formula:

$$g(d) = 2{,}0 / (1 + 0.036\, e^{0.0044d})$$

where:
g = gravitation
d = distance in metres

In this study, the gravitation was converted to a relative gravitation score from 0 to 100 by dividing all gravitation scores by the gravitation of 0 m, which equals approximately 1.93. A relative gravitation score of 100 represents a high willingness to walk the distance. In this case, it is expected that all elderly people are willing to walk the distance. When the gravitation becomes lower, so does the willingness to walk the distance. At a relative gravitation close to 0 the number of people who are willing to walk the distance is negligible.

3.2.2. Choice of transport

The choice of transport is also related to the distance travelled. People are more likely to travel short distances by foot, while longer distances are likely to be travelled by car or mobility scooter. Literature study showed that both mobility and health are positively related with the walkability of urban areas. Since mobility and health both influence the ability for elderly people to live independently, it was chosen to focus solely on transportation by foot in this study. In this study, transportation by foot includes using a walking cane, walker, walking rack or wheel chair.

However, although this study aims at walkability, this chapter also gives a short description of transport by car or mobility scooter. This is to show how other ways of transport could be implemented in the methodology using an approach similar to transportation by foot.

Accessibility by foot or walking device

The accessibility by foot or walking device is measured from the living location of the elderly to the necessary facilities. The action radius is a key factor here. After all, it is no use making parts of the city more accessible if they do not fall inside the action radius of the target audience anyway. This research uses the distance gravitation function of TNO (2004) as explained in paragraph 3.2.1.

The pavement is the used network for this way of transport. However, not all pavements are accessible, especially for walking devices such as walkers or wheel chairs. Cliëntenbelang Utrecht (2012) describes the criteria that should be met for pavement to be accessible to people with and without physical limitations.

These criteria include a range of minimum widths for pavement, namely:

- 1.2 m, excluding the curb, for standard pavement.
- 1.8 m, excluding the curb, for intensively used pavement. Intensively used is classified as pavement near shops, schools, special living facility or if it functions as a connecting route.
- 0.9 m, excluding the curb, for local narrowing of the pavement.

The upper minimum widths are excluding the curbs. Pavement in the large scale base map is registered including curbs and these curbs are not registered separately. Therefore an assumption had to be made about the minimum curb width to be able to translate the upper minimum widths (excluding the curb) to widths that include the curb. The assumption was made that the average curb width is 15 centimetres (cm). The widths described above were adjusted by adding 15 cm. This leads to the following minimum widths:

- 1.35 m for standard pavement.
- 1.95 m for intensively used pavement.
- 1.05 m for local narrowing of the pavement.

The adjusted widths were used to model the potential accessible pavement for the elderly with physical limitations. This was modelled as follows. All the pavements of Rotterdam were selected and all features were dissolved. Then, a negative buffer of half the desired width (1.35 m → 0.675 m, 1.05 → 0.525 m and 1.95 m → 0.975 m) was created. On the resulting datasets, a positive buffer of the same distance (0.675 m and 0.975 m) was created. This process eliminates all pavement with a width that is less than the desired width. This is illustrated in the figure below:

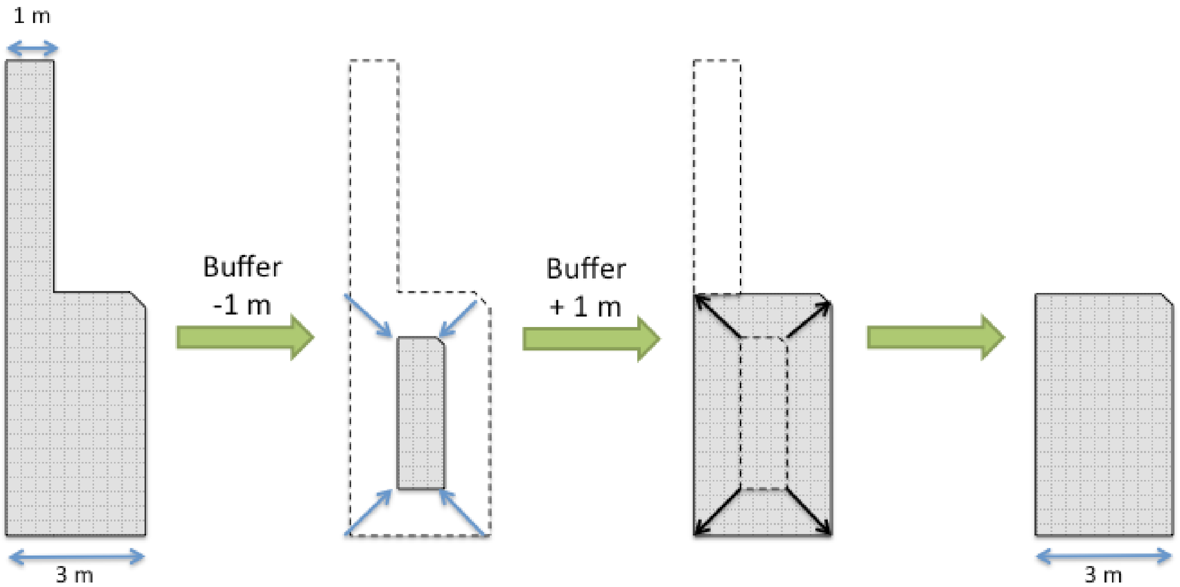

Figure 3.2: Using negative and positive buffers to filter out objects of a desired minimum width (2 m)

Accessibility by car

In this research, it is assumed that in a modern city such as Rotterdam, all parts are accessible by car. Thus by looking at the accessibility of services by foot from a parking space it can be verified which parking spaces provide good and which provide bad access to relevant services. This can be specified further by looking specifically at the locations of handicapped parking spaces. However, this falls outside the scope of this research project.

Accessibility by mobility scooter

Mobility scooters are allowed to use both the pavement and bike lanes. The requirements on the pavement correspond with the requirements for walking or when using a walking device (*Cliëntenbelang Utrecht, 2012*). Therefore, the same pavement transport network can be used, supplemented by roads that are accessible to bikes. The roads that are accessible to bikes can be extracted from the Small Scale Base Map (Kleinschalige basiskaart) by selecting actual bike lanes and streets, which are not main roads, that allowed mixed traffic.

Moreover, the action radius is expanded that people travel longer distances by mobility scooter, as compared to walking. However, to the knowledge of the author, no studies relating to the action radius of people travelling by mobility scooter were performed.

This study aims to develop a methodology to model accessibility of relevant services for the elderly by foot. However, the methodology for modelling accessibility by mobility scooter will match that of modelling accessibility by foot when bike lanes are added to the transport network and the action radius is expanded. Since changing the input parameters of the model does not change the methodology, the chosen methodology is expected to be also applicable for mobility scooters.

3.2.3. Route usability

If a person will take a certain route will also be determined by how easy or how difficult it is to pass. This can be described as the usability of a road. Also, attractiveness of the route is relevant for the motivation to take a certain route (*Borst C. et al., 2008 & 2009*). While walking outdoors, elderly people with physical limitations face different challenges than younger people experiencing no physical limitations. The relevant barriers and attraction features were extracted from literature.

These barriers and limitations are described in further detail in the following paragraphs.

Barriers

Barriers can be objects of any kind that prevent a person to continue his or her route. These objects can be defined as obstructions blocking the pavement. These obstructions provide the consequence that pedestrians need to change their route either by going back, or by moving to the main street. For elderly people with physical limitations, this might prove difficult.

Fixed objects above ground on the pedestrian area are assumed to be barriers that potentially block the passage of people with physical limitations. In this research, the following barriers were taken into account:

- petrol pumps
- bollards
- cabinets
- monuments
- parking meters
- trees
- billboards
- traffic signs
- phone booths
- city lights
- green elements
- play furniture
- street furniture
- wild grilles
- hedges
- containers
- staircases

Staircases are assumed to be barriers since they are not accessible for people using either walking devices. This was implemented by excluding staircases from the transport network.

The objects described above were extracted from the Large Scale Base Map (Grootschalige Basiskaart [GBKN]) and the Management System of Public Space of the Municipality of Rotterdam (Beheersysteem Buitenruimte [BSB]). As can be concluded from the list above, only fixed objects are included in this analysis.

Besides these fixed objects, movable objects such as parked bikes or mopeds could form barriers as well. However, since the location of these objects varies, it is chosen not to include these in this research.

This means that in certain areas, where many movable objects are present, the results could be too optimistic. However, when information about these movable objects is available they can be included in a similar manner as the fixed objects. In other words, the chosen methodology can easily be expanded with extra barrier information.

Chance that an object forms a barrier:

The minimum pavement width for local narrowing of the pavement as described in the criteria by Cliëntenbelang Utrecht (2012) is used in this research. This means that when there is less than 1,05 m accessible pavement surrounding a barrier object, it becomes an actual barrier that prevents passage for people with physical limitations.

The objects in the dataset (GBK) used for modelling the barriers have a spatial accuracy range between 5 cm and 50 cm, depending on the dataset. Therefore, the analysis method takes this spatial accuracy error into account.

The range width in which objects in the pavement can become barriers is calculated as follows when taking the positional error into account:

$w_{min} = d_{pass} + d_{poserr}$
$w_{max} = 2 * w_{min}$

w_{min} = minimal pavement width in metres
d_{pass} = minimal passing distance in metres
d_{poserr} = positional error distance in metres

If an object is positioned on the pavement with a width equal or less than w_{min}, it will certainly form a barrier. The chance of an object becoming a barrier reduces when the pavement is wider than w_{min}. When the pavement is wider than w_{max}, it is certain the object will not form a barrier. The figure below shows the difference between w_{min} and w_{max}.

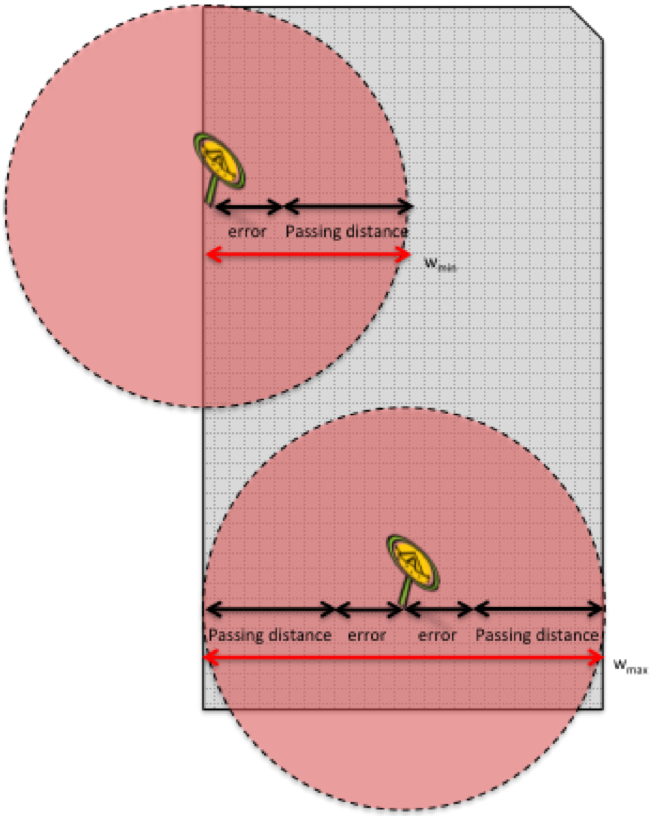

Figure 3.3: Determining w_{min} and w_{max} for potential barrier objects on pavement

The maximum spatial error of the dataset used for barriers is taken in this research to determine the change of an object becoming a barrier. Following the formula above this means:

w_{min} = 1.05 + 0.50 = 1.55 m
w_{max} = 2 * 1.55 = 3.10 m

This means that an object will certainly form a barrier if it stands on a pavement narrower than 1.05 m. If the object stands on a pavement wider than 1.05 m and narrower than 3.10 m, there is a chance that it will form a barrier. If the pavement is wider than 3.10 m, objects no longer form barriers.

3.2.4. Route attractiveness

Route attractiveness is an important criterion that determines a person's preferable route. However, the criteria are often subjective such as the presence of loitering youth or a dull or scary surrounding. To be able to monitor these subjective parameters, it is necessary to enquire local people on how they experience certain locations.

Since this study's scope is limited to using existing registers, it is chosen to limit the analysis to the physical accessibility of services. This will give an objective impression of the accessibility, which might be too optimistic for certain areas. However, city planners can refine this objective impression afterwards by adding knowledge about the attractiveness of certain areas or routes.

As a guide for city planners and policy makers, a literature study was performed on the objective and subjective criteria for route choice by elderly people. The results of this inventory are shown in Annexes 1 and 2. This inventory also includes if the criterion has a positive or negative influence on the route choice.

3.3 Important facilities (destinations) for the elderly

Next, it was important to find out the most important travel destinations of elderly people. These destinations were extracted from literature and can be found in Annex 5. The column "data source" describes the data source that is used for this study. If the data source was "unknown", no general registration was found and the destination was excluded from this study. This means that some relevant destination types are missing from the analysis.

Because this would result in an incomplete picture of the availability of important facilities for elderly people, it must be possible to add new destination types for future analysis. Therefore, the methodology allows to expand the number of destination types. Thus when information about missing destination types becomes available, this information can easily be added to the analysis.

The categories of Walk Score (2011) are used as guidelines for this study. However, not all categories were representing important destinations for the elderly as could be concluded from literature. In literature, the Walk Score category "schools" was not found to be a relevant destination for the elderly. This was to be expected since the elderly generally have no children going to school. Also, destinations that fit in the category "entertainment" were not mentioned in the literature available during this research project. It is for these reasons that these categories were excluded from the analysis.

It is also important to note that certain destinations did not fit into the categories of Walk Score, since Walk Score provides categories for people in general and not for elderly people specifically. Therefore, this research added six categories. Since no information could be found from literature about the importance of one destination type over another, the destination types were categorised based on global similarities. This means that a family doctor and a pharmacy fall in the same category (care). Once other studies show which destination types are less or more important, the chosen categories can be revised and different weights can be added to the different destination types.

The categories currently chosen for this study are shown in table 3.1. The table shows which categories were included in the Walk Score methodology, which were added and which were used in this study.

Table 3.1: destination categories included in this study

Category	Included in Walk Score?	Used for study
Grocery	Yes	Yes
Catering**	Yes	Yes
Shopping	Yes	Yes
Banks	Yes	Yes
Parks	Yes	Yes*
Schools	Yes	No
Entertainment	Yes	No
Government	No	Yes*
Care	No	Yes
Daily facilities	No	Yes*
Exercise	No	Yes
Recreation	No	Yes
Transport	No	Yes

* No base register was found that contained the necessary data. Therefore it was not implemented as a parameter in the final model.
** The categories coffee and restaurants are separated in Walk Score. However, since most catering facilities serve both coffee and meals, it is decided to treat them as one category named 'catering' in this study.

The separate destination types belonging to each category are shown in Annex 5. The registers used for the destinations in this study were the National Business Register (Bedrijvenregister) of 2011 and the Public Transport Open Data Service (Open OV). These registers were chosen because they are broadly available in the Netherlands, are frequently maintained and cover the whole country.

The business register was received as a .dbf file containing x,y-coordinates which was converted to a feature class that could be used in ArcGIS. The unique descriptions were extracted as a table and a selection of shops and facilities was made based on the given descriptions. The selections that were used to make subsets per category are included in Annex 5 in the column "selection criteria".

The public transport stops were received as separate KML files with lat lon coordinates. The KML files were merged and converted to a point feature class that could be used in ArcGIS using the Rijksdriehoekstelsel projection.

3.4 Setting up the accessibility analysis methodology

To model the accessibility of relevant services for the elderly, the methodology of Walk Score (2011) was explored. The methodology of Walk Score is directed at determining the walkability of certain locations to relevant facilities. For example, Walk Score takes one address and determines which and how many facilities are within walking distance of that address.

However, a limitation of Walk Score is that it treats distance as is seen "as the crow flies", instead of using street patterns. The algorithm used does not take barriers into account. In addition to that, Walk Score does not take health care facilities into account, which are an important type of facilities for the elderly. Finally, Walk Score states that the information about the location of services outside the United States is unreliable.

Following the arguments above, it can be concluded that the Walk Score methodology is not directly applicable to map accessibility by the elderly for a whole city in the Netherlands. Therefore, a different methodology that includes barriers was necessary. The so called "Cost Weighted Distance" gives the opportunity to model accessibility by foot, while including barriers. It is a raster-based method that uses a dataset with origins and destinations. An underlying cost raster models which areas are more or less accessible. In the cost raster, a raster cell gets the value ‘1’ when it is well accessible. If a cell is inaccessible, it gets no value.

The methodology consists of the four following steps. Firstly, a transport network was generated. Secondly, a cost weighted distance analysis was performed for each destination type, using the generated network. Then the cost weighted distance maps were converted into walking gravitation scores for each destination type using the formula of 3.2.1. Finally, the separate walking gravitation maps were combined to form a mean walking gravitation map of all destination types. This final map shows the overall accessibility of the city by elderly people in relation to the diversity of available facilities.

These steps are further explained in the next paragraph.

Why a raster-based over a vector-based approach?:
Accessibility can both be modelled using a raster-based and a vector-based network. A vector-based approach has the advantage to include multiple attributes to network segment. For example, one could include information about maximum speed, direction, resistance, allowed height, weight, etc. This is very useful when modelling transport by vehicles where certain limitations need to be taken into account. Vector-based networks are very well suited for finding the shortest route from a certain location to a certain destination.

However, for this study, the shortest distance to one specific location is not relevant, but the accessible area from a certain destination type is. Also, for transportation by foot, there are less variables to take into account. For example, people walk in whatever direction they choose, making the inclusion of direction unnecessary. Also speed limits do not apply to pedestrians. In fact, a transport network for pedestrians does not need more attributes than being either accessible (value = 1) or not (value = None).

One advantage of the raster-based approach is that also large open areas can be easily included in the accessibility analysis. This would be difficult using a vector based approach, since a vector-based network consists of centre lines only. What adds to the complexity is that the dataset containing pedestrian roads consists of surfaces (polygons). It requires much manual adjustments to convert surfaces to an interconnecting vector-based network for a whole city. By using a raster-based approach, it is possible to convert the surfaces to a raster dataset in a more direct way.

Because a vector-based approach adds complexity to the model without enriching it, the raster-based approach was chosen over a vector-based approach for this case study. The most important reason is because it is more suitable for modelling walkability in all directions. Added to that, the creation process of a raster-based network is more practical in the given time frame of this research project, when the available datasets consists of surfaces. Also the raster-based method gives the possibility to quickly convert distance to gravitation scores.

3.4.1. Generating the transport network

The relevant network for transport by foot and walking device is the pavement. The pavement was selected from the Large Scale Base Map of Rotterdam (GBKR). Besides the pavement, bridges and paths were also included in the transport network, since pedestrians also use them.

The network was enriched with information about the minimum width and the presence of potential barrier objects. To test the sensitivity of this approach, three network scenarios were created, based on the following assumptions:

1. Best-case scenario: This network only contains the pedestrian roads that are wide enough. Only objects of which it is sure that they will form barriers are taken into account. Therefore, there is a chance that some pedestrian roads still contain static barriers. This scenario is the most realistic scenario, since it includes both the necessary road width for pedestrians to be able to pass and the possibility that objects form barriers.

2. Worst-case scenario: This network only contains the pedestrian roads that are wide enough and that certainly do not contain static barriers. This scenario assumes that every possible barrier is an actual barrier for pedestrians. However, in reality, objects will not always form barriers. Therefore, this scenario is expected to be less realistic than the best-case scenario.

3. Control scenario: This network consists of all available pedestrian roads without taking demands for width or barriers into account. This scenario is added to test if the approach for modelling barrier objects influences the results.

A comparison of the outcome of the different scenario will indicate the reliability range of the chosen methodology.

The networks described above were based on the chance of barriers being present. This was analysed using the width of pedestrian roads and the presence of static objects. The width of pedestrian roads was determined using the buffer approach as described in 3.2.2. The chance of barriers was analysed following the approach as described in 3.2.3. This was achieved by determining if a road segment of a certain width intersects with a barrier. The possible scenarios for a road segment are listed below:

Table 3.2: Composition of networks per scenario considering pedestrian roads and the chance of barriers based on width and the presence of static objects

Minimum width in cm	Objects	Pavement is	Included in scenarios
310	No	Wide enough and no chance of barriers	Control, Best-case, Worst-case
310	Yes	Wide enough, but small chance of barriers (if objects are placed close together)	Control, Best-case, Worst-case
155	No	Wide enough and no chance of barriers	Control, Best-case, Worst-case
155	Yes	Wide enough, but reasonable chance of barriers	Control, Best-case
105	No	Wide enough and no chance of barriers	Control, Best-case, Worst-case
105	Yes	Wide enough, but objects certainly form barriers	Control
<105	No	Road is too narrow and therefore is a barrier in itself. However, there are no objects present.	Control
<105	Yes	Road is too narrow and therefore is a barrier in itself. Each object forms a barrier as well.	Control

All the networks were transformed into a cost surface raster, where accessible cells were given the value of “1” and inaccessible areas were given no value. The cell size of all network grids was 5x5 m. It was first attempted to perform the accessibility analysis on a grid with a cell size of 1x1 m for maximum accuracy. However, system limitations prevented the possibility to analyse the whole city of Rotterdam using this high resolution. Therefore, a cell size of 5x5 m was chosen. Compared to a cell size of 1x1m, it delivered very similar results, which was verified by a visual comparison of the gravitation maps for one district of Rotterdam.

When using a cost weighted distance approach, it is important that the raster network has no interruptions. This formed a challenge, since pedestrian roads are often interrupted by intersections. Also, the cost surface raster needed to take into account that people can cross roads at those intersections or even from one side of the road to the other. This was achieved by calculating a buffer around the pedestrian network. It was assumed that pedestrian roads at intersections would not be further apart than 20 m. Therefore, a buffer distance of 10 m was chosen. This buffer distance resulted in a continuous network, without connecting pavement where it was not likely to be able cross to the other side. The figure below shows a combination of the actual pedestrian roads (green and red) and the cost surface raster (grey).

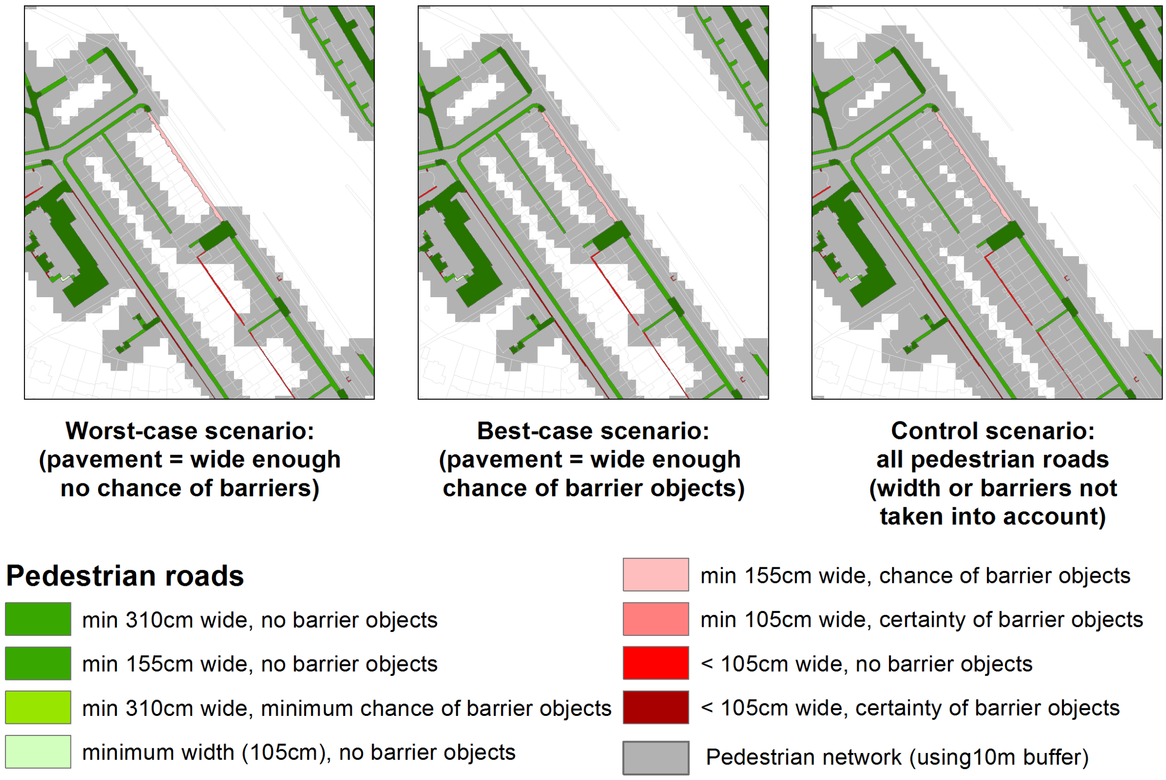

Figure 3.4: The travel networks following the three scenarios: worst-case, best-case and control

The figure above shows that the assumed buffer of 10 m ensures that a continued cost surface raster is formed at places where people can cross the road. The figure also shows the differences in the network among the three scenarios.

The control scenario on the right shows a network with all pedestrian roads included, without taking barriers into account. The worst-case scenario on the left shows a network that contains only the pedestrian roads that are wide enough and where no objects are present. The best-case scenario in the middle shows a network of the pedestrian roads that consists of roads that are wide enough. In this case however, there is still a chance that objects might form barriers. Annex 10 shows a larger example of analysis results on pedestrian roads width and potential barriers.

3.4.2. Determining the cost weighted distance per destination type

To determine the accessibility of each service type for the whole municipality of Rotterdam, a cost weighted distance map was generated. This was carried out for each destination category and for each of the three networks using ArcGIS 10 model builder. The used ArcGIS models can be found in Annex 7.

To keep the generated data from the cost distance analysis manageable, the distance was calculated from the destinations instead of the origins (home addresses) with a maximum distance of 3000 m. This maximum distance was based on the research from TNO (2004) and Walk Score (2011) where they concluded that the number of people who are willing to walk more than approximately 2500 m is negligible.

The destinations were not always directly connected to the pedestrian network because of spatial accuracy differences between the datasets. To be certain that the destinations were connected to the transport network, each destination was converted into a raster cell of 50x50 m. In this case the assumption was made that the first 25 m surrounding a service is accessible by foot. The figure below shows a schematic version of the process to generate a cost weighted distance raster based on a network, barriers and destinations.

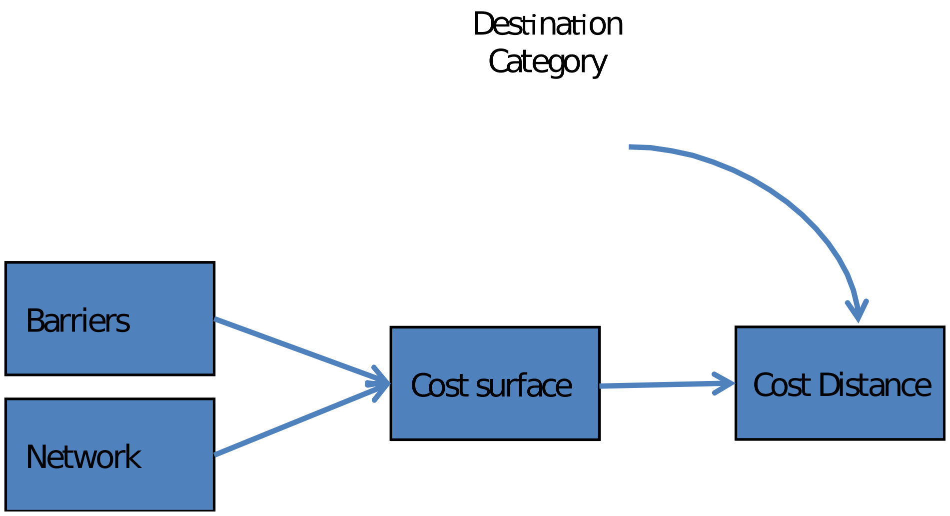

Figure 3.5: Methodology cost distance analysis

The resulting cost distance rasters represent the walking distance on a certain location from each type of destination.

3.4.3. Determining the walk gravitation per destination type

To get an indication of the willingness to walk a certain distance, the cost distance maps needed to be transformed into walking gravitation maps. Therefore, each of the “cost distance maps” was converted into a walking gravitation map to gain insight in the general accessibility of a destination type for the elderly with physical limitations. This was achieved by using the gravitation formula of TNO (2004) on each cell of the cost distance maps as described in 3.2.1. The gravitation maps per destination type can be found in Annex 3.

3.4.4. Determining the mean gravitation

To get an overview of the accessibility of relevant services for the elderly, the separate “gravitation maps” were combined into a mean gravitation map. This was performed for each of the three scenarios by using the “Multi-criteria” approach. This approach summarises the different destination maps and computes the mean value for each raster cell. The resulting mean gravitation map shows which areas are well equipped with relevant services accessible for the elderly and which areas are not. The figure below shows a schematic presentation of this process. The mean gravitation maps can be found in Annex 4.

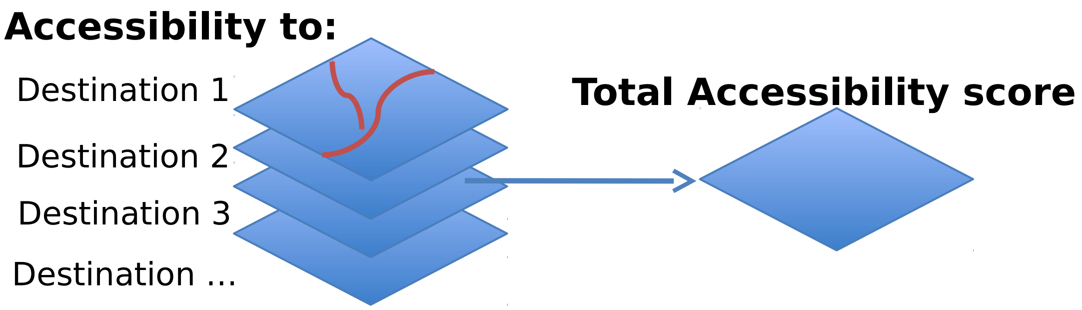

Figure 3.6: Methodology for calculating a total accessibility score using the multi-criteria method

In the multi-criteria analysis, all destination types were given the same weight, since no information was found in literature about the importance of one destination type over another. In future studies, weights can be added to each destination type when this information becomes available.

Combining the gravitation maps of the different destination types resulted in one overall gravitation map per scenario. This means that the gravitation map summarises the global accessibility for the elderly for each location.

3.4.5. Matching the gravitation maps with the living location of elderly

The mean gravitation scores were matched with the living locations of the elderly by spatially joining them with the transport network using a maximum search radius of 25 m. The maximum search radius was based on the fact that paths on private property are not registered in the Large Scale Base Map (GBKN). This means that the living locations of the elderly sometimes fall outside the covered area of the travel network. To overcome this, the assumption was made that the distance between a house and the public space could be up to 25 m. This is a plausible distance for a Dutch city. However, in other countries or in more rural areas the average distance from a house door to the street might be larger. The assumed maximum distance of 25 m between the street and a house is illustrated in figure 3.7.

The Statistics Office of Rotterdam provided a table of the age of every person in the municipality per address with 1 January 2013 as the reference date. The addresses were geocoded using the address location file of the municipality. 394 addresses were missing coordinates which meant that 254 of 614,647 persons could not be located (0.04%). This resulted to 18 persons of 50 years or older out of a total of 187,973 people of 50 years or older (0.01%) not being located.

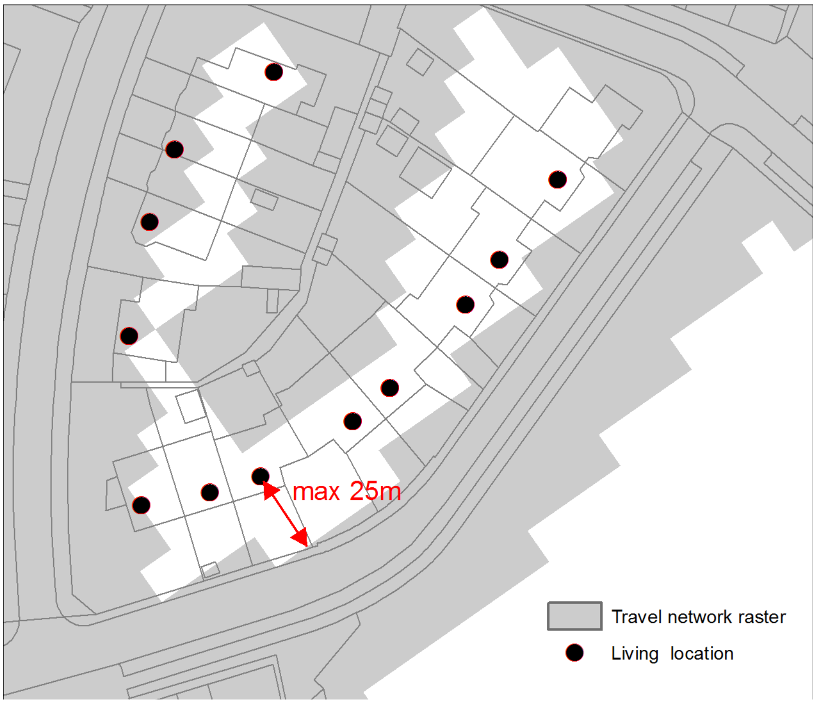

Figure 3.7: Example of living locations of the elderly that do not match the travel network

3.5 Determining validity and reliability of the methodology

To validate the chosen methodology, both the accuracy of the data and the impact of the chosen parameters on the results were analysed. Based on this analysis, suggestions were made for further improvements to the methodology and datasets. This analysis is described in more detail in the following paragraphs.

3.5.1. Accuracy of the data

Not all used datasets had the same spatial accuracy. There were also differences in actuality of the available datasets. Therefore, some adjustments needed to be made to the methodology.

The pedestrian roads were extracted from the Large Scale Base Map (Grootschalige basiskaart), which has a spatial accuracy of 5 cm. Therefore, the minimum width could be determined with reasonable accuracy and no adjustments on the methodology were necessary.

The potential barriers were extracted from a subset of the Large Scale Base Map. This subset had a spatial accuracy of 5 to 50 cm. Because of this limited spatial accuracy, it was not possible to exactly determine if an object forms a barrier on a pedestrian road. Therefore, it was chosen to determine the chance that an object forms a barrier, following the method as described in 3.2.3. The sensitivity of this approach on the outcome of the analysis was tested following the scenarios: worst-case, best-case and control.

The spatial accuracy of both the business register and the public transport stops from Open OV were not known. Based on a visual inspection, it was determined that by converting the locations to a raster size of 50x50 m, the connection with the transport network was assured.

3.5.2. Completeness of the data

No specific tests were performed on the completeness of the data. However, the Large Scale Base Map of Rotterdam is updated on a daily basis with an actuality of 2 months. Also, the Business Register of the Netherlands is updated on a daily basis. The website of Open OV (openov.nl) does not describe the completeness of the data. However, it also provides real-time information and receives its information directly from public transport companies. Therefore, it is assumed that the data provided is complete.

3.5.3. Sensitivity of chosen parameters

The reliability of the way that barriers are modelled was validated. Because of limited accuracy of barrier data, only the chance that an object forms a barrier could be determined following the method as described in 3.4.1. Using the three network scenarios (worst-case, best-case and control) it was determined how the chance of barrier objects affects the outcome of the analysis.

To determine the sensitivity of the methodology, the overall difference among the scenario outcomes was analysed for one district in Rotterdam. Also, the mean gravitation outcomes for Rotterdam were compared spatially to get an indication of the spatial variety between scenarios. The results of this sensitivity test are described in more detail in 4.6.

Importance of facility types:
The current methodology does not take into account the importance of different categories of facilities. This means that facilities that are low in number have a relative large impact on the outcome of the mean gravitation scores, even if they are less important than other service types. For example, daily facilities such as a grocery store might be more important to be situated at walking distance, while it is less important to have a hospital situated at walking distance. This means that the results of the current methodology will show somewhat distorted mean gravitation scores, because importance of different destination types were not taken into account.

However, in future studies, the different facilities could be given weight based on their importance to be within walking distance. However, to the knowledge of the author, no literature was available on that subject. Information about the importance of different service types can also be gathered by performing surveys among elderly people. However, this falls outside the scope of this thesis.

3.6 Assumptions

During the development of the methodology, some assumptions had to be made. In general the used datasets were assumed to be complete and accurate. The GBKN road network was expected to form a complete picture of all pedestrian roads in Rotterdam. Also, an assumption on the curb width was necessary to be able to transform the minimum pavement widths as described by Cliëntenbelang Utrecht (2012). The proposed minimum pavement widths by Cliëntenbelang Utrecht excluded the curbs. Because the pavement in the GBKN road network includes curbs, the curb widths were assumed to have an average width of 15 cm. In reality, the curb widths will vary between 10 and 30 cm. Also, the objects that were extracted from the GBKN as potential barrier were expected to give a complete view of all fixed objects that could form barriers.

This research project aims to gain insight in the accessibility of important services by foot for elderly people with physical limitations. Since the chance of physical limitations increases with age (*CBS, 2012*), it is assumed in this research that every elderly person could potentially experience physical limitations, currently, or in the future. Physical limitations in this research can be described as limitations in the capability to walk. The literature study showed a strong relation between the mobility of elderly people and the walkability and design of public space. Therefore, in this study, it is assumed that the number of relevant services that are accessible by foot stimulates mobility and thus health.

For the network analysis, it was necessary that the pedestrian roads formed a closed network. Since the pedestrian roads are separated by intersections an artificial connection had to be made. This was achieved by assuming that, when the pedestrian roads were no further than 20m separated, one could crossover from one road to the other.

The gravitation maps were matched with the living location of the elderly. Since the generated travel network did not directly connect to the home addresses of elderly people, it was assumed that the distance between the home address and the street was no further than 25 m. Because the spatial accuracy of the different destination types was not exactly known, it was anticipated that the accuracy fell within 50x50 meters. Therefore, the destination types were converted into raster cells of 50x50 meters.

The destination types were partly categorised following Walkscore. However, the destination types that could not be placed into one of the Walkscore, had to be placed in new categories. These categories were formed by educated guess and based on global similarities of the destination types. This means that both hospitals and family doctors were placed in the same category “care”.

3.7 Scope and limitations

This study aims to develop a methodology that helps gaining insight into the accessibility of public space. Therefore, private space and house interior or exterior fall outside the scope of this research. This is justified by the fact that this is already covered in by other research *(SEV, 2012)*. Also the research is limited to accessibility by foot, since other studies showed this has the largest impact on mobility and therefore health (*Montero-Odasso, M. et al., 2009, Jacobs, M. et al., 2008, Clarke, P.J. et al., 2011)*.

The target group of this research is limited to elderly people of 50 years and older who have physical limitations. This age limit was chosen, because Statistical data from the Central Statistics Bureau of the Netherlands (statline, CBS) shows that the demand for health care increases from age 50 and up. This is further supported by other studies that show that ageing is strongly linked with the need for health care (Caley, M. & Sidhu, K. 2010, Denton, F.T. & Spencer, B.G., 1999 and Martini, E., 2007). The minimum age of 50 years was chosen to get an indication of the living locations of elderly in the future, since most people tend to stay where they live as long as possible (*Smets, 2012*).

Since no registration of people with physical limitations exists, this research states that all elderly people might experience physical limitation, now or in the future. Therefore, all the living locations of people ageing 50 years and older were included in this study.

One of the goals of this study was to develop a methodology that is reusable for other cities. Therefore, broadly available datasets were used as much as possible. Further, the limited time-frame of this thesis did not allow to perform interviews with elderly people. This means the outcomes of the developed methodology could not be tested against gathered field data. However, the developed methodology can function as a proof of concept that can be further expanded with knowledge gathered in future studies.

4. Results

The methodology described in chapter 3 was implemented using ArcGIS software. This chapter describes the results from this research project by answering the research questions from Chapter 1.

4.1 Which spatial characteristics support accessibility of the public space for elderly people with physical limitations?

A literature study was performed on the spatial characteristics that influence accessibility of public space for elderly people with physical limitations. From this study it became clear that the accessibility of public space is influenced by multiple factors.

The first characteristic is the distance to a destination, which can be translated to the willingness to travel a certain distance. (Elderly) people are only willing to travel a certain distance by foot. Once past a certain distance, the willingness to walk decreases significantly. Also, the choice of transport is a determining factor for accessibility. Namely, the distance that people travel by foot is shorter than when they travel using other forms of transport such as a mobility scooter or a car.

Next, there is the usability of a route, which is an objective characteristic. This can be translated to the physical barriers that people have to overcome to be able to travel a certain route. In practice, this means that the width of pavement roads and the absence of barriers are important to the usability and therefore accessibility of a route.

Also the attractiveness of a route influences accessibility. This is based on how attractive or unattractive people find a certain route, or location. The attractiveness can result from both objective and subjective factors. Examples of subjective factors are “feeling safe” and “beautiful surroundings”. Examples of more objective parameters are “parked cars” and “traffic volume”. Annexes 1 and 2 summarize both the objective and subjective parameters that influence the attractiveness of a route. However, because no measurement method for attractiveness could be found in literature, this variable was not implemented in the methodology described in this thesis.

Finally, it is important that relevant facilities for the elderly are within reach. Annex 5 summarises these facilities. This annex also shows which facilities were included in this study and which could not, since no appropriate register was available.

4.2 How can these characteristics be translated to measurable parameters using GIS techniques?

The accessibility factors “distance to destination”, “usability of the route” and “relevant facilities” were implemented as follows. The willingness to travel a certain distance by foot was implemented using the relative walking gravitation function from TNO (2004), which was based on travel surveys of elderly people.

The usability of the route was implemented by determining the width of the pavement and the presence of fixed barrier objects. The pavement width was implemented following the guidelines of Cliëntenbelang Utrecht (2012) using the method described in 3.2.1. Since the spatial accuracy of the fixed barrier objects was 0.5 m, it was not possible to define the exact location of these objects. However, the change that objects form barriers could be determined following the method described in 3.2.3.

The attractiveness of routes was not implemented, since no literature of measurable parameters could be found. Therefore, implementing attractiveness will remain a possible expansion of the methodology for future studies.

The location of relevant services was implemented by an expanded form of the Walkscore (2011) categories. However, not all relevant services could be found in the available registers. Therefore, not all relevant services could be implemented in the methodology.

Of each category, a cost weighted distance raster was calculated, which was then transformed into a gravitation map. These maps show the probability that elderly people are willing to travel the distance by foot to a specific service.

Three scenarios were chosen to test the sensitivity of the methodology for the way that barrier objects are implemented. These scenarios were:

1. <u>Best-case scenario:</u> This network only contains the pedestrian roads that are wide enough. Only objects of which it is sure that they will form barriers are taken into account. Therefore there is a chance that some pedestrian roads still contain static barriers.

2. <u>Worst-case scenario:</u> This network only contains the pedestrian roads that are wide enough and that certainly do not contain static barriers. This scenario assumes that every possible barrier is an actual barrier for pedestrians.

3. <u>Control scenario:</u> This network consists of all available pedestrian roads without taking demands for width or barriers into account.

For each of the scenarios, gravitation maps were created for each service category. The gravitation maps per scenario and service category can be found in Annex 3. Next, for each scenario, a mean gravitation map was computed that represented the total gravitation score for all included service types, which can be found in Annex 4.

The gravitation scale starts at 0, meaning: ‘no willingness to walk the distance’, and ends at 100 which means: ‘high willingness to walk the distance’.

4.3 Where do elderly people live independently in Rotterdam and which of the spatial characteristics found in the literature research are present there?

To the knowledge of the author, no registration exists that specifically contains the location of elderly people who live independently. Therefore, the living locations of all elderly people of 50 years or older were taken into account. Because of computational limitations it was not possible to analyse the whole municipality of Rotterdam. Therefore, one specific district was chosen for further analysis on the accessibility of services by foot from the living locations of elderly people.

The district that was chosen was Hillegersberg-Schiebroek. This district was chosen because it showed a mixture of areas with good and poor access to relevant services. In this district, the access to public transport, care and catering is above average. Elderly people who live in the centre can easily walk to the grocery store or recreation areas. However, if they live along the borders of Hillegersberg-Schiebroek they will need different ways of transport. Banks and locations to find books are only accessible from certain locations in Hillegersberg-Schiebroek., but again at the borders access to these services is poor. Shops and places to exercise are well spread over the district. Only the neighborhood “Terbregge” has poor access to these services.

4.4 Which parts of the public space have good or poor access to services for the elderly?

For each of the scenarios, gravitation maps were created per service category, which can be found in Annex 3. These maps show the areas with a gravitation above 50 in green, the areas with gravitation around 50 in yellow and areas with gravitation scores under 50 in red. This classification does not represent if an area has good or bad access to a specific service category, but it does show which areas score above or below average. These gravitation maps per service category were combined into mean gravitation maps, which can be found in Annex 4. Each service category is further discussed below.

Public transport stops:
Public transport stops show an even spread along Rotterdam. Consequently the access for elderly people to public transport stops is above average in most areas of Rotterdam. Only certain areas, such as ‘Overschie’, the northern part of ‘Kralingen-Crooswijk’ and the southern part of ‘Hoogvliet’ show gravitation scores of under 50 meaning that they are less accessible when it comes to public transport stops.

Groceries:
Locations where people can do groceries are less accessible for the elderly travelling by foot in comparison to public transport stops. However, in the centre of Rotterdam there are enough locations for groceries in the districts: ‘Delfshaven’, ‘Rotterdam Centrum’ and ‘Noord’. Nevertheless, the other districts are only partly accessible by foot for doing groceries. Especially the districts ‘Overschie’, ‘IJsselmonde’, ‘Hillegersberg-Schiebroek’, ‘Charlois’ and ‘Kralingen-Crooswijk’ show large areas with gravitation scores under 50.

Shopping:
Shops are evenly spread all over the municipality of Rotterdam. Only the districts ‘Overschie’, ‘Kralingen-Crooswijk’ and ‘Noord’ show relatively large areas with gravitation scores under 50, meaning that access to shops by foot is limited in these areas.

Books:
One can only find books at very specific locations in Rotterdam. This results in a gravitation score below 50 in most areas of Rotterdam, with the exception of the district ‘Delfshaven’ which shows a high gravitation. This means that currently most people need to find other ways of transportation to get their books.

Care:
There are many locations in Rotterdam where some type of care is provided. Most areas are within walking distance of a care service, which is shown in high gravitation scores. However, again the district ‘Overschie’ shows a large area that is badly accessible to care services, as indicated from the gravitation scores below 50.

Banks:
Banks are mainly clustered in the centre of Rotterdam. Especially the districts ‘Rotterdam Centraal’, ‘Noord’ and the eastern part of ‘Delfshaven’ show a high overall gravitation score. In other parts of Rotterdam, most people will need to find a different way of transport to go to their bank.

Recreation:
Recreational services are much lower in number, compared to shops or public transport stops. This type of service seems to be clustered at the centre of Rotterdam in the districts: ‘Noord’, ‘Delfshaven’ and ‘Rotterdam Centrum’. This results in high gravitation scores in these areas. The other districts in Rotterdam do have some recreational services, but they are only accessible by foot from a relatively small part of the district.

Exercise:
Most districts in Rotterdam have areas with gravitation scores under 50 for exercise. This is the result of an uneven spread of exercise facilities in Rotterdam. This means that accessibility by foot to a location where elderly people can exercise is limited in the areas of Rotterdam where gravitation scores are low.

Catering:
Rotterdam has many catering facilities which are evenly spread all over the municipality. This results in high gravitation scores for most areas in Rotterdam. Only the districts ‘Overschie’ and ‘Hillegersberg-Schiebroek’ show large areas with gravitation scores below 50.

Overall access to services (mean gravitation maps):
The service categories described above were combined into mean gravitation maps that show the average access to all service categories. These gravitation maps can be found in Annex 4. The districts 'Noord', 'Delfshaven' and 'Rotterdam Centraal' show the highest overall gravitation scores, meaning that these areas have the best access to services relevant to elderly people. In other districts, large areas show low gravitation scores, or low access to services. These areas include: ‘Pernis’, most of ‘Hoogvliet’, about half of the area of ‘IJsselmonde’ and large areas of ‘Overschie’, ‘Hillegersberg-Schiebroek’, ‘Prins-Alexander’ and ‘Charlois’. The district ‘Feijenoord’ shows an overall gravitation score of around 50.

4.4.1. Relationship between living locations of the elderly and gravitation score

For the district 'Hillegersberg-Schiebroek', the relationship was analysed between the living locations of the elderly and the access from those locations to relevant services. This was achieved by computing the average gravitation score per neighbourhood following the method described in 3.4.5. To get an indication of the effect of access to services on different age groups, this was done for the age groups: 55-65, 65-75, 75-85 and 85+. Also, the overall score for each neighbourhood was computed for all potential elderly people of the age of 50 years and older. This was done to get insight in the effect of access to services on all potential elderly people. The results for the separate age groups can be found in Annex 7. The following tables show the results for the living locations of people of 50 years or older for the different scenarios.

Table 4.1: Gravitation scores of living locations of people aged 50 and up in Hillegersberg-Schiebroek. Best-case scenario.

	Gravitation class									
Neighbourhood name	**0-10**	**10-20**	**20-30**	**30-40**	**40-50**	**50-60**	**60-70**	**70-80**	**80-90**	**90-100**
Hillegersberg Noord	6%	1%	2%	3%	3%	5%	28%	24%	29%	0%
Hillegersberg Zuid	3%	0%	0%	0%	1%	4%	2%	16%	61%	13%
Molenlaankwartier	7%	3%	0%	1%	6%	19%	38%	20%	5%	0%
Schiebroek	3%	1%	0%	0%	1%	2%	13%	38%	37%	5%
Terbregge	28%	13%	30%	21%	8%	0%	0%	0%	0%	0%
End total	**6%**	**2%**	**2%**	**2%**	**3%**	**6%**	**20%**	**26%**	**30%**	**3%**

Table 4.2: Gravitation scores of living locations of people aged 50 and up in Hillegersberg-Schiebroek. Control scenario.

	Gravitation class									
Neighbourhood name	**0-10**	**10-20**	**20-30**	**30-40**	**40-50**	**50-60**	**60-70**	**70-80**	**80-90**	**90-100**
Hillegersberg Noord	1%	0%	1%	4%	0%	9%	34%	25%	26%	0%
Hillegersberg Zuid	0%	0%	0%	0%	1%	4%	1%	16%	65%	13%
Molenlaankwartier	1%	0%	0%	2%	5%	15%	32%	31%	14%	0%
Schiebroek	0%	0%	0%	0%	0%	1%	11%	40%	42%	5%
Terbregge	17%	7%	16%	29%	31%	0%	0%	0%	0%	0%
End total	**1%**	**0%**	**1%**	**3%**	**3%**	**6%**	**19%**	**29%**	**33%**	**4%**

Table 4.3: Gravitation scores of living locations of people aged 50 and up in Hillegersberg-Schiebroek. Worst-case scenario.

	Gravitation class									
Neighbourhood name	**0-10**	**10-20**	**20-30**	**30-40**	**40-50**	**50-60**	**60-70**	**70-80**	**80-90**	**90-100**
Hillegersberg Noord	1%	0%	3%	2%	5%	19%	19%	25%	26%	0%
Hillegersberg Zuid	0%	0%	0%	0%	2%	2%	1%	18%	64%	12%
Molenlaankwartier	1%	0%	1%	4%	6%	12%	28%	38%	9%	0%
Schiebroek	0%	0%	0%	0%	0%	2%	14%	42%	37%	4%
Terbregge	19%	20%	27%	34%	0%	0%	0%	0%	0%	0%
End Total	**2%**	**1%**	**2%**	**3%**	**3%**	**8%**	**15%**	**32%**	**30%**	**3%**

Figure 4.1 shows the average distribution of gravitation scores per scenario. This figure shows that most elderly people live in areas with gravitation scores

between 60 and 90, which means that access to relevant services is above average. Only a small percentage of elderly people lives in areas where the mean gravitation is between 90 and 100. The percentage of elderly people that live on locations where access to services is below average (gravitation < 50) varies between 9 and 11%, depending on the scenario.

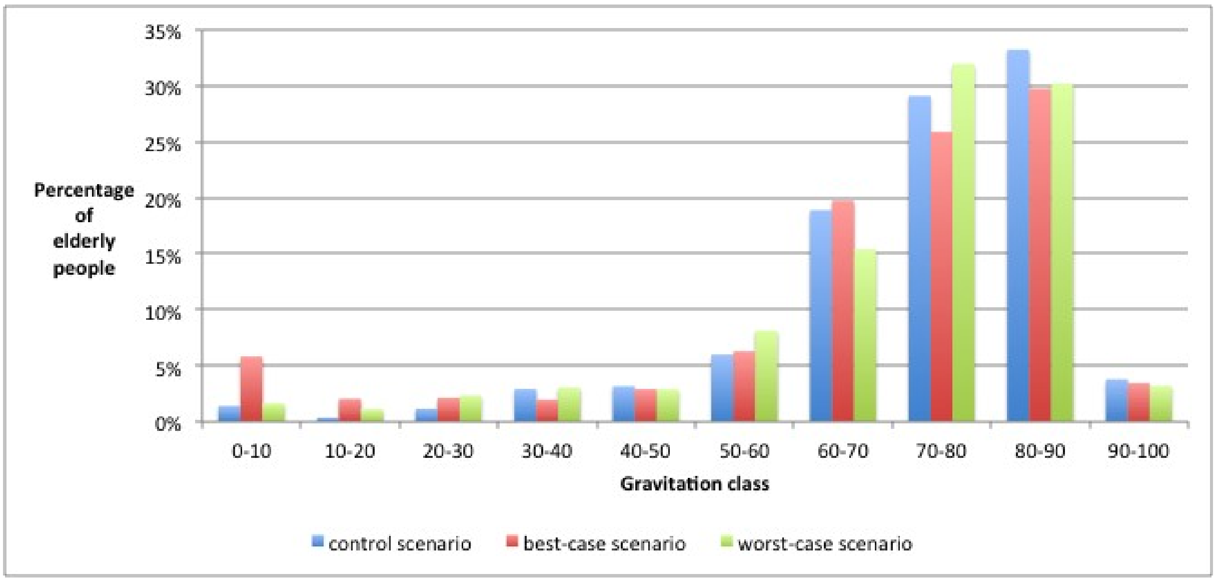

Figure 4.1: Comparison of the percentage of elderly people per gravitation class for district Hillegersberg-Schiebroek for the different scenarios

Annex 9 shows a combination of the mean gravitation maps for district Hillegersberg-Schiebroek and the living location of elderly people of age 50 and older. The exact living locations of elderly people could not be shown because of privacy reasons. Therefore, the living locations are shown as areas. These maps show a relatively high overall gravitation in the areas where elderly people live. The exceptions are the neighbourhood ‘Terbregge’ and the northern parts of ‘Molenlaankwartier’ and ‘Hillegersberg Noord’, which show low gravitation scores, meaning that the accessibility is low.

4.5 When taking related spatial characteristics into account, which composition of services will make areas with limited accessibility to services more suitable for the elderly?

Not all relevant services to the elderly that were found in literature could be gathered from broadly available datasets. This meant that only a selection of services could be analysed following the methodology of this study. Since this gives an incomplete picture of all relevant facilities, it is not possible to give a definite optimum composition of services per location based on the results of this study. However, the mean gravitation maps in Annex 4 do show how well the included services are represented within Rotterdam.

4.6 Sensitivity of the methodology

To determine the sensitivity of the methodology, the overall difference between the scenario outcomes was analysed for the district Hillegersberg-Schiebroek in

Rotterdam. Also the mean gravitation outcomes for Rotterdam were compared spatially to get an indication of the spatial variety between scenarios.

Overall difference between scenarios:
Figure 4.1 and Table 4.4 show the total gravitation scores for district Hillegersberg-Schiebroek for the different scenarios. The scenarios are different in the amount of pedestrian roads that are included in the travel network. However, no clear trend is visible between the different scenarios when comparing the percentages of elderly people per gravitation class. The average gravitation for the best-case and worst-case are lower in comparison with the control scenario. This is expected since the control scenario has more pedestrian roads available in its network than the other two scenarios. This is caused by the fact that the control scenario models people as if they can travel any kind of pedestrian road.

However, the best-case scenario shows a lower average gravitation in comparison with the worst-case scenario. This is unexpected since the best-case scenario has more pedestrian roads available in its network than the worst-case scenario. However, this can be explained by the fact that the accessibility to services is actually lower in areas were less people live. Therefore the worst-case scenario and the best-case scenario show similar gravitation scores. This means that no clear trend is visible when comparing the best-case and the worst-case scenario.

Table 4.4: Comparison of the percentage of elderly people per gravitation class for district Hillegersberg-Schiebroek for the different scenarios

	Gravitation class										
Scenario	**0-10**	**10-20**	**20-30**	**30-40**	**40-50**	**50-60**	**60-70**	**70-80**	**80-90**	**90-100**	**Average gravitation**
Control	1%	0%	1%	3%	3%	6%	19%	29%	33%	4%	72
Best-case	6%	2%	2%	2%	3%	6%	20%	26%	30%	3%	67
Worst-case	2%	1%	2%	3%	3%	8%	15%	32%	30%	3%	69

Spatial difference between scenarios:
To get an indication of the spatial sensitivity of the chosen methodology, the mean results of the different scenarios were compared with each other. Annex 8 contains maps that show the absolute difference between the mean scenarios. The dark red areas show the differences between the used transport networks. These areas also show the difference between spatial accessibility of the different scenarios. The light green to yellow areas represent locations where there is a more subtle difference in accessibility between the compared scenarios. The worst-case scenario shows the largest differences in accessibility when compared with the other two scenarios. Also in spatial sense, the differences in accessibility between the control scenario and the best-case scenario are less obvious.

5. Conclusions

The methodology described in this study can inform policy makers about the accessibility of services relevant for the elderly when travelling by foot on a regional and local level. This chapter will describe the conclusions in detail, following the research questions from the beginning of this study.

5.1 Which spatial characteristics support accessibility of the public space for elderly people with physical limitations? (based on literature study)

This study provides a comprehensive overview of the characteristics that influence the accessibility of public space for elderly people with physical limitations. The accessibility of public space is influenced by:

- The distance to a destination which can be translated to the willingness to travel a certain distance. (Elderly) people are only willing to travel a certain distance by foot. Once past a certain distance, the willingness to walk decreases significantly.
- The choice of transport: the distance that people travel by foot is shorter than when they travel using other forms of transport such as a mobility scooter or a car.
- The usability of the route: an objective characteristic, which can be translated to the physical barriers that people have to overcome to be able to travel a certain route. The width of pavement roads and the absence of barriers are important to the usability of a route.
- The attractiveness of a route: a more subjective characteristic, which is based on how attractive or unattractive people find a certain route, or location. This study shows the parameters that influence attractiveness of a route. However, this variable could not be implemented in the methodology, since in literature no measurable parameters were found that could be used to implement this variable. Therefore, this variable remains a subject for future studies.
- The relevant facilities for the elderly must be within reach.

5.2 How can these characteristics be translated to measurable parameters using GIS techniques?

The characteristics “distance to destination”, “usability of the route” and “relevant facilities” were translated to a model for travel by foot or walking device. The accessibility by foot was examined on two levels:

<u>On a local level:</u>
The chosen method provides information on a local level by determining the minimum width of pedestrian roads needed for elderly people to pass and the presence of potential barriers. The chosen methodology provided a detailed overview of pedestrian roads that were wide enough and the ones that were not. The spatial accuracy of the objects on pedestrian roads varied between 5 and 50

cm. However, with the chosen methodology, it was still possible to give an indication if an object had a high or low chance to form a barrier.

On a regional level:
The information gathered on the local level was translated into travel networks. Using a cost weighted distance approach, the travel distance by foot to relevant services for the elderly could be modelled for the whole municipality of Rotterdam. By translating the distance to gravitation maps an indication could be given of how willing people are to walk the distance to a certain service at any location in the city. Policy makers could use this information for spatial planning of future services.

5.3 Where do elderly people live independently in Rotterdam and which of the spatial characteristics found in the literature research are present there?

No registration was found that specifically contains the location of elderly people who live independently. Therefore, the living locations of all elderly people of 50 years or older were taken into account. When data for all the services relevant to the elderly is available, the chosen methodology can give a global overview of the accessibility of those services for elderly people.

For the services that were found in registers, the methodology provided insight in the location and accessibility of services. The methodology gave insight in how well services were spread over the municipality and how well they were accessible to walking elderly people. It also provided insight in if one might have to face barriers when taking certain routes.

5.4 Which parts of the public space are accessible to the elderly and which are not?

On a local level, the method gave a decent indication of the minimum width of pedestrian roads and the presence of potential barrier objects. The model showed clearly where services were located and how accessible they were on a regional level. The gravitation maps also showed how well different areas of Rotterdam were provided with services and how accessible they were by foot.

The districts 'Noord', 'Delfshaven' and 'Rotterdam Centraal' have the best access to services relevant to elderly people. In other districts, large areas show low access to services. These areas include: ‘Pernis’, most of ‘Hoogvliet’, about half of the area of ‘IJsselmonde’ and large areas of ‘Overschie’, ‘Hillegersberg-Schiebroek’, ‘Prins-Alexander’ and ‘Charlois’. The district ‘Feijenoord’ has average access to services.

5.5 When taking related spatial characteristics into account, which composition of services will make areas with limited accessibility to services more suitable for the elderly?

Not all services relevant to the elderly that were found in literature could be gathered from broadly available datasets. This meant that only a selection of services could be analysed following the methodology of this study. Since this gives an incomplete picture of all relevant facilities, it is not possible to give a definite optimum composition of services per location based on the results of this study. However, the results of this study do show how well the included services are represented within Rotterdam. On a local level, policy makers can use the service inventory from this study as a checklist to test if a location in the city has the relevant services for the elderly.

5.6 Overall conclusions about the methodology

The control scenario showed better access to services in comparison with the best-case and worst-case scenarios. However, there was only a small total and spatial difference in accessibility between the best-case and worst-case scenarios, following the chosen methodology. This means that no clear trend is visible when comparing the best-case and the worst-case scenario.

Although the differences between the worst-case and best-case scenarios are small, they do show lower access to services in comparison with the control scenario where barriers were not taken into account. However, to test how accurate the results of the different scenarios fit reality, they must be validated using field data. Since the time-frame of this thesis did not allow for extensive field work, this remains a subject for future studies.

This future field work could result in the advice to change the methodology or to gather more accurate data.

6. Discussion

The methodology in this study tries to model some aspects of accessibility by walking elderly people using GIS techniques. However, in its current form, it can at the most give an approximation of reality. Nevertheless, the methodology does offer a framework for further development. To develop the methodology further, it is necessary to test the outcomes of the model with gathered field data. This was not possible for this study because of the limited time frame. This chapter describes in further detail how the methodology can be improved further.

<u>Possible improvements to the methodology:</u>
The analysis in this research does not take different street levels into account. Therefore, it could occur that areas with different levels, such as an overpass show either an over or underestimation of accessibility. The analysis could be improved by taking these different levels into account.

The coverage of pavement by plants from private gardens is not included in this research. However, these plants could form an obstacle that is difficult or impossible to pass for people with physical limitations. Since such information is difficult to keep up to date, it is advisable to set up some kind of monitoring. An official could monitor this but it would probably be more efficient to stimulate people with physical limitations to report obstacles they encounter in public spaces.

The importance of the different types of services was not included in this study. For example, a grocery store might be more important to be accessible by foot, since one does groceries there on a daily basis. Locations with books however, might be less important to be accessible by foot, since one goes there only on an ad hoc basis. Therefore, the outcome of the model can be further improved by researching the importance of accessibility per service type. Another related question is if all service types need to be accessible by foot. Literature does describe relevant services to elderly people, but it does not describe specifically if these services need to be accessible by foot. It could be that services that are 'less important' also have a lower urgency for being accessible by foot.

The chosen methodology did not take into account how intensively the pavement is used in certain areas such as shopping areas. In those areas it might be necessary for the pavement to be wider than the absolute minimum, since multiple people use the pavement simultaneously and need enough space to pass each other. Because this is not implemented in the current methodology, the results of the current analysis could be to be too optimistic in shopping areas.

The assumption was made that objects on pavement, wider than 3.10 m, could not form barriers. In theory however, it could occur that objects are placed in clusters. If the space between the objects is smaller than 1.05 m, they also become barrier objects. However, in Rotterdam, this situation was not found to occur in practice.

In this case study, the choice was made to model accessibility following a raster-based approach. This was done to limit complexity of the methodology. However, when in the future, more information becomes available that can be linked to the travel network, a raster-based method might not be sufficient. In that case, a vector-based model might prove more suitable, when research uncovers more information about how to measure variables such as route attractiveness and the locations of crossings. However, this would add to the complexity of the model and more adjustments need to be made to the raw data.

<u>Scope limitations:</u>
This study only modelled the accessibility of relevant services for the elderly by foot, based on the available information from other studies. The accessibility by mobility scooter is expected to be more optimistic, since the travel network by foot will be expanded by bike lanes and the action radius will be larger. When information about the action radius of mobility scooter users becomes available it might be useful to also model this way of transport.

Also the accessibility by car was not included in this study. However, it is important that all necessary facilities are accessible once the car is parked, either by foot or by walking device. The accessibility by car can therefore be measured using the gravitation maps for transport by foot or walking device from a parking space for the handicapped. This means that also in this case, the pavement will be used as the modelled transport network.

The possibility that the location of services or the way services are provided might change was not taken into account. For example, in the future, it might become very easy for the elderly to order medicines online. When added to that, pharmacists provide a one-hour delivery service, the location of pharmacists becomes less relevant.

The municipality possesses an object-oriented large scale map (GBKN). In other words, all objects are available as polygons. However, the national version of the GBKN is distributed by the cadastre bureau as a line-based map. This means that the pedestrian roads in the national version will need conversion to be able to use them for the methodology that was developed during this thesis study. However, currently all municipalities are working on an object-based version of the GBKN in the form of the “Basisregistratie Grootschalige Topografie”, also known as BGT. When the BGT becomes available the object based pedestrian roads can easily be used in the developed methodology.

It was assumed that the distance between the home address and the street was no further than 25 m. Although in large cities in the Netherlands this distance is a plausible assumption, in more rural areas, the distance might be larger. Therefore, it is expected that this parameter should be adjusted according to the average distance between houses and streets in the desired study area.

<u>Information that could complement the methodology:</u>
The availability of ramps on the pavement is not registered in the municipality of Rotterdam, making it difficult to determine the possibility to enter and exit the pavement. It is advisable to register ramps making a more reliable analysis of the accessibility of the pavement by the elderly possible.

No information about curb widths in pavement was available. Although the curb widths can vary, a general assumption was made that the average curb width is 15 cm. This assumption could result in an over or underestimation in the analysis for the minimum width of the pavement and therefore the available roads in the analysis network.

Accessibility for the visually-impaired is not included in this research since no information was available about location of guiding lines (ribbed tiles) on the street. To be able to include this group in the analysis, it is advisable to start registering the locations where guiding lines are present.

The exact dimensions of barriers as described in this research were not known. Therefore, the calculation was based on the point representation of the object. This means that the calculated accessibility of the pavement with objects could be too optimistic. It is expected that this could be the case for objects that are known to have a larger footprint, such as plant pots and containers, play furniture or street furniture. For objects with a smaller footprint such as poles, lantern posts and traffic signs, this issue is less relevant. Since the dimensions of many of these larger objects are standardised, it is advisable to include these measurements in the object's registration. A more accurate analysis of the actual blockage of these objects would be possible in this way.

Since no specific information of the action radius of elderly people with physical limitations was available, the action radius of elderly people in general was used. It is plausible that the action radius of people with physical limitations is smaller than that of people without physical limitations. Therefore, the maximum walking distance might be too optimistic. It would be advisable to do research on the action radius of elderly people with physical limitations by foot or by walking device so that the model could be further improved with more reliable information.

Only fixed barriers are included in the described analysis. However, movable objects such as parked bikes or mopeds could also form barriers that prevent a person from passing. This information cannot be obtained from base registration but needs to be gathered by inspection in the field.

Not all relevant facilities for the elderly as described in literature could be found in broadly available registers. Since this study aimed at developing a methodology that could be used in any municipality in the Netherlands, it was chosen to not include those facilities in this study. However, the methodology is flexible enough to include additional data sources in future studies.

The analysis for barriers did not take into account that objects in the pavement could also form a barrier if the distance separating them is smaller than 3.10 m.

Route attractiveness was not included in the methodology described in this thesis. However, the way that a route is perceived, strongly influences the willingness to take that route. If it feels unsafe, people tend to take a route that feels safer. These subjective variables are difficult to implement, since no method was found in literature to make these variables measurable. No literature could be found that translates these subjective variables into measurable ones. Therefore, more research is needed on how these subjective variables can be translated into measurable parameters.

At the start of this study, it was intended to match the accessibility results with the prognosis of the location of elderly in the future. However, this information was too much aggregated to be able to make a match with the gravitation maps.

Therefore, the assumption was made that elderly people stay where they live currently and in the future.

To be certain that the destinations were connected to the transport network, each destination was converted into a raster cell of 50x50 m. No tests were performed to determine how adjustments to this raster size would influence the outcome of the analysis. However, the assumption that the first 25 meters around a destination type is walkable seems plausible, since if they were not accessible, they would not be viable.

Recommendations for future study:

Although from literature, general categories of relevant facilities could be extracted, the exact type of facilities was not described. For example, the facility type ‘exercise’ is important, but it is not clearly described which kinds of exercise are typical for elderly people. The selection of exercise facilities as used in this study could therefore be too optimistic, since all exercise facilities were included. To form a more accurate selection of facilities, it is therefore recommended to study exactly which facility types are relevant to the elderly.

It is also recommended to follow the described methodology on a different ‘kind’ of city. Rotterdam is a relatively modern city, which might explain why there was no large difference in accessibility between the different scenarios. In the case of Rotterdam, the barriers seemed to have limited impact on the accessibility of services. However, the outcome might be different with a city of an older structure. Cities such as Delft or Amsterdam have a very different street pattern, when compared to Rotterdam. Also, older streets tend to have narrower pavement and therefore probably more objects that form barriers. During this study, an attempt was made to use the same methodology on information from Amsterdam. However, the time frame for this study was too limited to gather all information in the desired format.

Although this study shows that it is possible to give an indication of the accessibility of services by foot, it is not possible to describe this accessibility score as either good or bad. If 75% of the people is willing to travel a certain distance, it might be good, since it is the majority of the people who live there. However, it might be bad from the perspective of a policy maker since not all people can access the service.

7. Summary

This case study describes a GIS approach to determine if the spatial characteristics of a city meet the standards that need to be met to make the city as accessible as possible for elderly people with physical limitations. This model can help city planners and policy makers to determine on which parameters and where in the city adjustments need to be made for optimal accessibility for the elderly.

7.1 Background

The Netherlands and other western countries are facing a rapid rise in the average age of the population. At the same time, the number of working people decreases. Without taking measures, this will result in a rise in costs for health care without the funds to cover these costs. Therefore, the expected increase in health care costs brings about a different approach to providing health care.

This is implemented in the Dutch policy by promoting independent living by the elderly. This policy, known as ‘Living Service Areas’, describes a regional approach to the planning of services in the area of living, care and welfare. In this approach, the accessibility of these services is important. However, accessibility cannot be expressed in terms of distance, but depends on how ‘near’ the service ‘feels’ to a person.

Also, accessible pavement should be wide enough and free from obstructions, public transit stops should be available, etc. This case study aims to gain insight in how to model the spatial characteristics of public urban Rotterdam and their influence on the accessibility of relevant services for elderly people by foot using GIS techniques.

7.2 Methodology

The municipality of Rotterdam functioned as the spatial scope for this case study. ‘Elderly people’ are described as people living in Rotterdam of age 50 and up. The minimum age of 50 years was chosen to get an indication of the living locations of elderly in the future, since most people tend to stay where they live as long as possible.

A literature study showed that the characteristics that determine the accessibility of a certain destination are: “the distance to destination”, “the usability of the route” and “the relevant facilities”. To model accessibility by foot, a cost weighted distance approach was used. The pedestrian roads functioned as a network. Three scenarios were analysed based on the width of pedestrian roads and the chance of barriers. The usability of the route was approached as the chance that someone will face barriers when travelling by foot. This was determined, based on the minimum width of pedestrian roads and the presence of objects on those roads. The ‘feeling’ of accessibility was modelled following a gravitation function, which represents the willingness to walk a certain distance.

The relevant service types for elderly people were extracted from literature. For each service type, the accessibility was determined for the whole municipality. For each of the three scenarios, these maps were combined to determine the mean accessibility for all service types combined. Finally the results were compared with the living locations of elderly people.

7.3 Results

For the whole of Rotterdam the access to services was calculated as a gravitation score, where a low gravitation represents low accessibility and a high gravitation represents high accessibility. The central part of Rotterdam showed the highest gravitation for the different service types included in this study. Certain areas however showed very low gravitation scores.

For the district 'Hillegersberg-Schiebroek' the average gravitation score per neighbourhood was computed. This was done for the age groups: 55-65, 65-75, 75-85 and 85+. The overall access to relevant services for elderly people of the age of 50 years and older was also computed for each neighbourhood in Hillegersberg-Schiebroek.

The chosen scenarios were different in the amount of pedestrian roads they have available. However, no clear trend was visible between the different scenarios when comparing the percentages of elderly people per gravitation class. The percentage of people, living in an area with a high gravitation score, lowers for the scenarios that take barriers into account. This is caused by the fact that the scenarios that take barriers into account contain less usable pedestrian roads than the scenario where barriers were not taken into account. Also in spatial sense, the differences in accessibility between the control scenario and the best-case scenario are very small.

7.4 Conclusions

This study provides a comprehensive overview of the characteristics that influence the accessibility of public space for elderly people with physical limitations. The characteristics "distance to destination", "usability of the route" and "relevant facilities" were translated to a GIS model for travel by foot or walking device.

The accessibility by foot was examined on a local and regional level. The chosen method provides detailed information on a local level by determining the minimum width of pedestrian roads needed for elderly people to pass and the presence of potential barriers. The spatial accuracy of the objects on pedestrian roads varied between 5 and 50 cm. However, with the chosen methodology, it was still possible to give an indication if an object had a high or low chance to form a barrier.

The model showed clearly where services were located and how accessible they were on a regional level. The gravitation maps showed how well different areas of Rotterdam were provided with services and how accessible they were by foot.

There was only a small total and spatial difference in accessibility between the different scenarios, following the chosen methodology. Although the differences between the worst-case and best-case scenarios are small, they do show lower access to services in comparison with the control scenario where barriers were not taken into account. However, to test how accurate the results of the different scenarios fit reality, they must be validated using field data. Since the time-frame of this thesis did not allow for extensive field work, this remains a subject for future studies. This future field work could result in the advice to either change the methodology or to gather more accurate data.

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Annex 1 (1/2): Objective parameters influencing route attractiveness found in literature

Objective Route Attractiveness	Influence	Described by
City centre	positive	TNO, 2004, Borst C., 2008
Walking loop	positive	Rodiek, S., 2006
Handrails on stairs	positive	Wennberg, H. 2009, Carsson, G. 2004, Lavery, I. et.al., 1996
Well-contrasted steps on stairs	positive	Wennberg, H. 2009, Carlsson G., 2004
protection from sun and rain	positive	Rodiek, S., 2006
presence of activity or other people	positive	Borst C., 2008
link length	positive	Borst, H.C. et al., 2009
traffic lights without audio signal	negative	Lavery, I. et.al, 1996, Carrlsson, G., 2004
High-rise (>3 storeys)	negative	TNO, 2004
Business buildings	positive	TNO, 2004, Borst C., 2008 & 2009
Vacant buildings	negative	TNO, 2004
Density of dwellings	negative	TNO, 2004
industry	negative	TNO, 2004
blind walls	negative	Borst, H.C. et al., 2009
dwellings on ground or first floor	positive	Borst, H.C. et al., 2009
Zebra crossings	positive	TNO, 2004, Wennberg, H. 2009, Tranter R.T., 1991, Borst C., 2008 & 2009
Porches	positive	Rodiek, S., 2006
Gazebos	positive	Rodiek, S., 2006
Trees along route	positive	TNO, 2004, Borst C., 2008 & 2009
Front gardens	positive	TNO, 2004, Borst C., 2008 & 2009
Park	positive	TNO, 2004, Veldacademie 2012a & 2012b, Borst C., 2008 & 2009
Water features	positive	Rodiek, S., 2006, TNO, 2004
Nature (animals, flowers, greenery)	positive	Rodiek, S., 2006, Gant R. 2010, Borst, H.C. et al., 2009
Litter on street	negative	TNO, 2004, Wennberg, H. 2009, Borst, H.C. et al., 2009
Deterioration of materials	negative	Rodiek, S., 2006
lack of adequate maintenance	negative	Rodiek, S., 2006, Tranter R.T., 1991, TNO, 2004
small holes	negative	Carlsson, G., 2004
no pavement	negative	TNO, 2004, Tranter R.T., 1991, Borst, H.C. et al., 2009
branches hanging over pathway	negative	Veldacademie 2012a & 2012b, Carlsson, G., 2004, Wennberg, H. 2009
uneven pavement	negative	Veldacademie 2012a & 2012b, Carlsson, G., 2004, Wennberg, H. 2009, TNO, 2004, Tranter R.T., 1991
rain gullies in pavement	negative	Tranter R.T., 1991
Slopes and/or stairs	positive	TNO, 2004, Borst C., 2008 & 2009
ramps of sidewalks blocked by parked cars	negative	Veldacademie 2012a & 2012b,, Rodiek, S., 2006
high kerbs	negative	Wennberg, H. 2009, Carlsson, G. 2004, Tranter R.T., 1991, Gant R. 2010
hills	negative	Tranter R.T., 1991
differences in levels	negative	Carlsson G., 2004
steps	negative	Carlsson G., 2004, Gant R. 2010
Playgrounds	positive	Veldacademie 2012a & 2012b, Gant R. 2010
Swings	positive	Rodiek, S., 2006

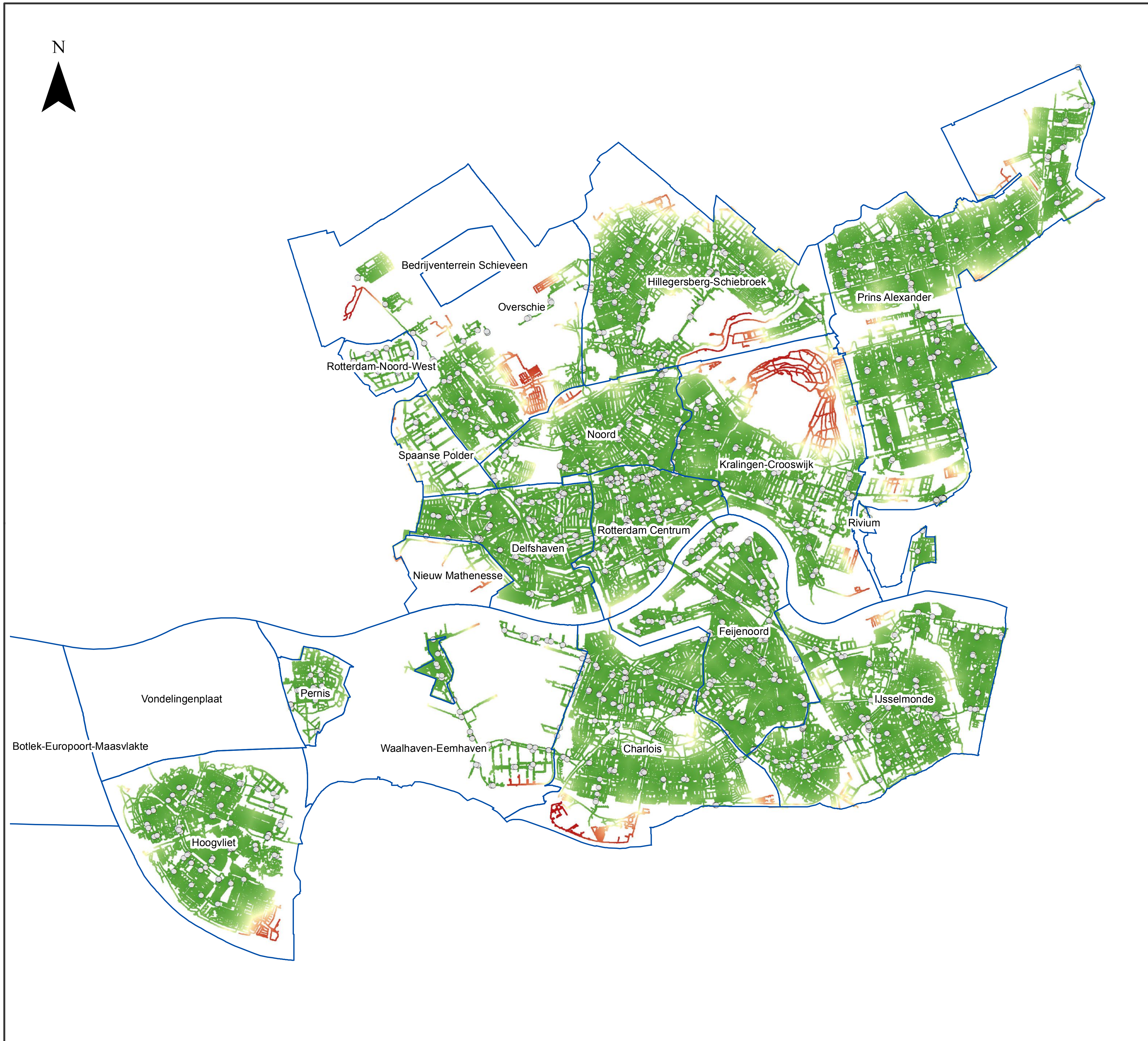
Annex 1 (2/2): Objective parameters influencing route attractiveness found in literature

Objective Route Attractiveness	Influence	Described by
Benches	positive	TNO, 2004, Veldacademie 2012a & 2012b, Rodiek, S., 2006, Carlsson, G. 2004, Gant R. 2010, Wennberg, H. 2009, Lavery, I. et.al. 1996
Overhead shelter	positive	Rodiek, S., 2006, Wennberg, H. 2009
no traffic islands	negative	Carlsson G., 2004
Shops	positive	TNO, 2004, Veldacademie 2012a & 2012b, Borst C., 2008 & 2009
Catering establishments	positive	TNO, 2004, Veldacademie 2012a & 2012b, Borst C., 2008 & 2009
Blocking (commercial) signs	negative	?
limited sight near a crossing	negative	Carlsson G., 2004
Traffic volume	negative	TNO, 2004, Veldacademie 2012a & 2012b, Borst C., 2008 & 2009
Parked cars	negative	TNO, 2004, Rodiek, S., 2006, Tranter R.T., 1991
Parked bicycles / scooters	negative	TNO, 2004, Wennberg, H. 2009
Cyclists in pedestrian areas	negative	Wennberg, H. 2009
scooters / mopeds driving on sidewalks	negative	TNO, 2004
mixed traffic crossings & paths	negative	Veldacademie 2012a & 2012b
combined pedestrian and cycle-way	negative	Carlsson G., 2004
traffic from two directions	negative	Carlsson G., 2004
Bus or tram stops	positive	TNO, 2004, Veldacademie 2012a & 2012b, Rodiek, S., 2006, Borst C., 2008 & 2009
no disabled parking	negative	Veldacademie 2012a & 2012b, Lavery, I. et.al, 1996

Annex 2: Subjective parameters influencing route attractiveness found in literature

Subjective Route Attractiveness	Influence	Described by
loitering youth	negative	TNO, 2004
feeling unsafe	negative	TNO, 2004
dull	negative	TNO, 2004
population composition	?	TNO, 2004
dog poop / dirty	negative	TNO, 2004
narrow / scary	negative	TNO, 2004
uncomfortable	negative	TNO, 2004
cold / windy	negative	TNO, 2004
stench	negative	TNO, 2004
impoverishment	negative	TNO, 2004
(traffic) noise	negative	TNO, 2004, Borst, H.C. et al., 2009
difficult to cross	negative	TNO, 2004
Fresh air	positive	Rodiek, S., 2006
Sunshine	positive	Rodiek, S., 2006
heavy traffic	Subjective	TNO, 2004, Veldacademie 2012a & 2012b, Carlsson, G. 2004
poor lighting	Subjective	TNO, 2004, Wennberg, H. 2009
too narrow pathway	Subjective	Carlsson, G., 2004, Rodiek, S., 2006, Carlsson G., 2004, Gant R. 2010
lack of adopted toilets	Subjective	Lavery I. et. al. 1996
Lack of dropped kerbs	Subjective	Lavery I. et. al. 1996, Borst, H.C. et al., 2009
distance too far	Subjective	Rodiek, S., 2006, Carlsson G., 2004
ramps too steep	Subjective	Tranter R.T., 1991, Carlsson G., 2004
crossings wrongly located	Subjective	Tranter R.T., 1991
quiet	positive	TNO, 2004
cozy	positive	TNO, 2004
beautiful / historical buildings	positive	TNO, 2004
spacious / clear overview	positive	TNO, 2004
beautiful / fun	positive	TNO, 2004, Borst C., 2008
clean streets	positive	TNO, 2004, Borst C., 2008

Annex 3: Walking gravitation maps per destination type and network scenario



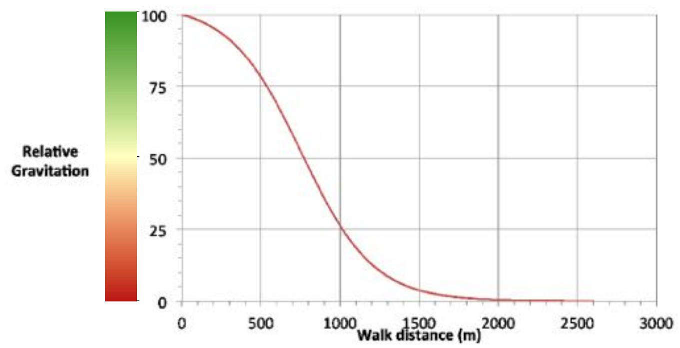
Walking gravitation to service

Public transport: control scenario

District border

Service point

Relative gravitation function
(based on TNO, 2004)

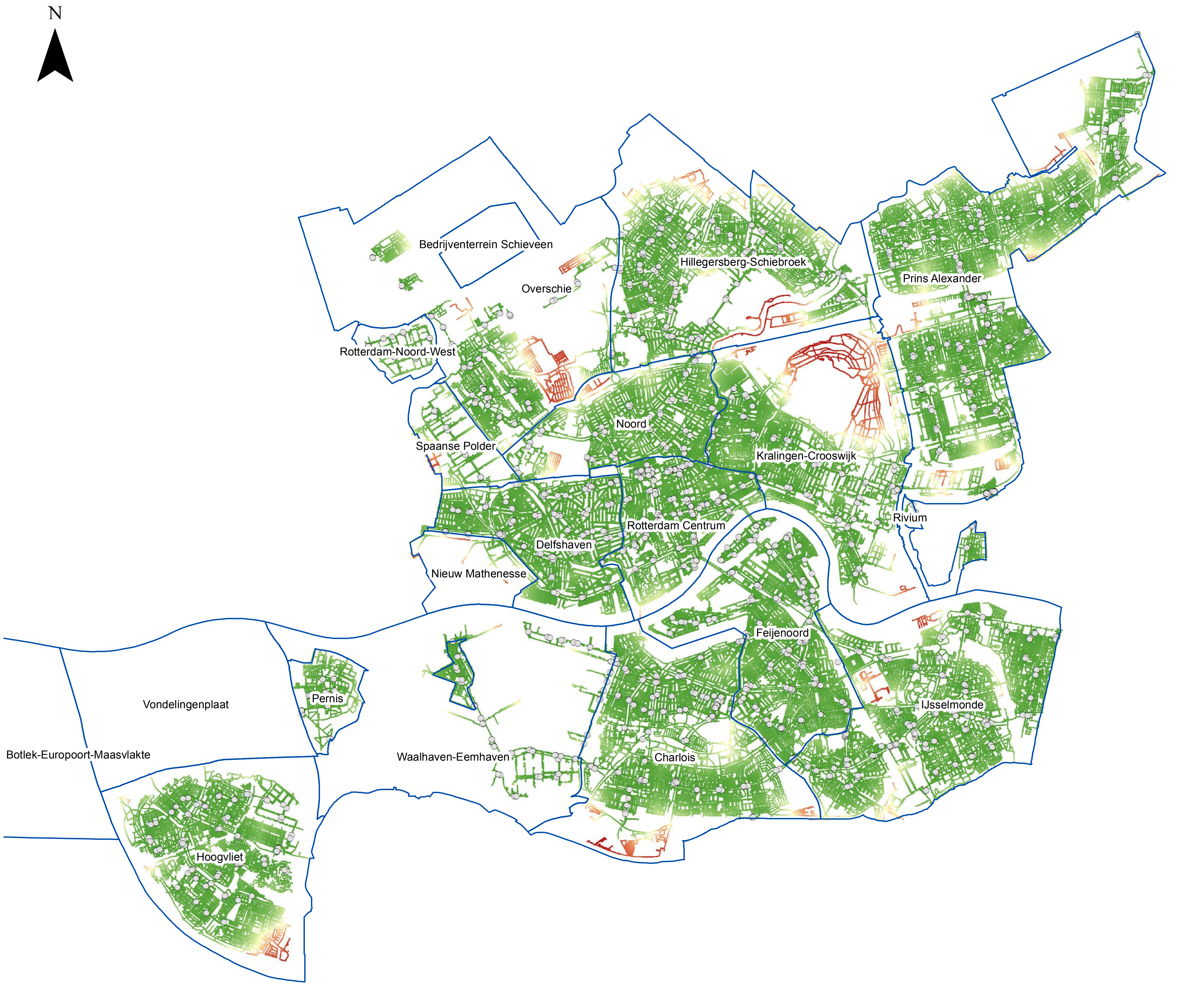


Used source data:
- Large scale base map (GBKR 2012)
- Business register (Bedrijvenregister 2011)

Author:	Creation date:	Scale:	Format:
Mark Verschuur	7/22/2013	1:70,000	A3

Walking gravitation to service

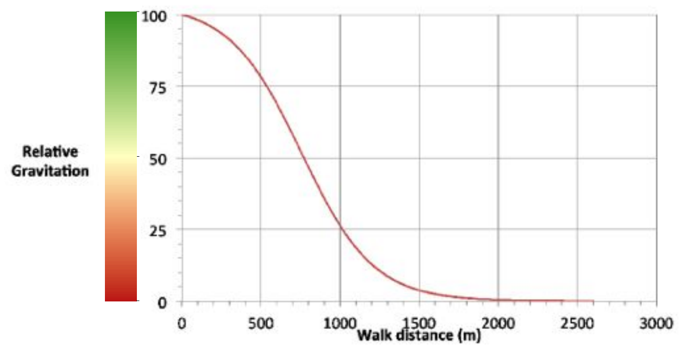
Public transport: best-case scenario



District border

Service point

Relative gravitation function
(based on TNO, 2004)



Used source data:
- Large scale base map (GBKR 2012)
- Business register (Bedrijvenregister 2011)

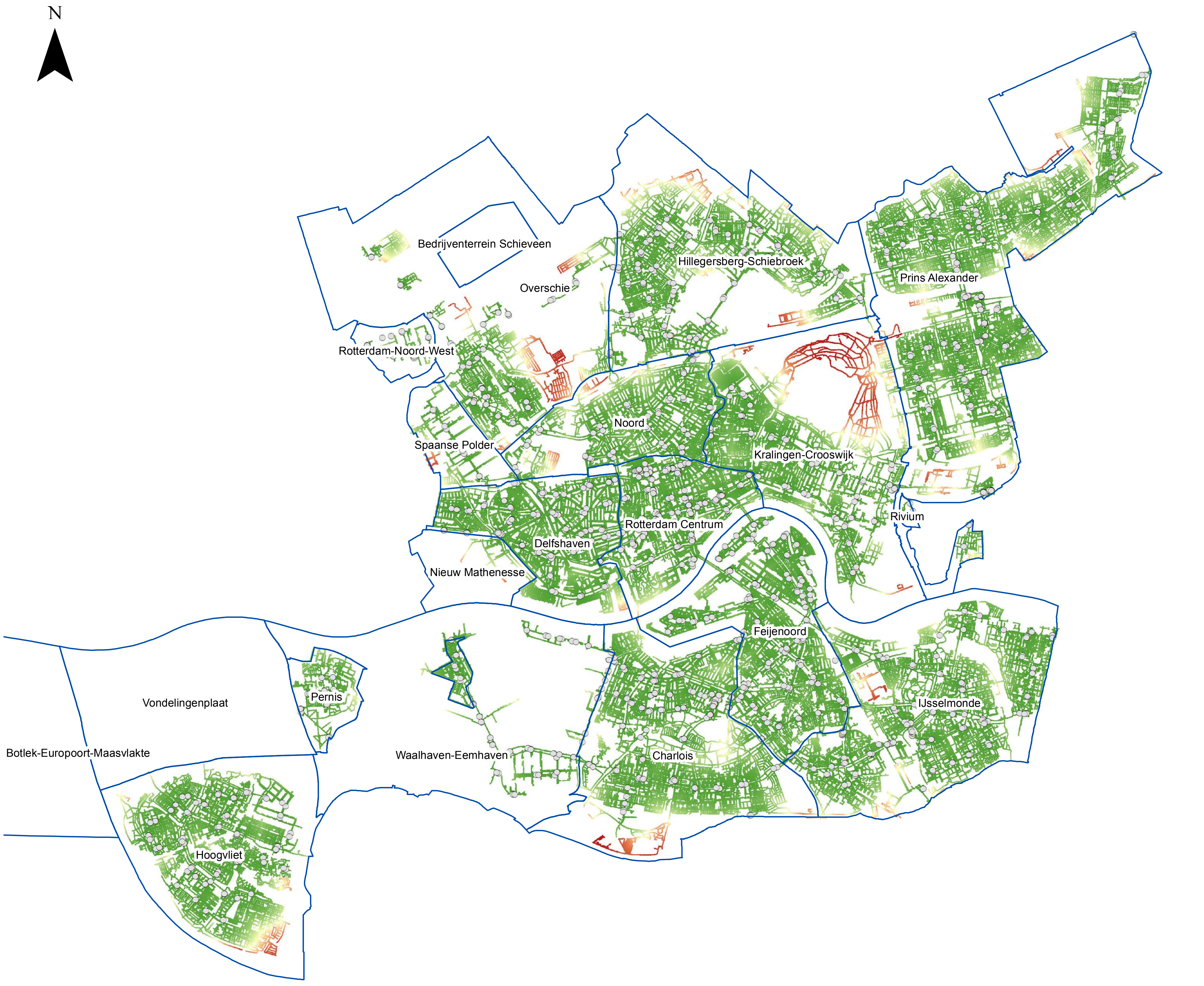
Author:	Creation date:	Scale:	Format:
Mark Verschuur	7/22/2013	1:70,000	A3

Walking gravitation to service

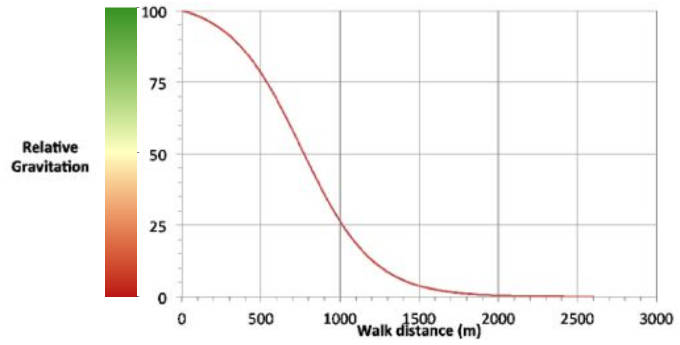
Public transport: worst-case scenario

District border

Service point



Relative gravitation function
(based on TNO, 2004)



Used source data:
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- Business register (Bedrijvenregister 2011)

Author:	Creation date:	Scale:	Format:
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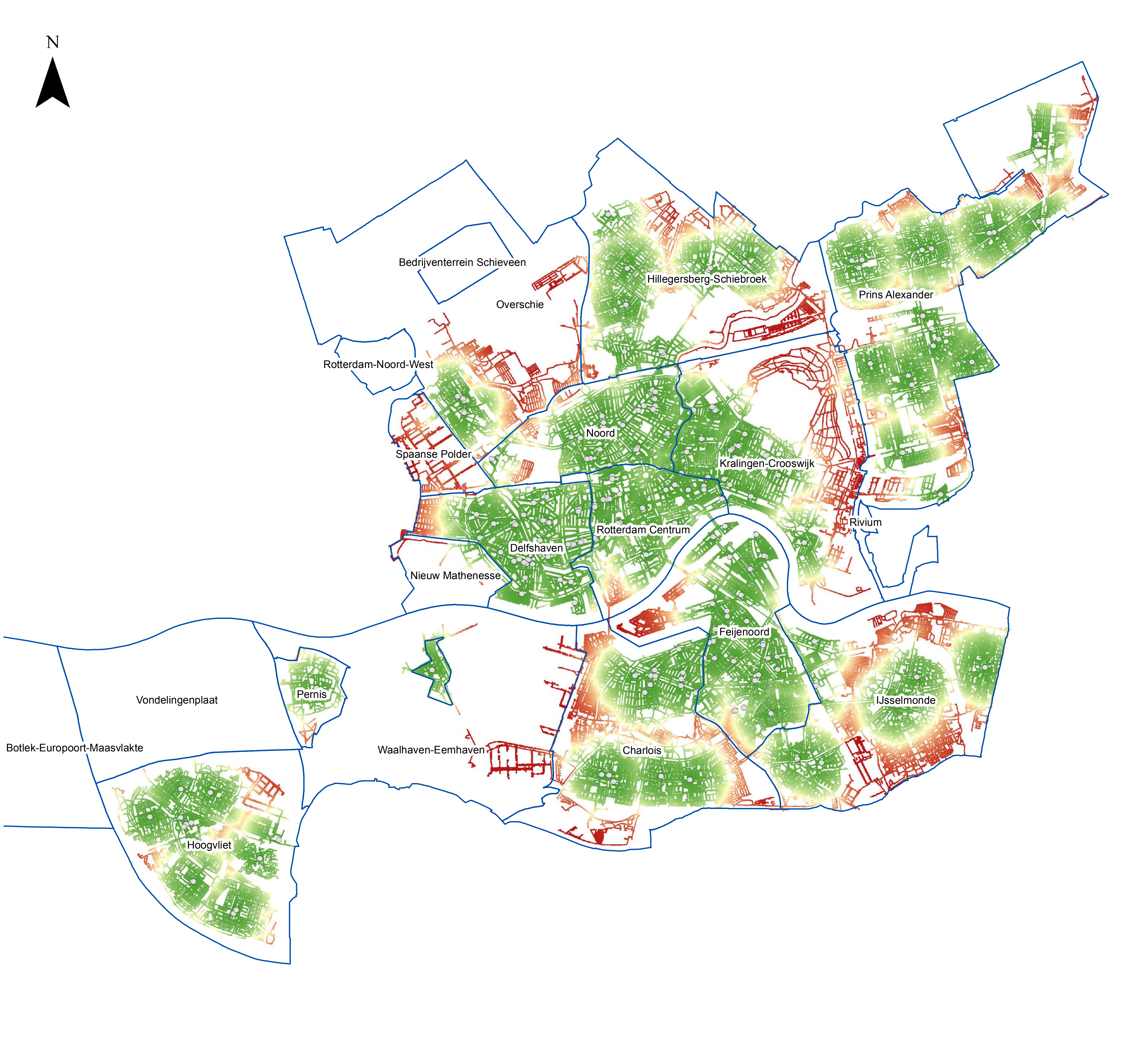


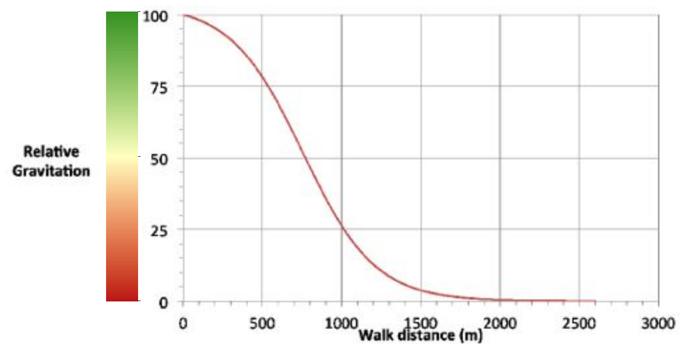
Walking gravitation to service

Groceries: best-case scenario

District border

Service point

Relative gravitation function
(based on TNO, 2004)



Used source data:
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- Business register (Bedrijvenregister 2011)

Author:	Creation date:	Scale:	Format:
Mark Verschuur	7/22/2013	1:70,000	A3

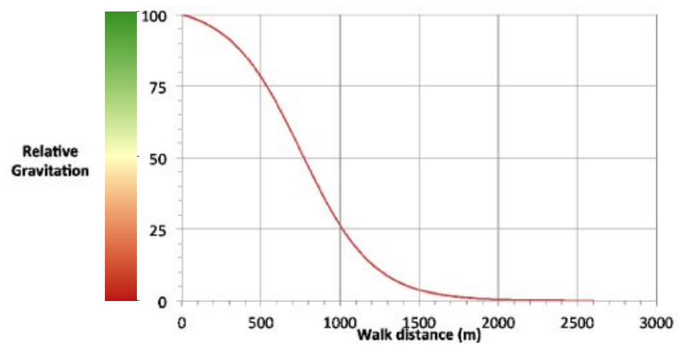
Walking gravitation to service

Groceries: control scenario

District border

Service point

Relative gravitation function
(based on TNO, 2004)



Used source data:
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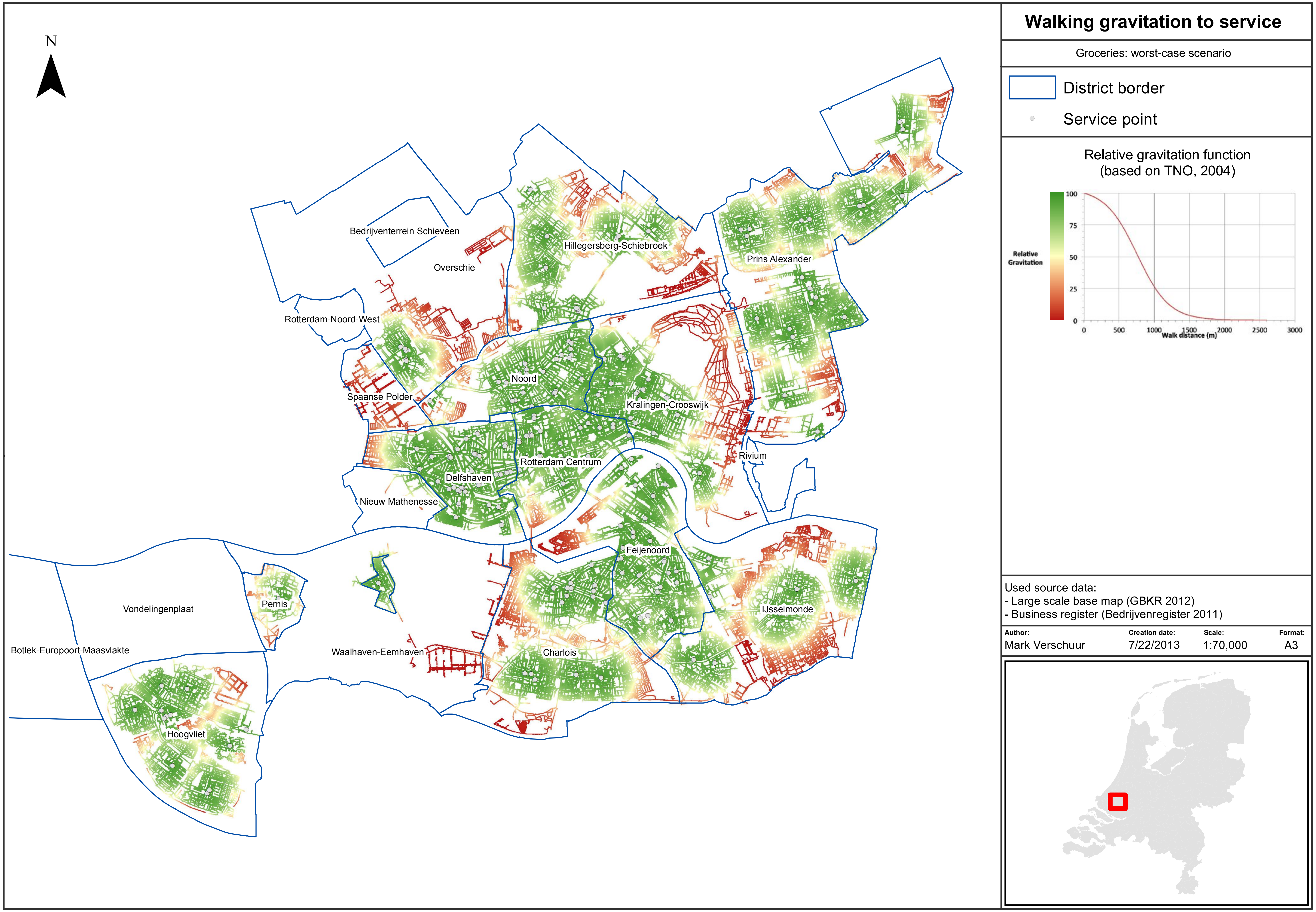
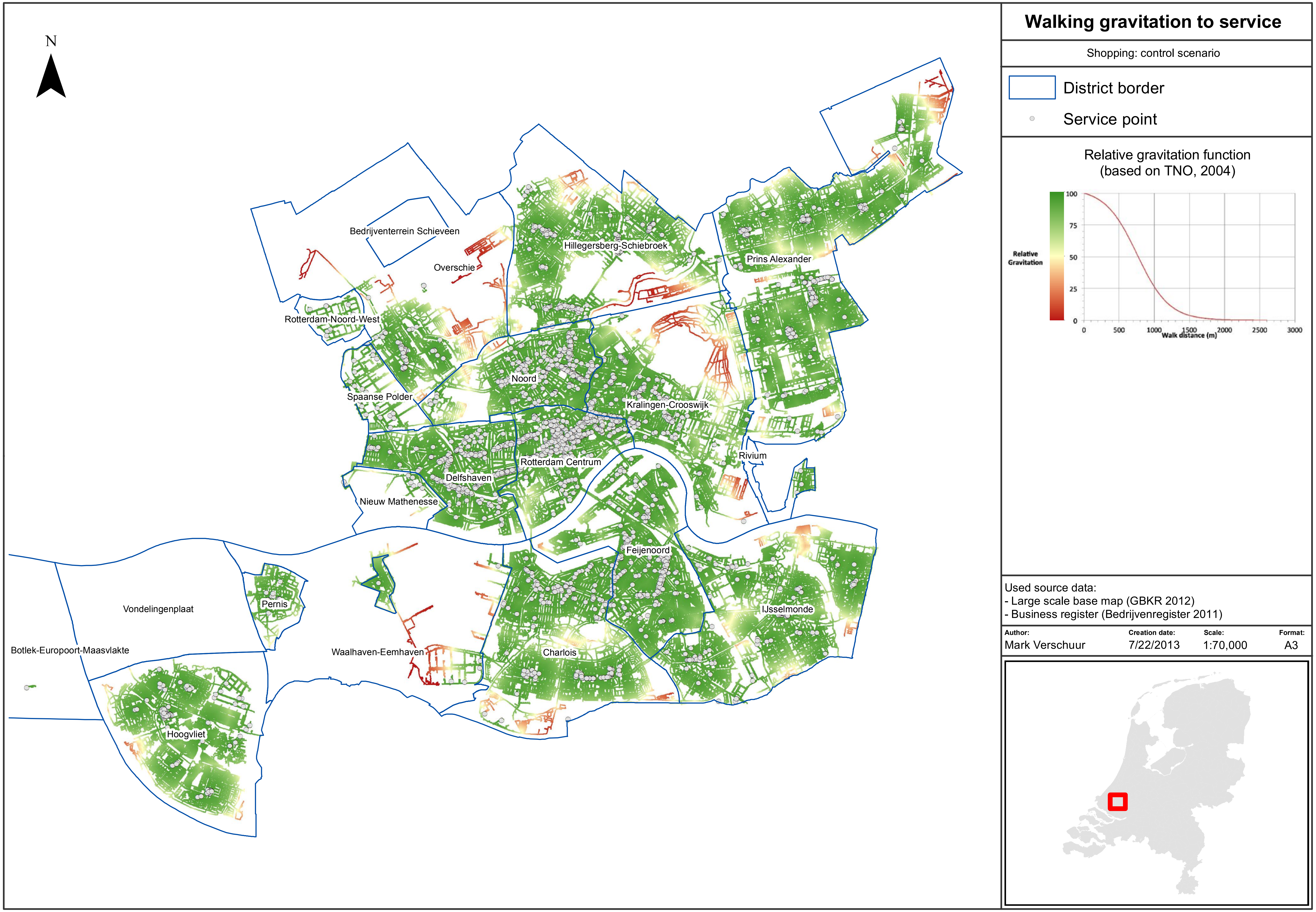
- Business register (Bedrijvenregister 2011)

Author:	Creation date:	Scale:	Format:
Mark Verschuur	7/22/2013	1:70,000	A3


Walking gravitation to service
Groceries: worst-case scenario
District border
Service point
Relative gravitation function
(based on TNO, 2004)
Relative Gravitation
100
75
50
25
0
0
500
1000
1500
2000
2500
3000
Walk distance (m)
Used source data:
- Large scale base map (GBKR 2012)
- Business register (Bedrijvenregister 2011)
Author:
Mark Verschuur
Creation date:
7/22/2013
Scale:
1:70,000
Format:
A3
N
Bedrijventerrein Schieveen
Overschie
Hillegersberg-Schiebroek
Prins Alexander
Rotterdam-Noord-West
Noord
Spaanse Polder
Kralingen-Crooswijk
Rotterdam Centrum
Rivium
Delfshaven
Nieuw Mathenesse
Feijenoord
Pernis
Vondelingenplaat
IJsselmonde
Botlek-Europoort-Maasvlakte
Waalhaven-Eemhaven
Charlois
Hoogvliet


Walking gravitation to service
Shopping: control scenario
District border
Service point
Relative gravitation function
(based on TNO, 2004)
Relative Gravitation
100
75
50
25
0
0
500
1000
1500
2000
2500
3000
Walk distance (m)
Used source data:
- Large scale base map (GBKR 2012)
- Business register (Bedrijvenregister 2011)
Author:
Mark Verschuur
Creation date:
7/22/2013
Scale:
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Format:
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Overschie
Hillegersberg-Schiebroek
Prins Alexander
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Noord
Spaanse Polder
Kralingen-Crooswijk
Rotterdam Centrum
Delfshaven
Rivium
Nieuw Mathenesse
Feijenoord
Pernis
Vondelingenplaat
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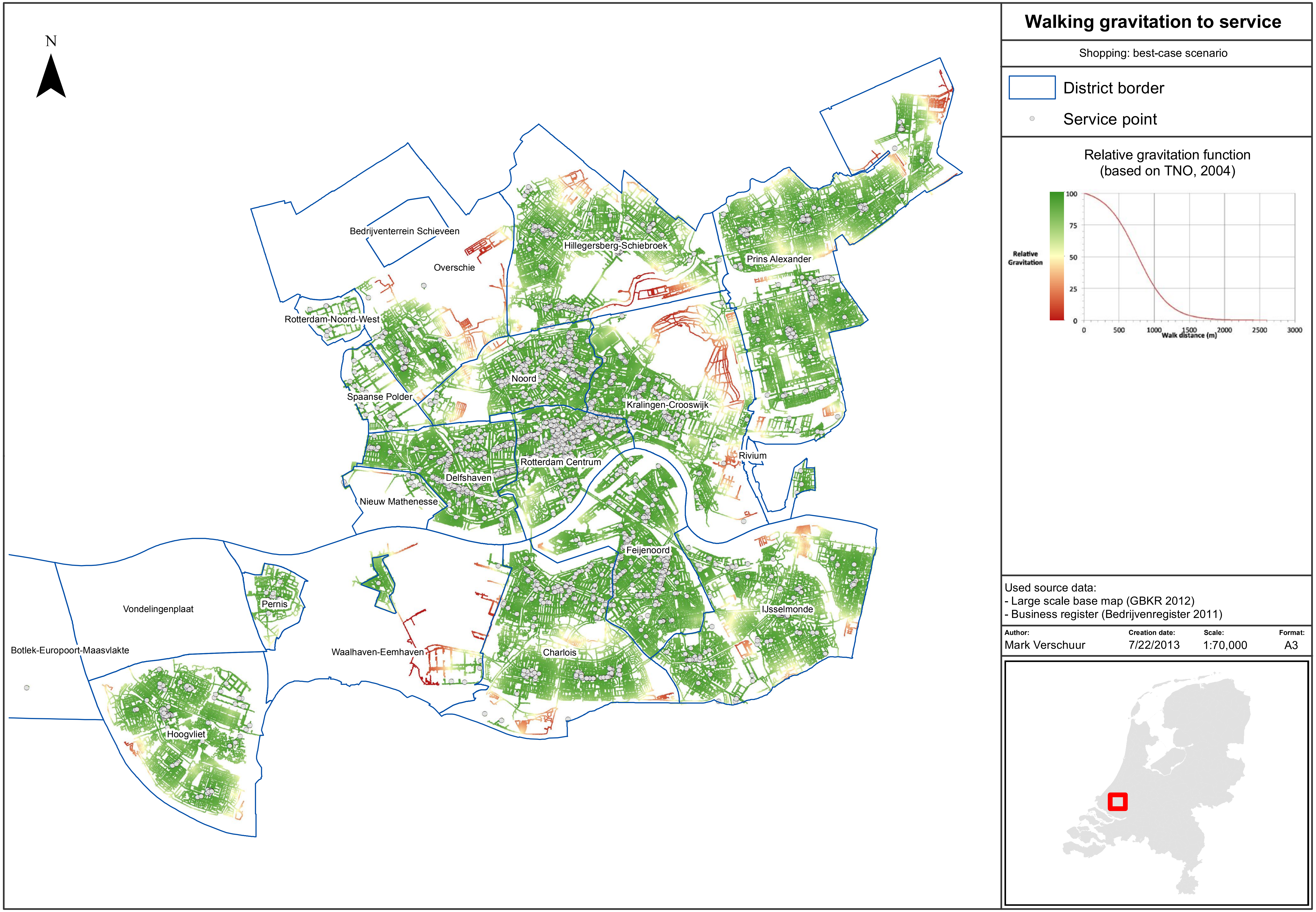
Botlek-Europoort-Maasvlakte
Waalhaven-Eemhaven
Charlois
Hoogvliet


Walking gravitation to service
Shopping: best-case scenario
District border
Service point
Relative gravitation function
(based on TNO, 2004)
Relative Gravitation
100
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2000
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Walk distance (m)
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Bedrijventerrein Schieveen
Overschie
Hillegersberg-Schiebroek
Prins Alexander
Rotterdam-Noord-West
Noord
Spaanse Polder
Kralingen-Crooswijk
Rotterdam Centrum
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Delfshaven
Nieuw Mathenesse
Feijenoord
Pernis
Vondelingenplaat
IJsselmonde
Botlek-Europoort-Maasvlakte
Waalhaven-Eemhaven
Charlois
Hoogvliet
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- Business register (Bedrijvenregister 2011)
Author:
Mark Verschuur
Creation date:
7/22/2013
Scale:
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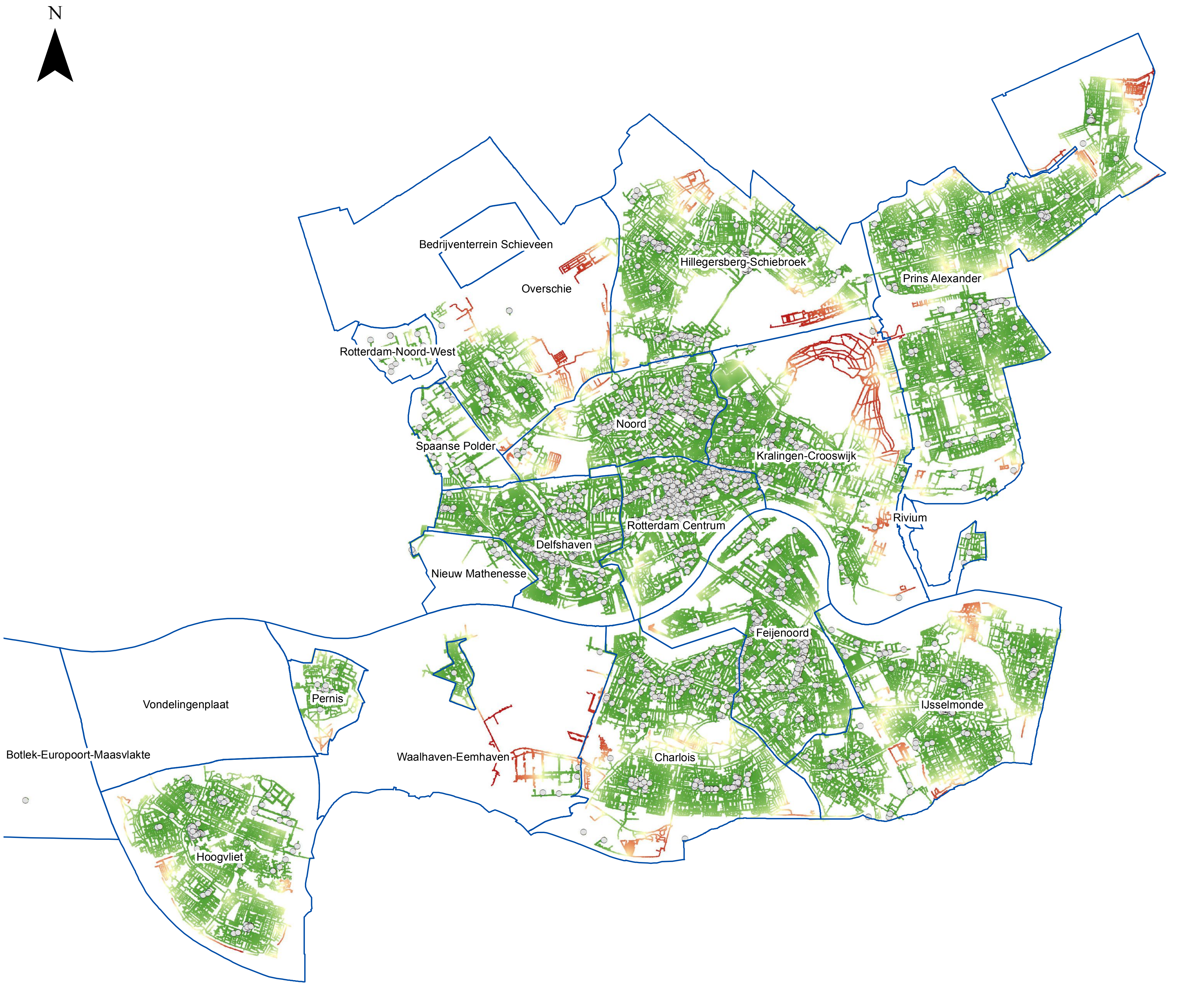
Format:
A3

Walking gravitation to service

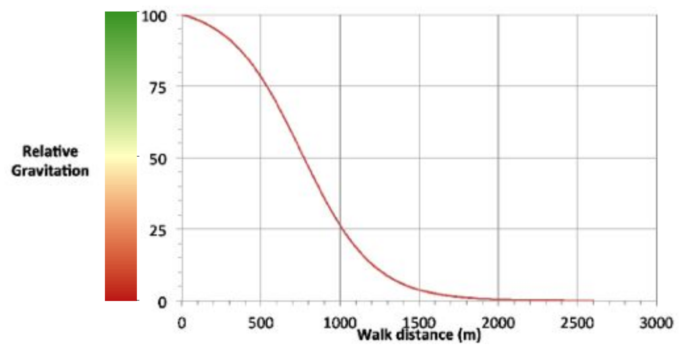
Shopping: worst-case scenario

District border

Service point



Relative gravitation function
(based on TNO, 2004)



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- Business register (Bedrijvenregister 2011)

Author:	Creation date:	Scale:	Format:
Mark Verschuur	7/22/2013	1:70,000	A3

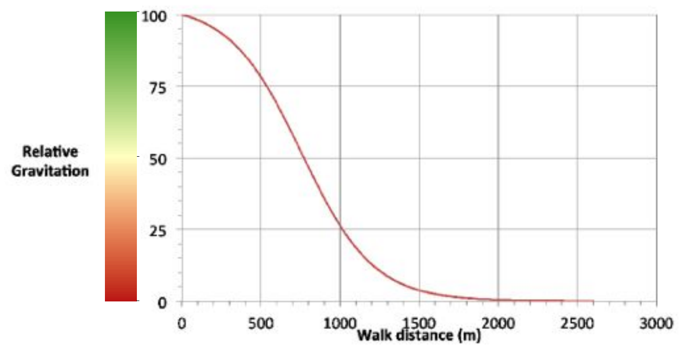
Walking gravitation to service

Books: best-case scenario

District border

Service point

Relative gravitation function
(based on TNO, 2004)



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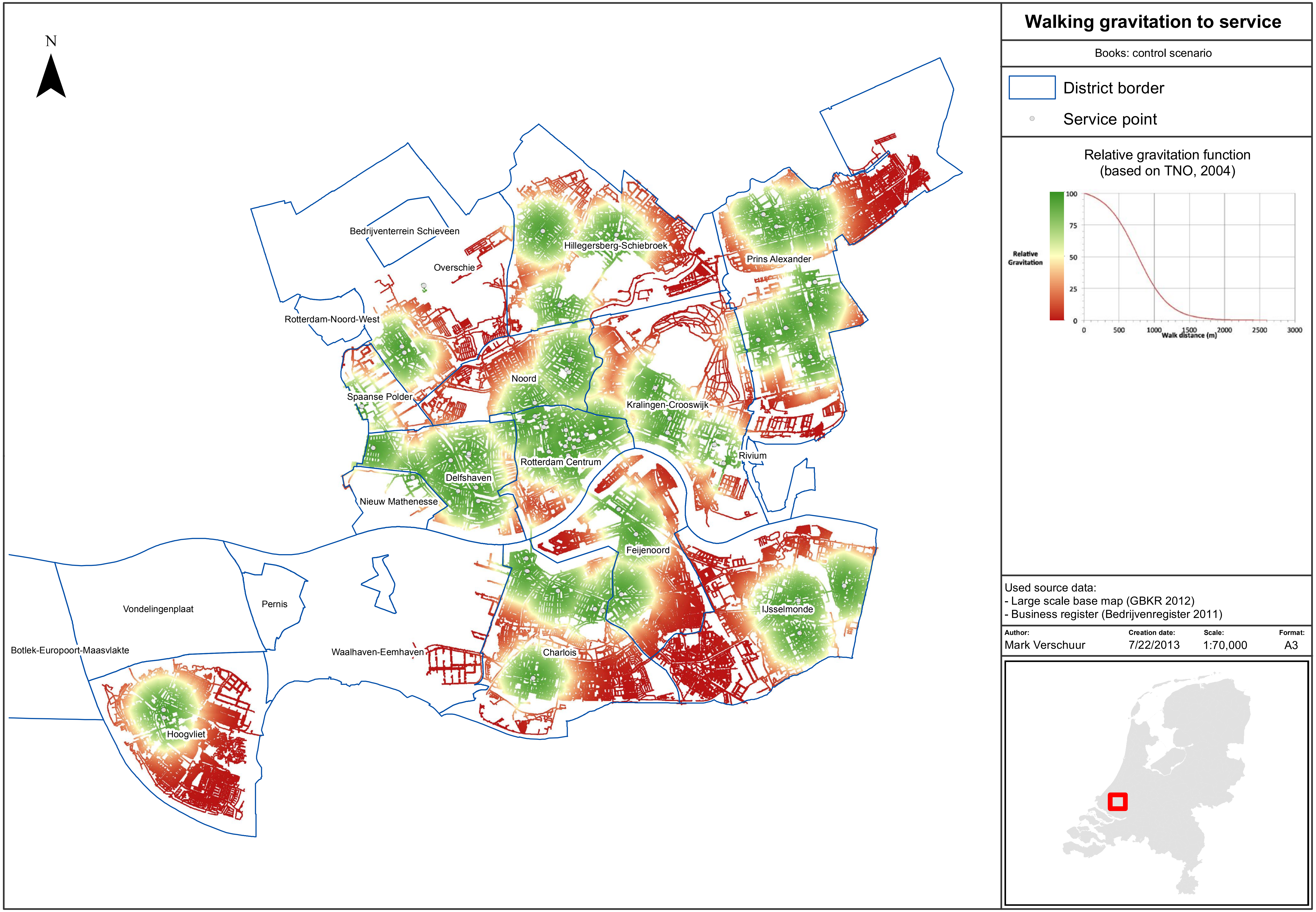

Walking gravitation to service
Books: control scenario
District border
Service point
Relative gravitation function
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Relative Gravitation
100
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Walk distance (m)
Used source data:
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- Business register (Bedrijvenregister 2011)
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Bedrijventerrein Schieveen
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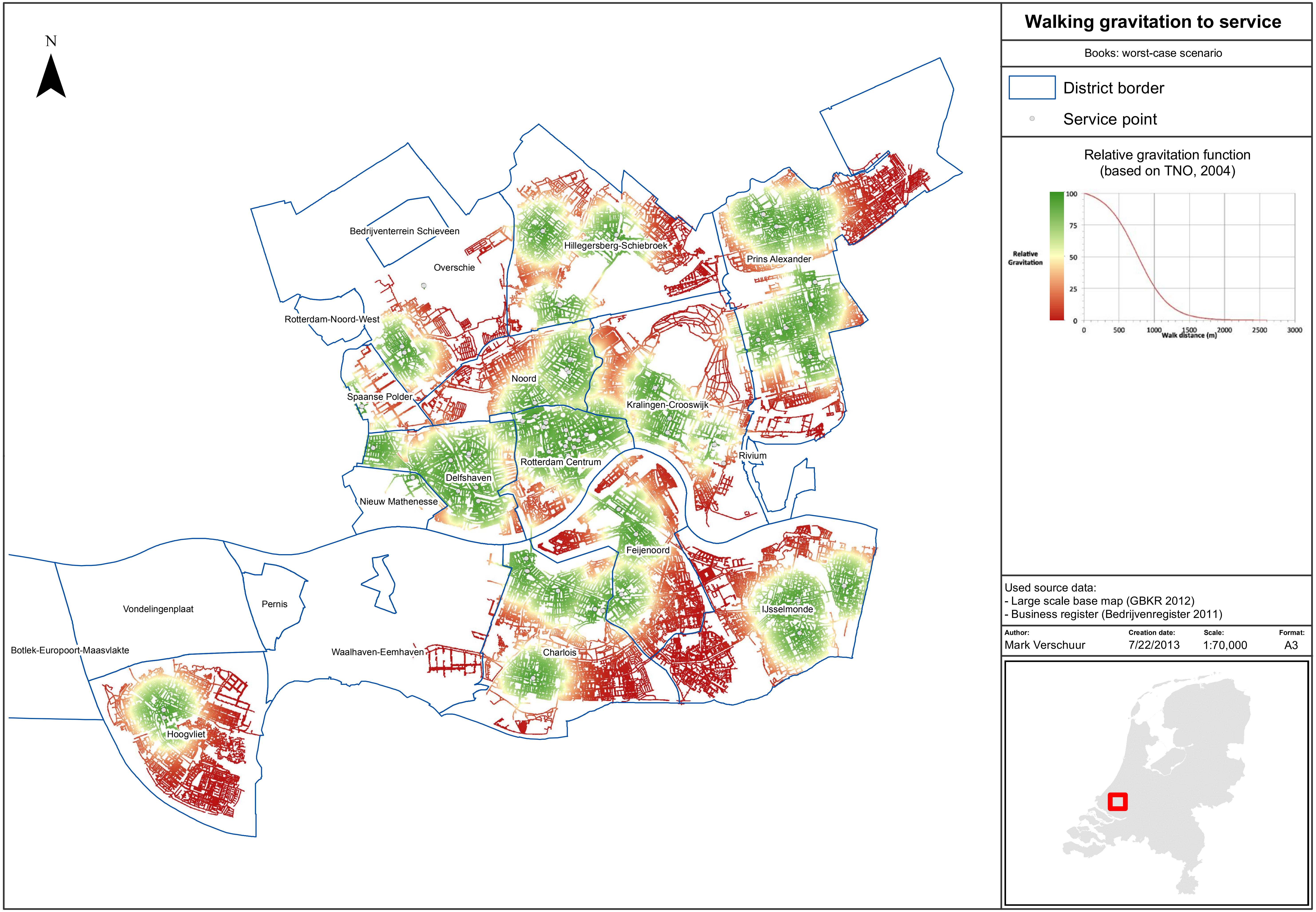
Charlois
Hoogvliet



Walking gravitation to service
Books: worst-case scenario
District border
Service point
Relative gravitation function
(based on TNO, 2004)
Relative Gravitation
100
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50
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0
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Walk distance (m)
Used source data:
- Large scale base map (GBKR 2012)
- Business register (Bedrijvenregister 2011)
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Waalhaven-Eemhaven
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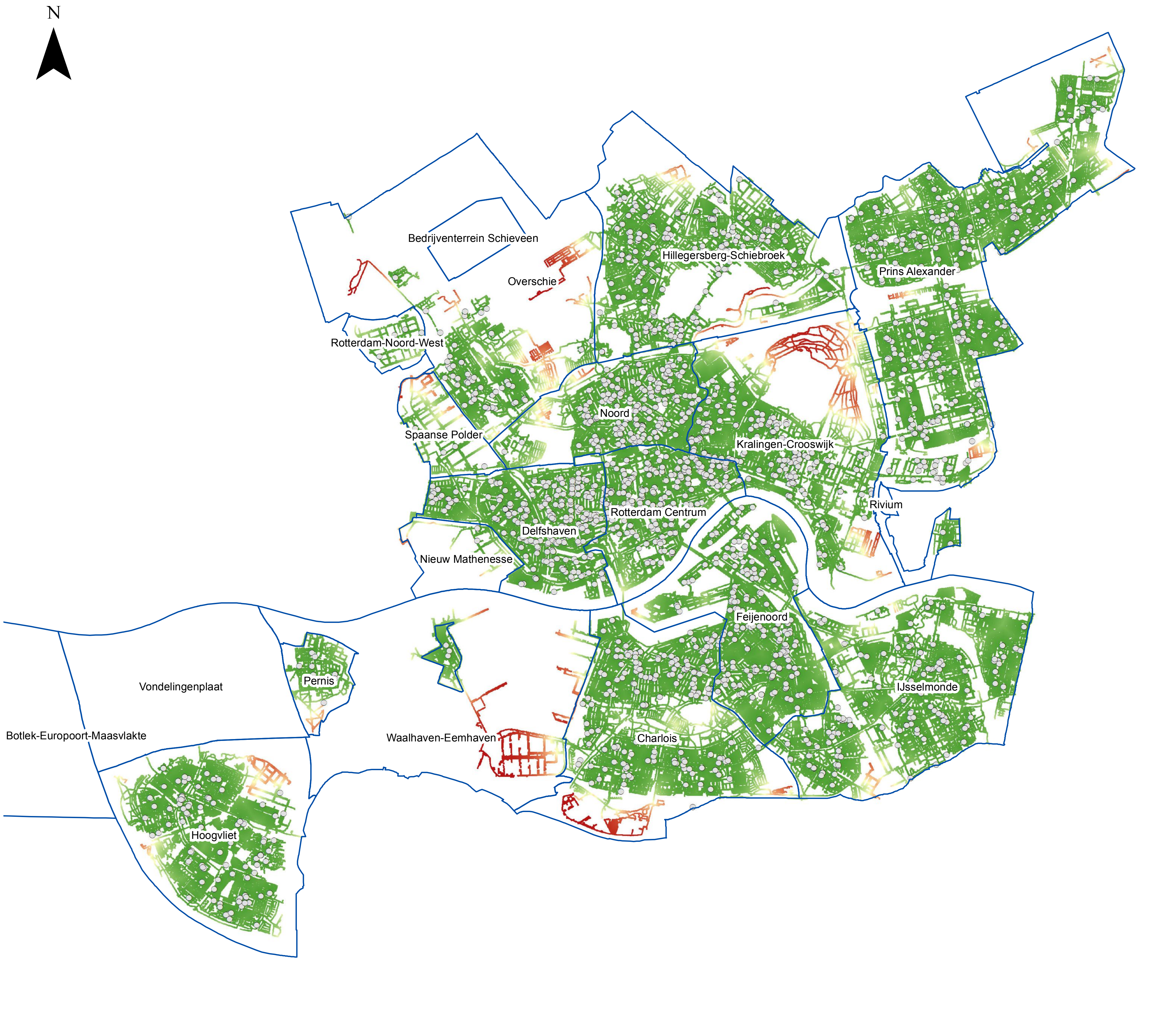
Hoogvliet



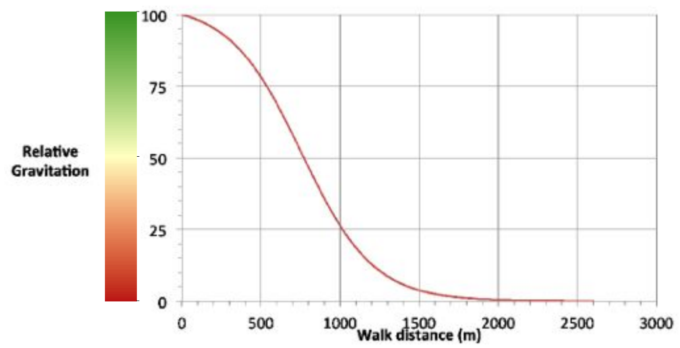
Walking gravitation to service

Care: control scenario

District border

Service point

Relative gravitation function
(based on TNO, 2004)



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Author:	Creation date:	Scale:	Format:
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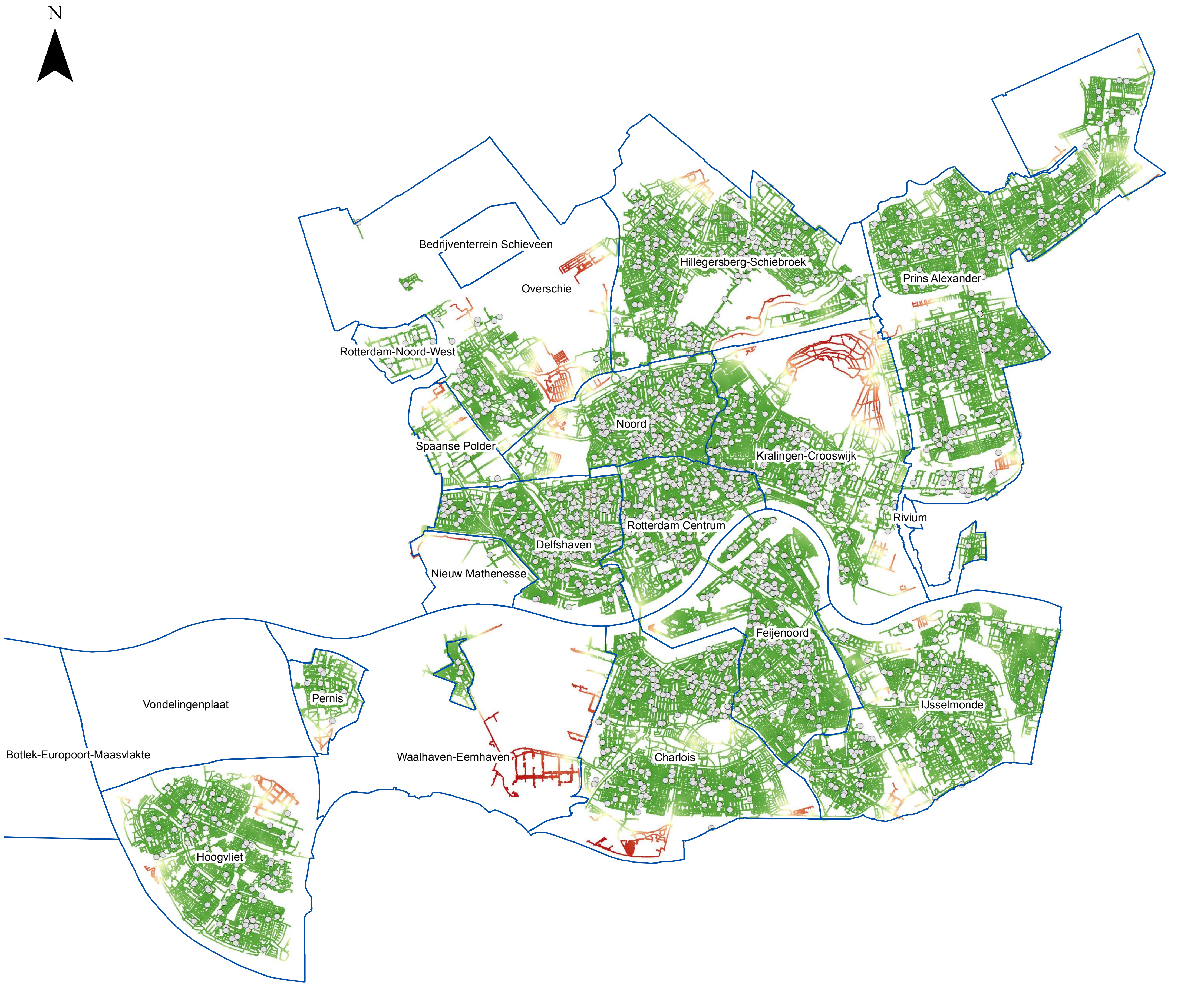


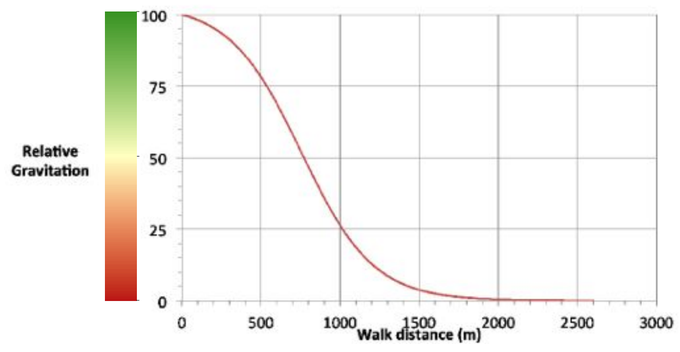
Walking gravitation to service

Care: best-case scenario

District border

Service point

Relative gravitation function
(based on TNO, 2004)



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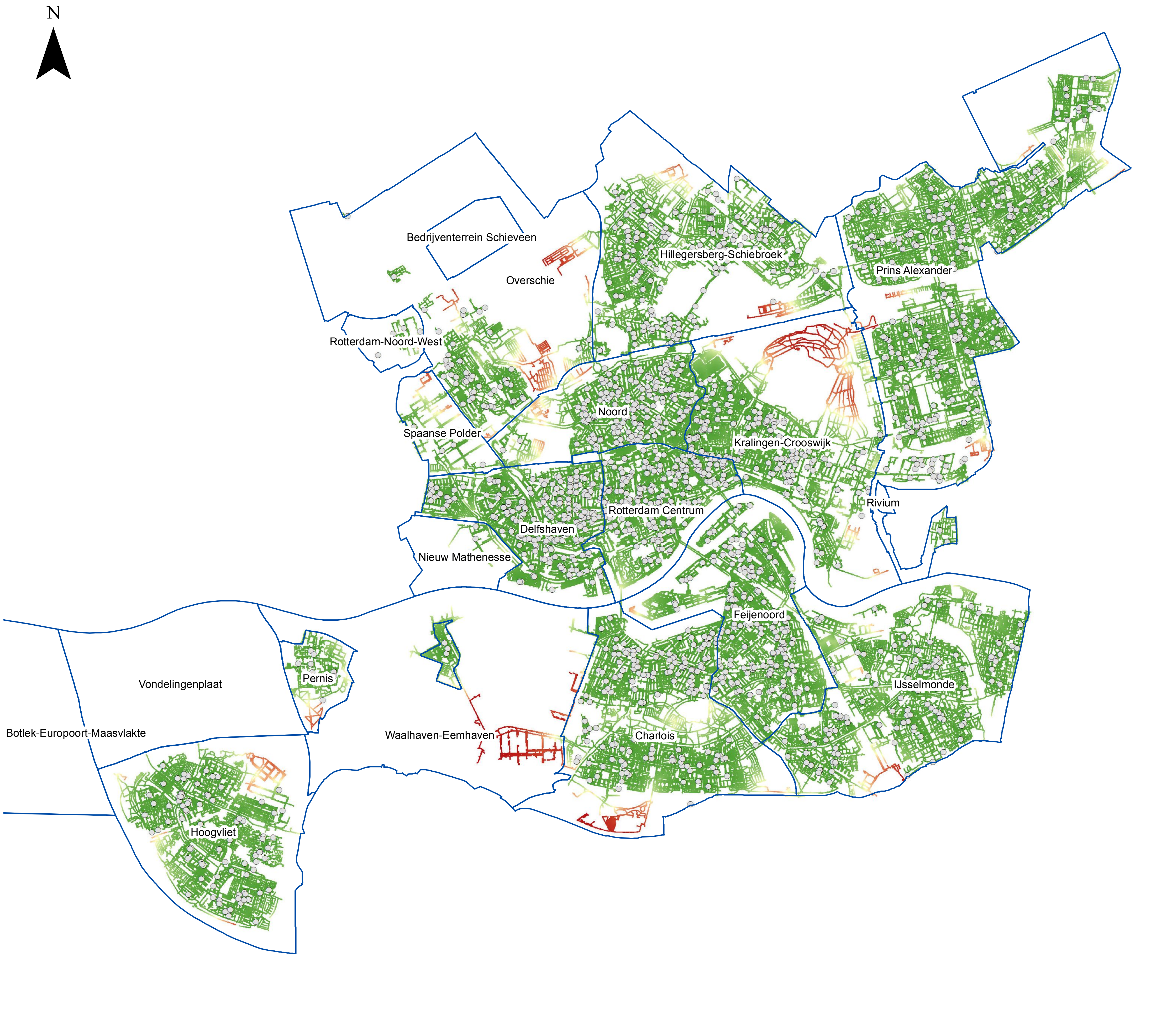


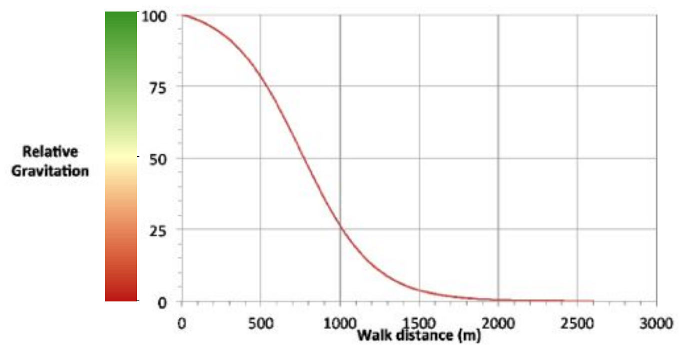
Walking gravitation to service

Care: worst-case scenario

District border

Service point

Relative gravitation function
(based on TNO, 2004)



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- Business register (Bedrijvenregister 2011)

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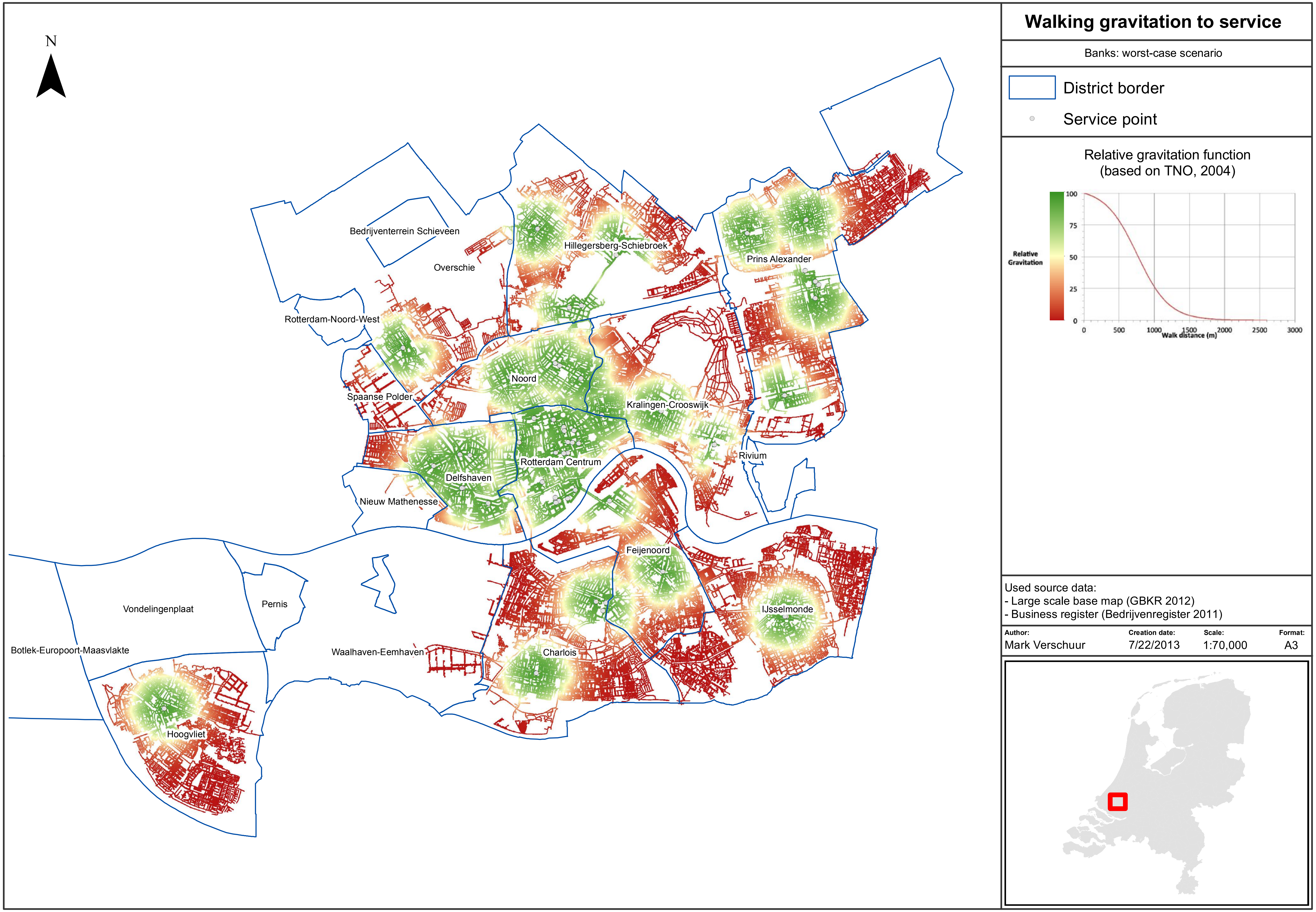
Walking gravitation to service
Banks: worst-case scenario
District border
Service point
Relative gravitation function
(based on TNO, 2004)
Relative Gravitation
100
75
50
25
0
0
500
1000
1500
2000
2500
3000
Walk distance (m)
Used source data:
- Large scale base map (GBKR 2012)
- Business register (Bedrijvenregister 2011)
Author:
Mark Verschuur
Creation date:
7/22/2013
Scale:
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Format:
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Noord
Spaanse Polder
Kralingen-Crooswijk
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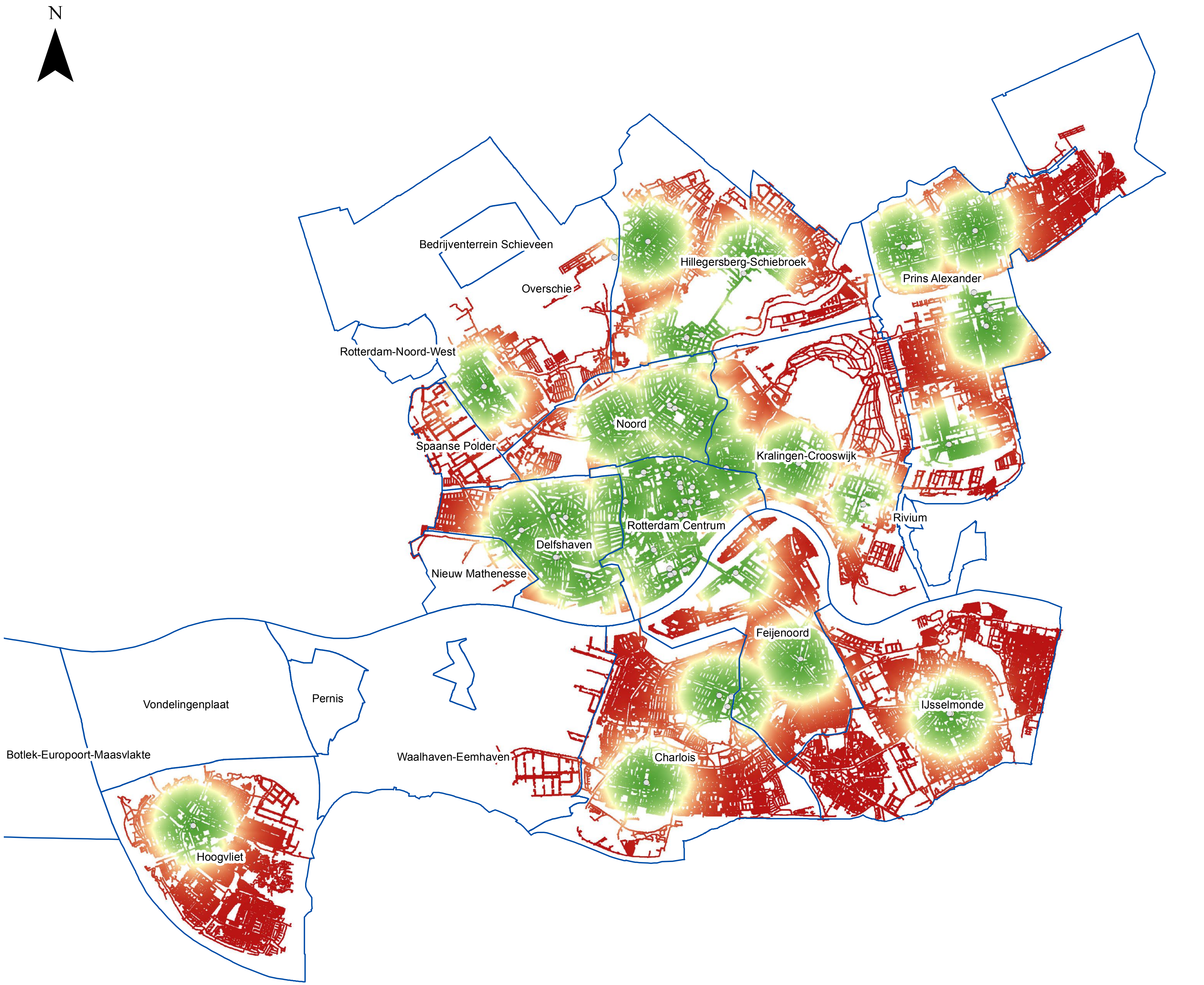
Botlek-Europoort-Maasvlakte
Waalhaven-Eemhaven
Charlois
Hoogvliet



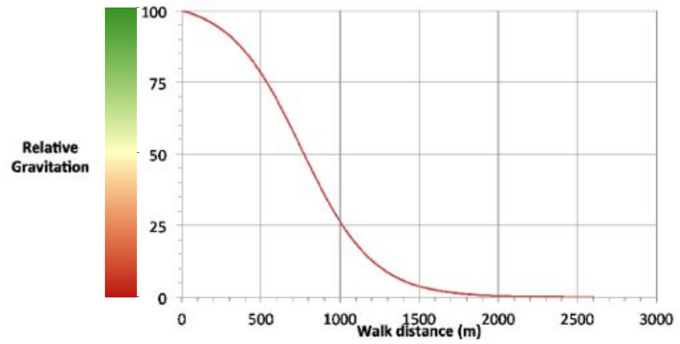
Walking gravitation to service

Banks: control scenario

District border

Service point

Relative gravitation function
(based on TNO, 2004)



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- Business register (Bedrijvenregister 2011)

Author:	Creation date:	Scale:	Format:
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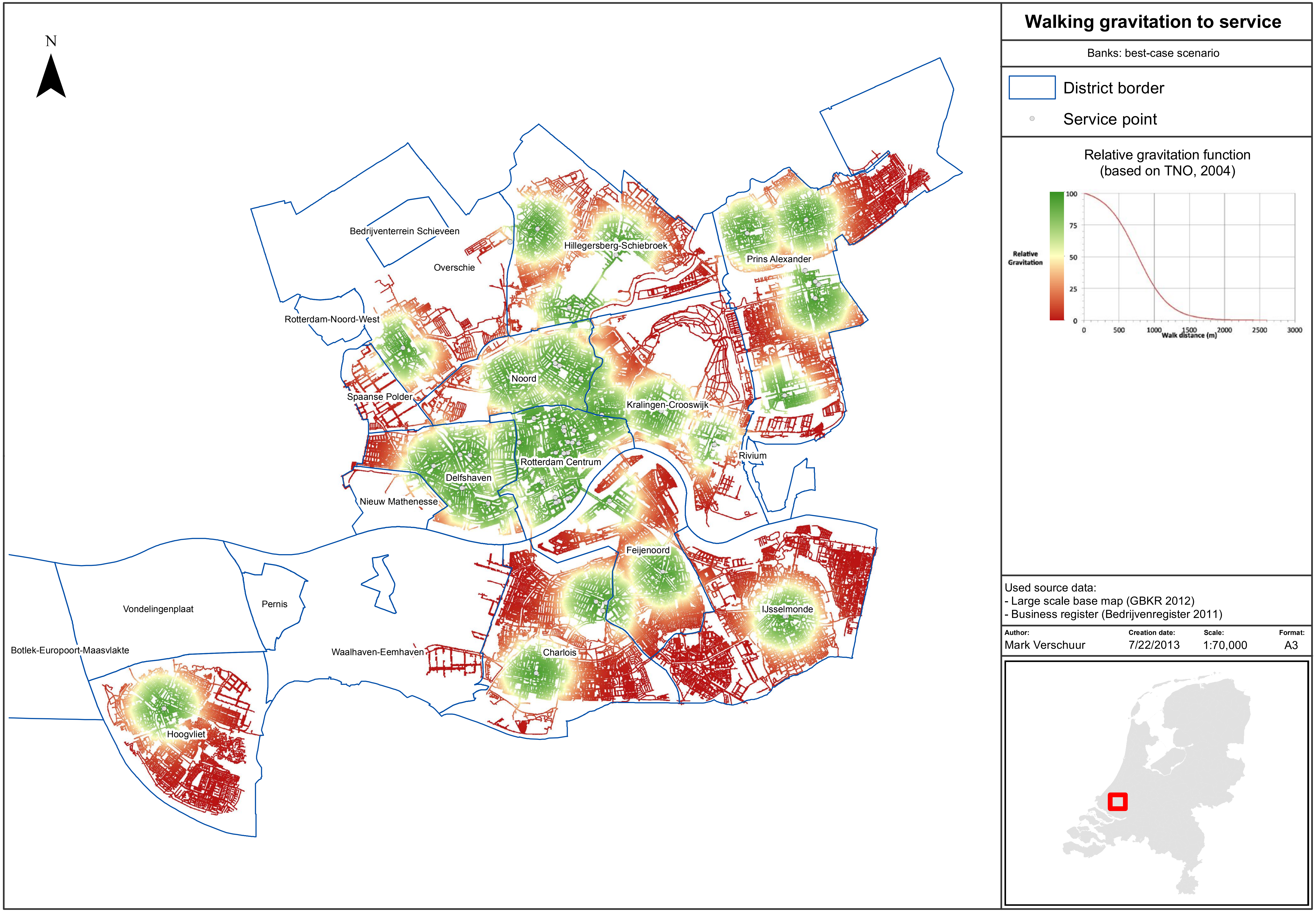
Walking gravitation to service
Banks: best-case scenario
District border
Service point
Relative gravitation function
(based on TNO, 2004)
Relative Gravitation
100
75
50
25
0
0
500
1000
1500
2000
2500
3000
Walk distance (m)
Used source data:
- Large scale base map (GBKR 2012)
- Business register (Bedrijvenregister 2011)
Author:
Mark Verschuur
Creation date:
7/22/2013
Scale:
1:70,000
Format:
A3
N
Bedrijventerrein Schieveen
Overschie
Hillegersberg-Schiebroek
Prins Alexander
Rotterdam-Noord-West
Noord
Spaanse Polder
Kralingen-Crooswijk
Rotterdam Centrum
Delfshaven
Rivium
Nieuw Mathenesse
Feijenoord
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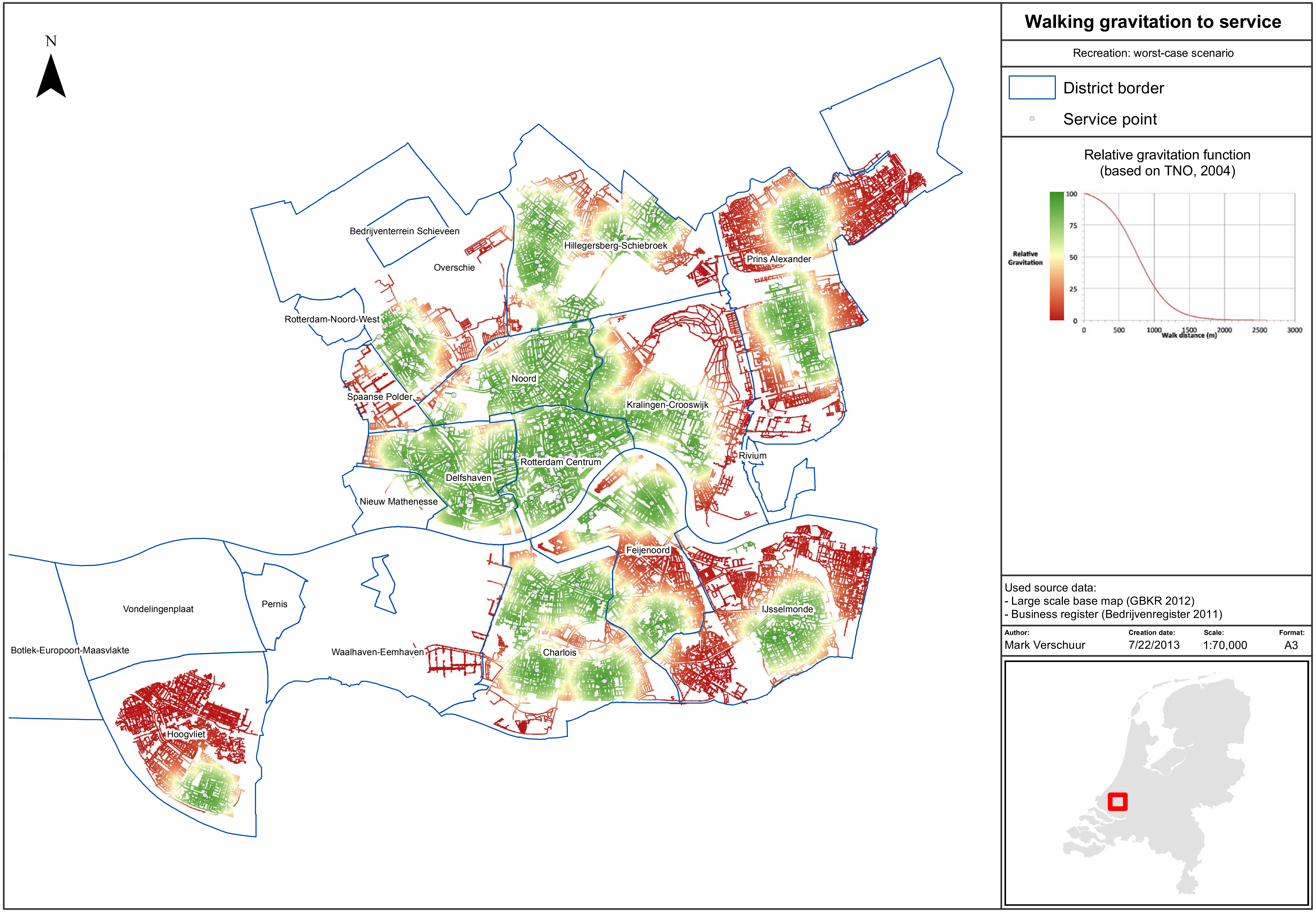
Pernis
IJsselmonde
Botlek-Europoort-Maasvlakte
Waalhaven-Eemhaven
Charlois
Hoogvliet


Walking gravitation to service
Recreation: worst-case scenario
District border
Service point
Relative gravitation function
(based on TNO, 2004)
Relative Gravitation
100
75
50
25
0
0
500
1000
1500
2000
2500
3000
Walk distance (m)
Used source data:
- Large scale base map (GBKR 2012)
- Business register (Bedrijvenregister 2011)
Author:
Mark Verschuur
Creation date:
7/22/2013
Scale:
1:70,000
Format:
A3
N
Bedrijventerrein Schieveen
Overschie
Hillegersberg-Schiebroek
Prins Alexander
Rotterdam-Noord-West
Noord
Spaanse Polder
Kralingen-Crooswijk
Rotterdam Centrum
Delfshaven
Rivium
Nieuw Mathenesse
Feijenoord
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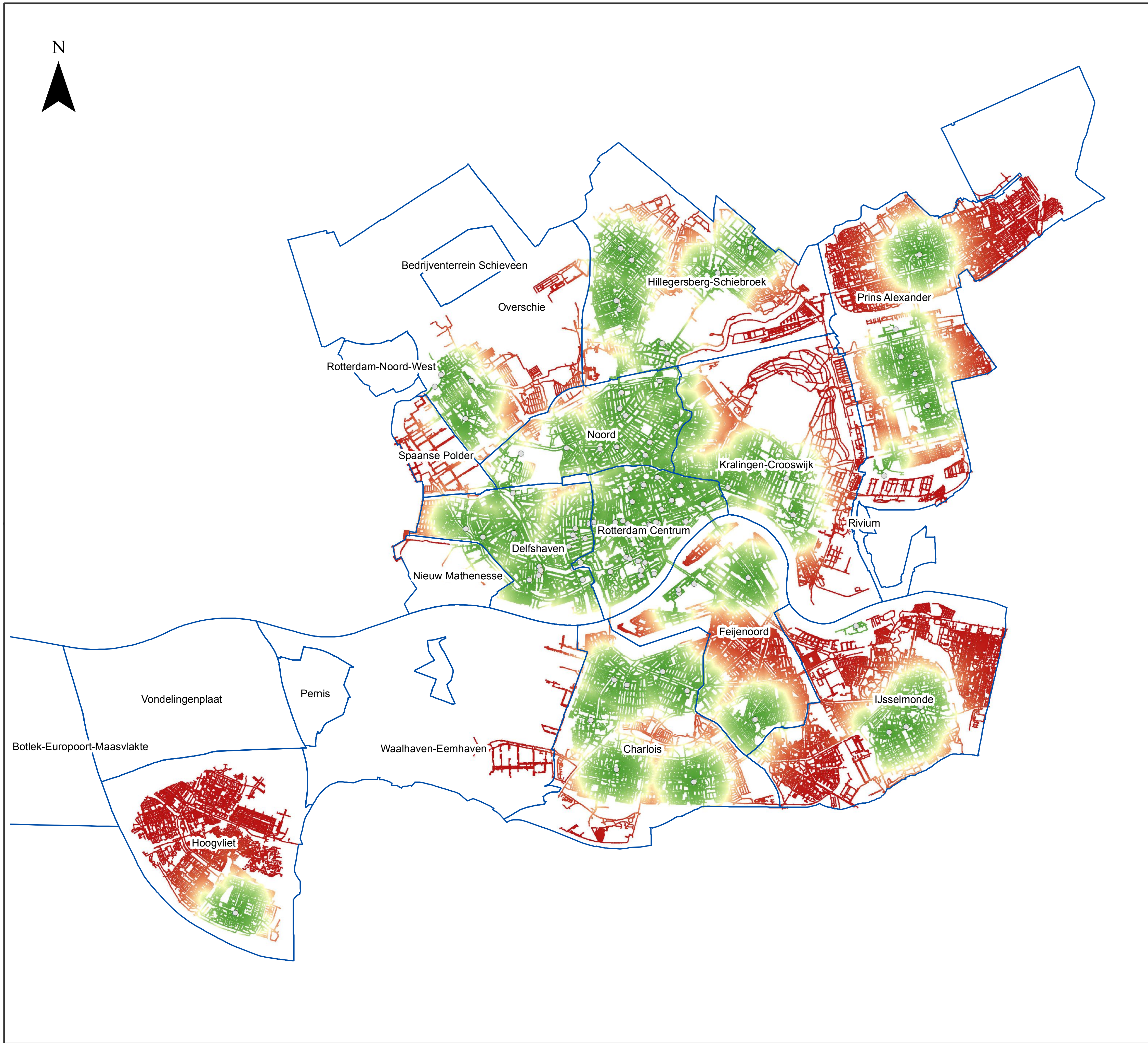
Waalhaven-Eemhaven
Charlois
Hoogvliet



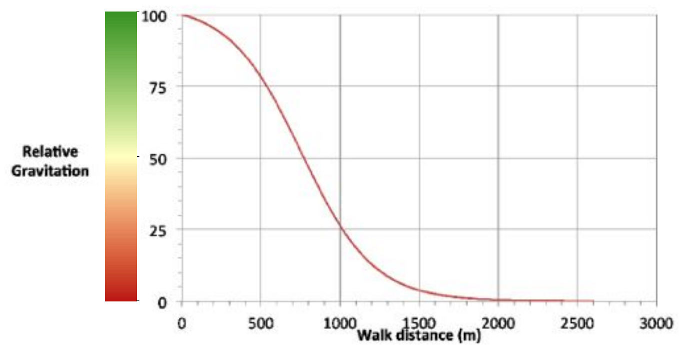
Walking gravitation to service

Recreation: control scenario

District border

Service point

Relative gravitation function
(based on TNO, 2004)



Used source data:
- Large scale base map (GBKR 2012)
- Business register (Bedrijvenregister 2011)

Author:	Creation date:	Scale:	Format:
Mark Verschuur	7/22/2013	1:70,000	A3

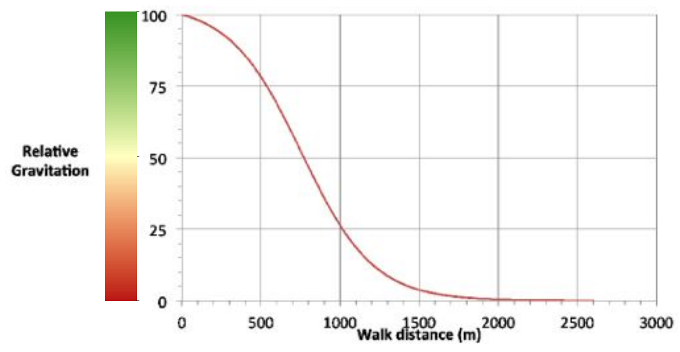
Walking gravitation to service

Recreation: best-case scenario

District border

Service point

Relative gravitation function
(based on TNO, 2004)



Used source data:
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- Business register (Bedrijvenregister 2011)

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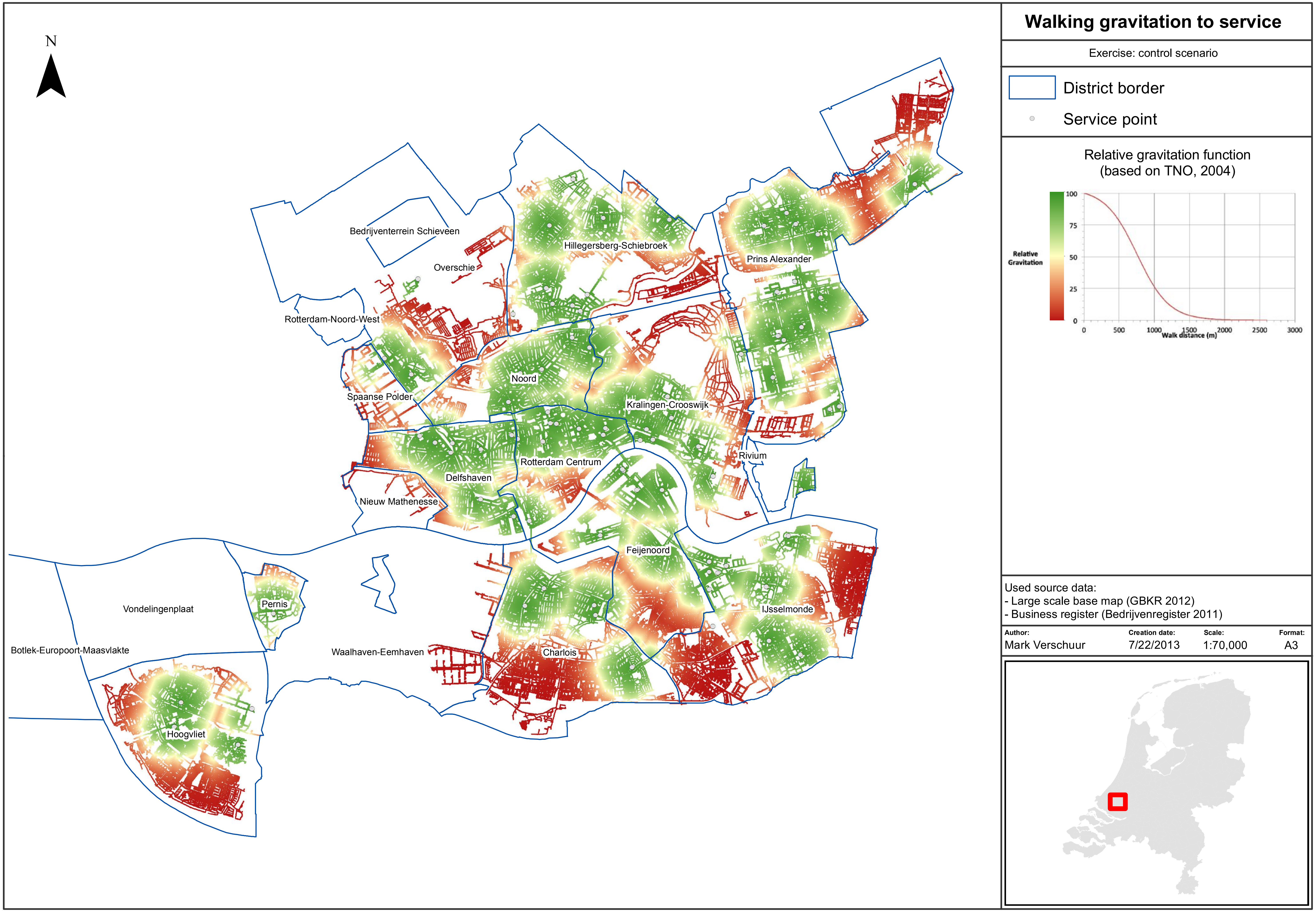
Walking gravitation to service
Exercise: control scenario
District border
Service point
Relative gravitation function
(based on TNO, 2004)
Relative Gravitation
100
75
50
25
0
0
500
1000
1500
2000
2500
3000
Walk distance (m)
Used source data:
- Large scale base map (GBKR 2012)
- Business register (Bedrijvenregister 2011)
Author:
Mark Verschuur
Creation date:
7/22/2013
Scale:
1:70,000
Format:
A3
N
Bedrijventerrein Schieveen
Overschie
Hillegersberg-Schiebroek
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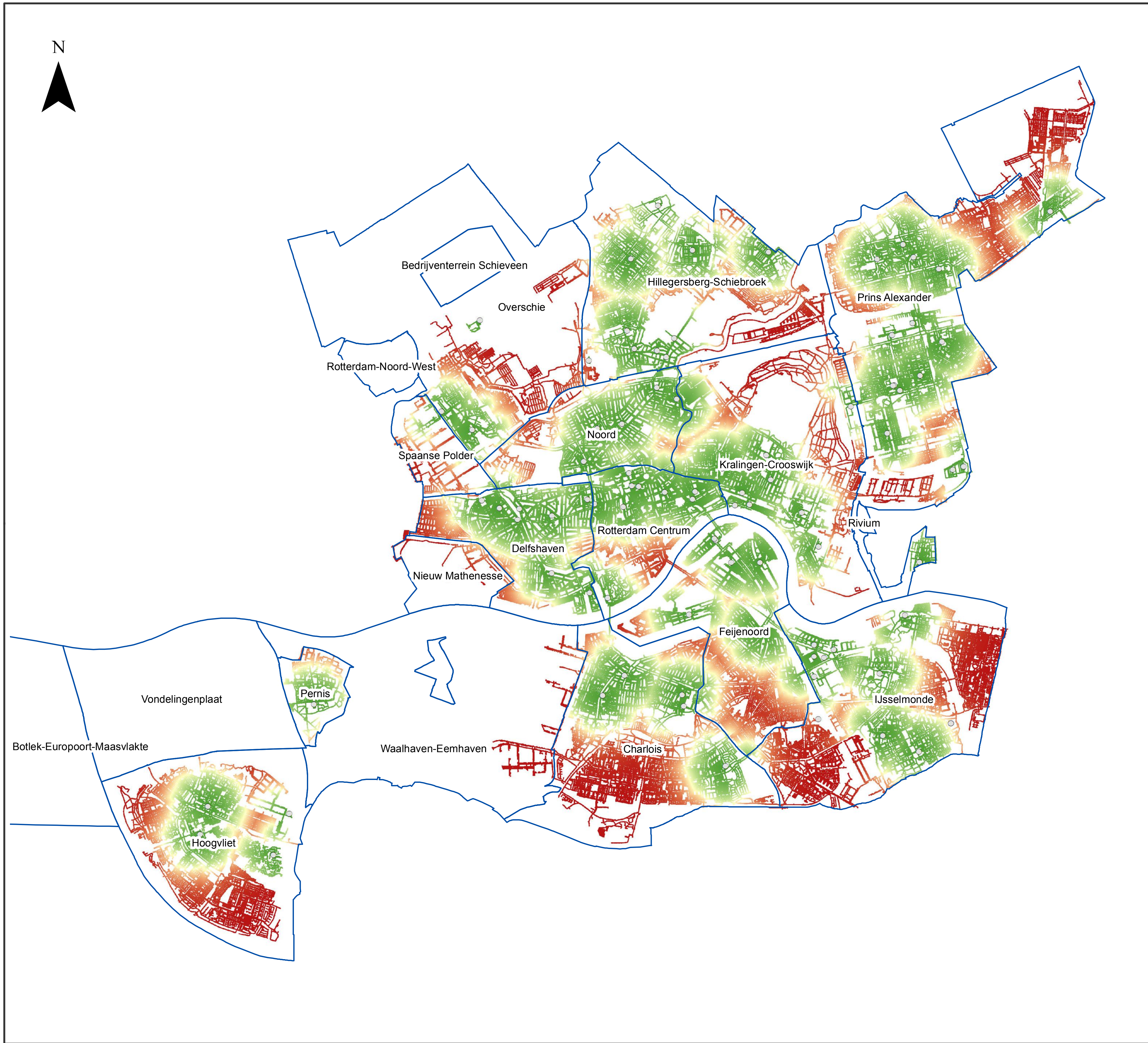
Noord
Spaanse Polder
Kralingen-Crooswijk
Rotterdam Centrum
Delfshaven
Rivium
Nieuw Mathenesse
Feijenoord
Pernis
Vondelingenplaat
IJsselmonde
Botlek-Europoort-Maasvlakte
Waalhaven-Eemhaven
Charlois
Hoogvliet

Walking gravitation to service

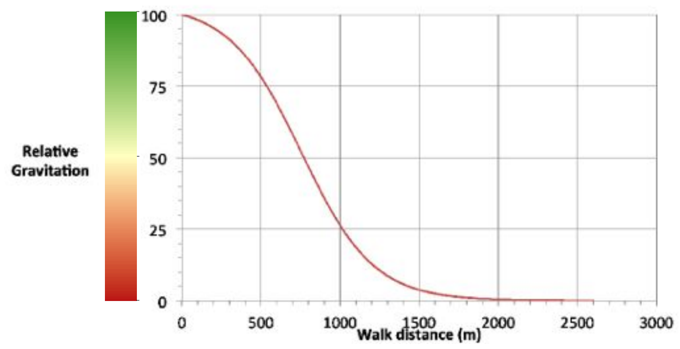
Exercise: best-case scenario



District border

Service point

Relative gravitation function
(based on TNO, 2004)

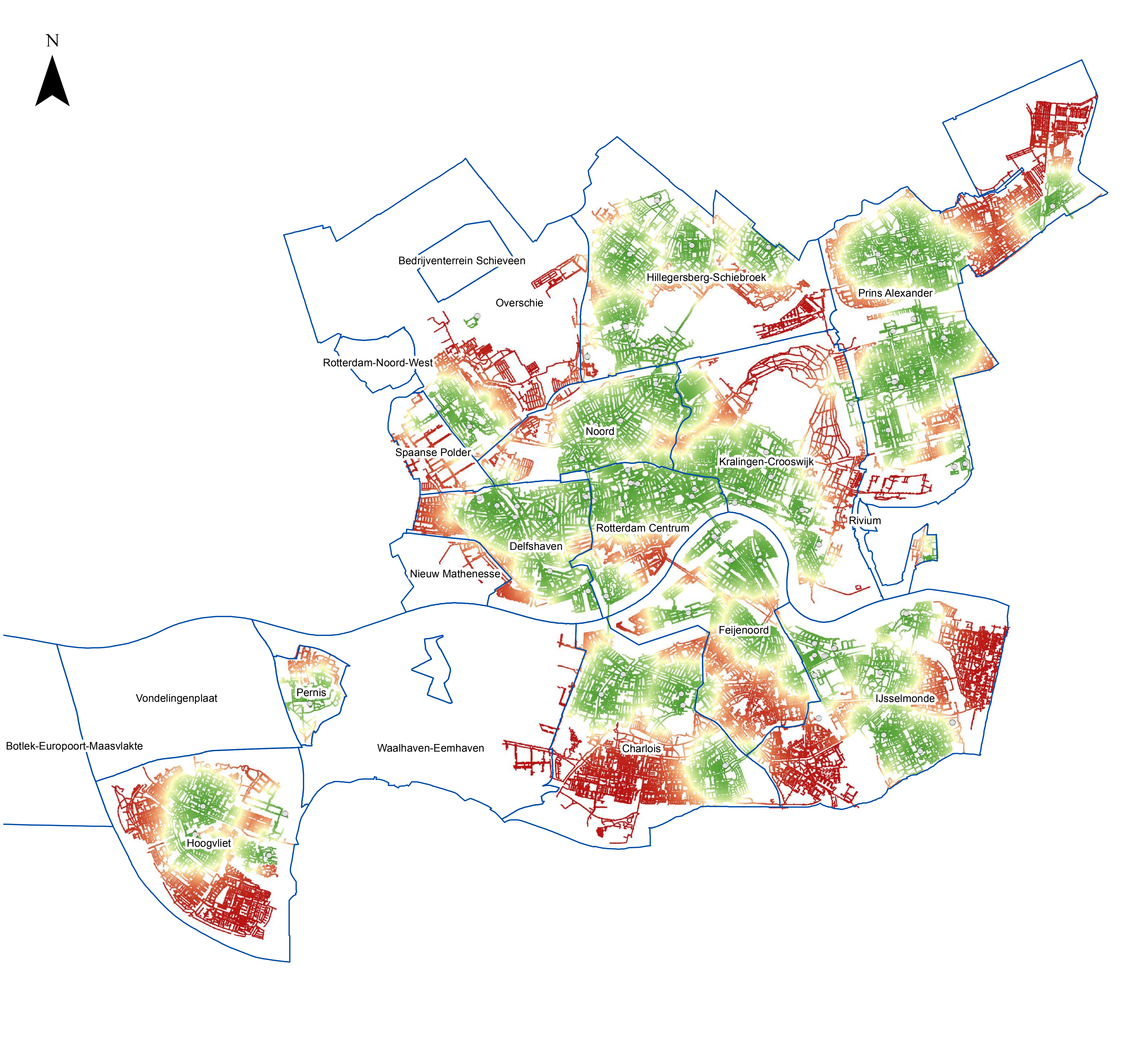


Used source data:
- Large scale base map (GBKR 2012)
- Business register (Bedrijvenregister 2011)

Author:	Creation date:	Scale:	Format:
Mark Verschuur	7/22/2013	1:70,000	A3

Walking gravitation to service

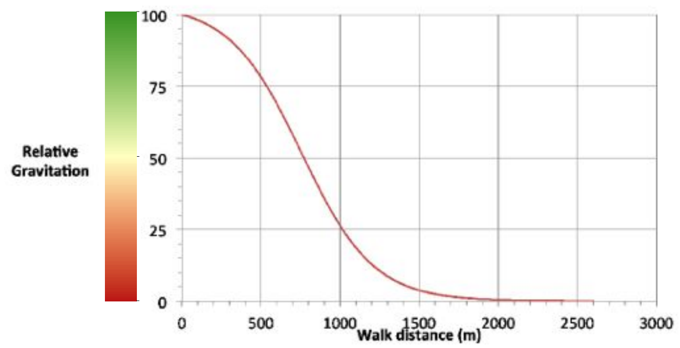
Exercise: worst-case scenario



District border

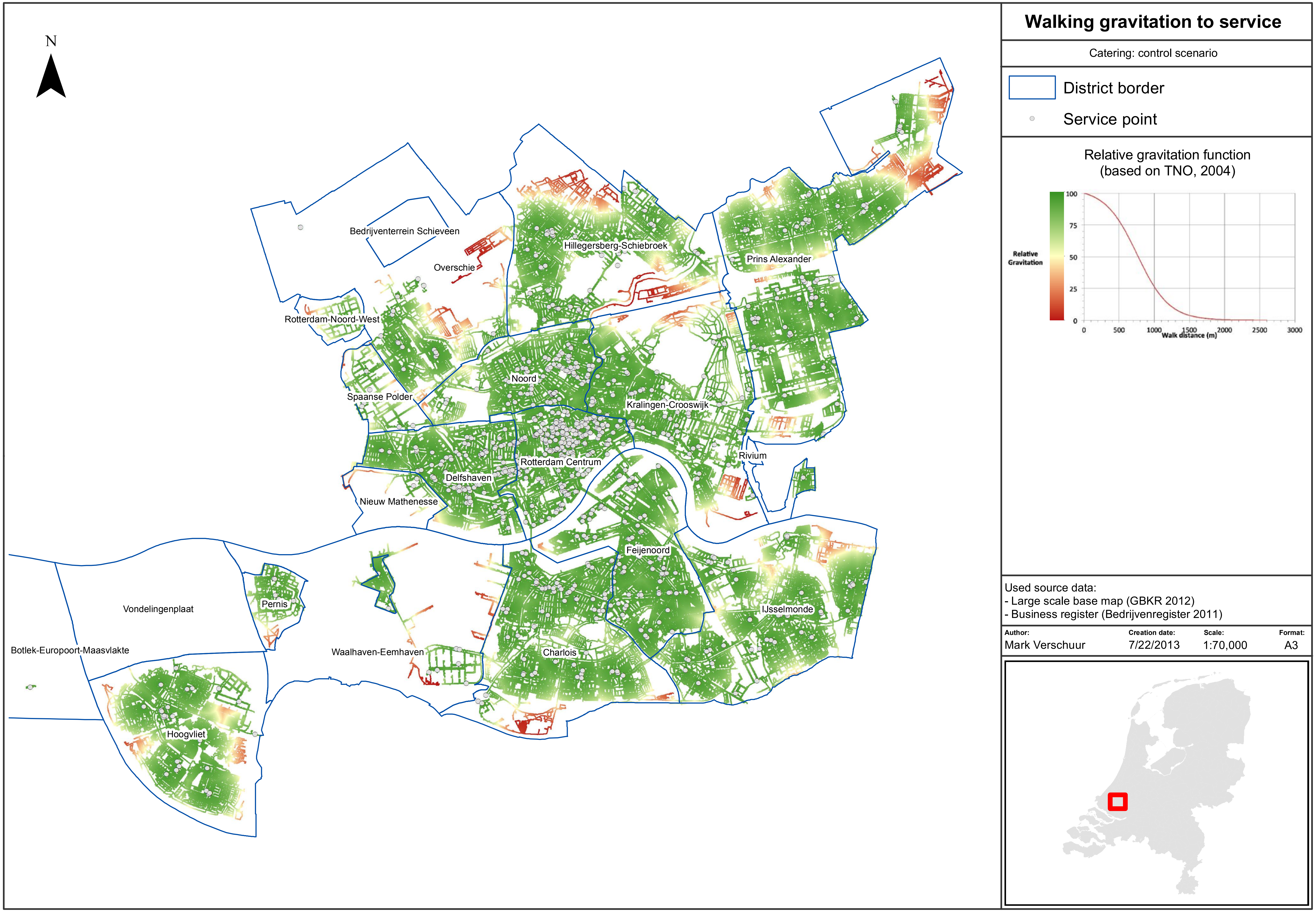
Service point

Relative gravitation function
(based on TNO, 2004)



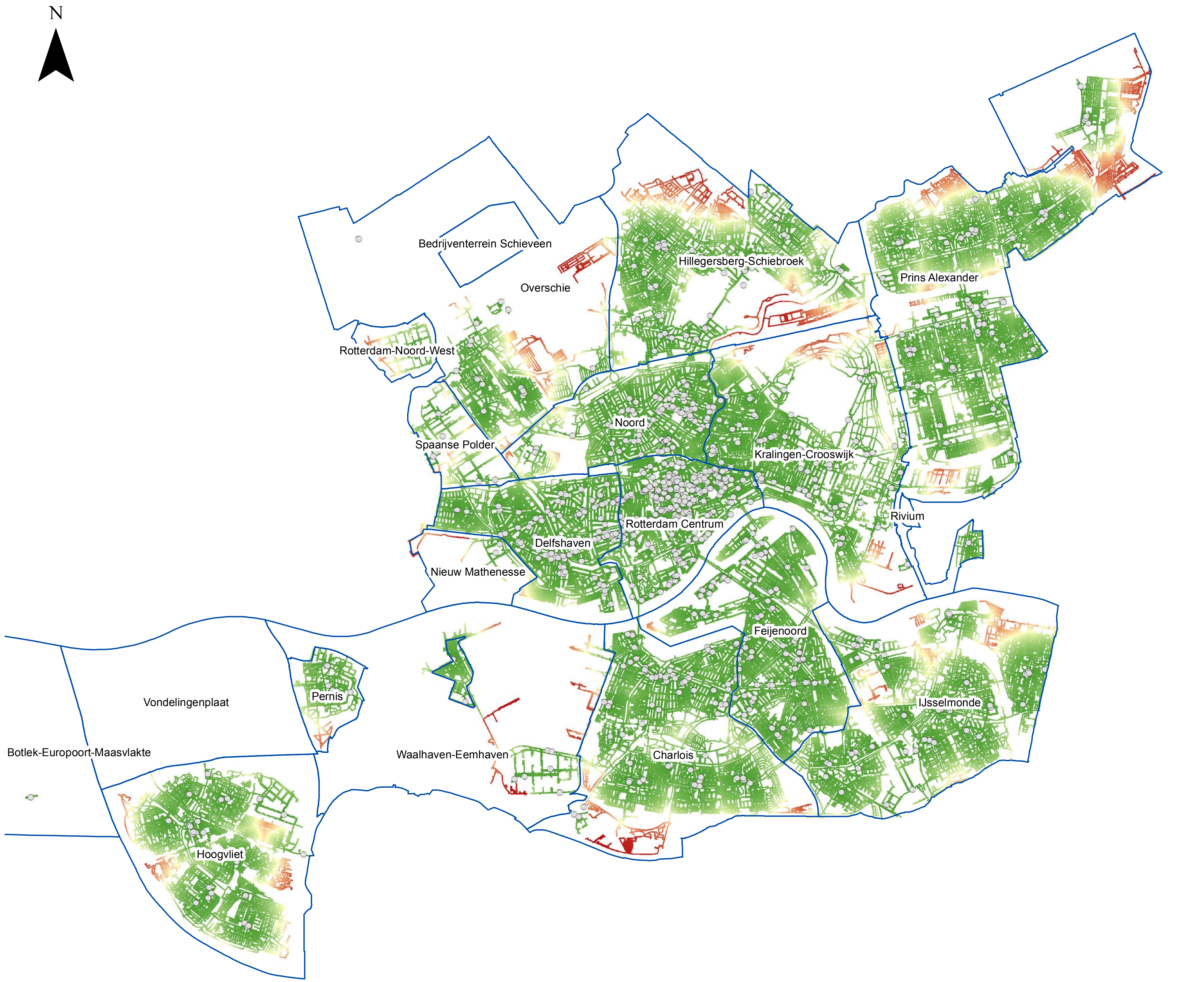
Used source data:
- Large scale base map (GBKR 2012)
- Business register (Bedrijvenregister 2011)

Author:	Creation date:	Scale:	Format:
Mark Verschuur	7/22/2013	1:70,000	A3


Walking gravitation to service
Catering: control scenario
District border
Service point
Relative gravitation function
(based on TNO, 2004)
Relative Gravitation
100
75
50
25
0
0
500
1000
1500
2000
2500
3000
Walk distance (m)
Used source data:
- Large scale base map (GBKR 2012)
- Business register (Bedrijvenregister 2011)
Author:
Mark Verschuur
Creation date:
7/22/2013
Scale:
1:70,000
Format:
A3
N
Bedrijventerrein Schieveen
Overschie
Hillegersberg-Schiebroek
Prins Alexander
Rotterdam-Noord-West
Noord
Spaanse Polder
Kralingen-Crooswijk
Rotterdam Centrum
Delfshaven
Rivium
Nieuw Mathenesse
Feijenoord
Vondelingenplaat
Pernis
IJsselmonde
Botlek-Europoort-Maasvlakte
Waalhaven-Eemhaven
Charlois
Hoogvliet

Walking gravitation to service

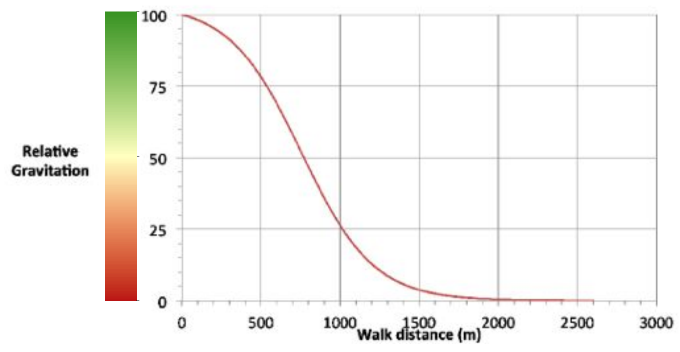
Catering: best-case scenario



District border

Service point

Relative gravitation function
(based on TNO, 2004)

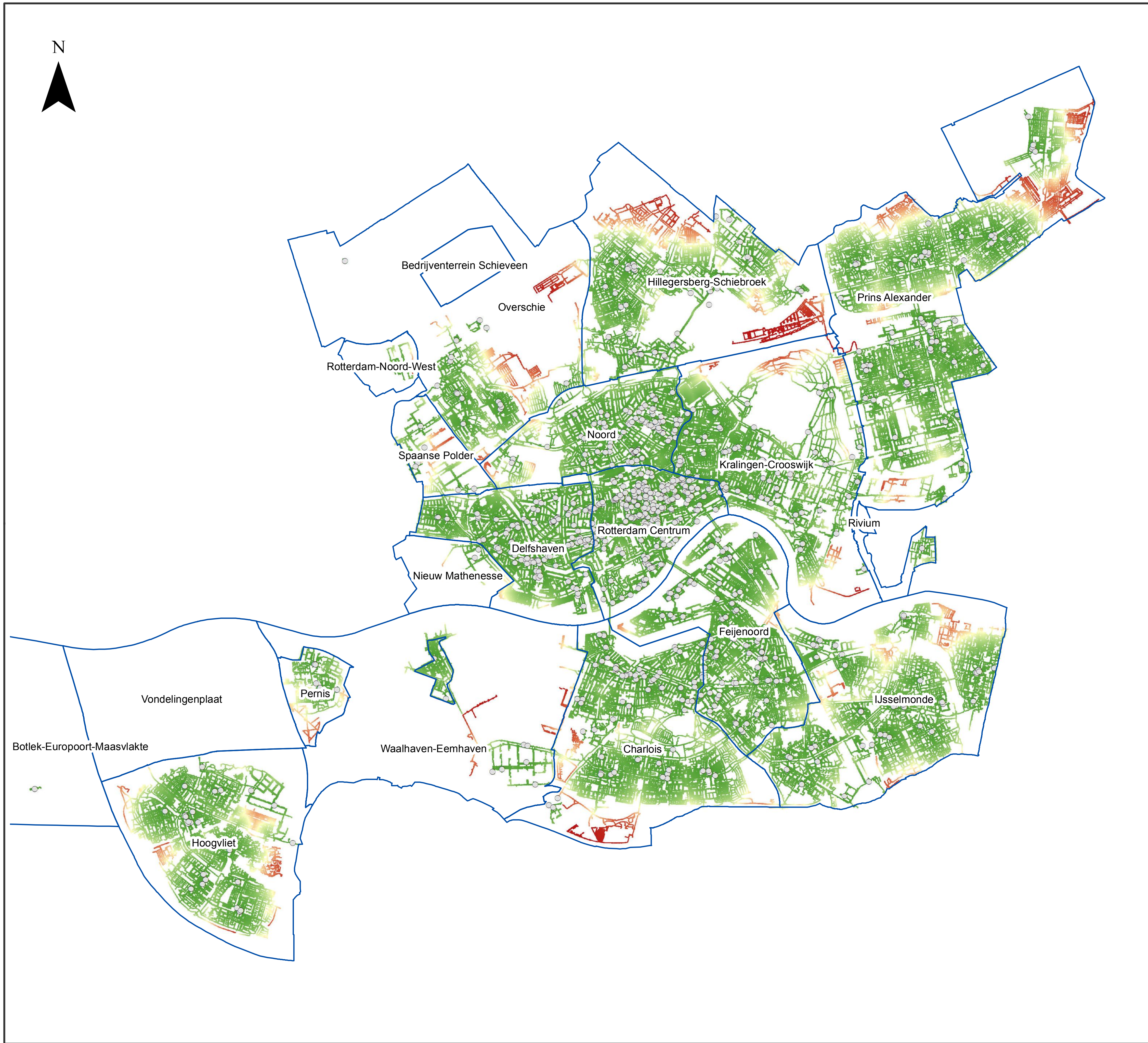


Used source data:
- Large scale base map (GBKR 2012)
- Business register (Bedrijvenregister 2011)

Author:	Creation date:	Scale:	Format:
Mark Verschuur	7/22/2013	1:70,000	A3

Walking gravitation to service

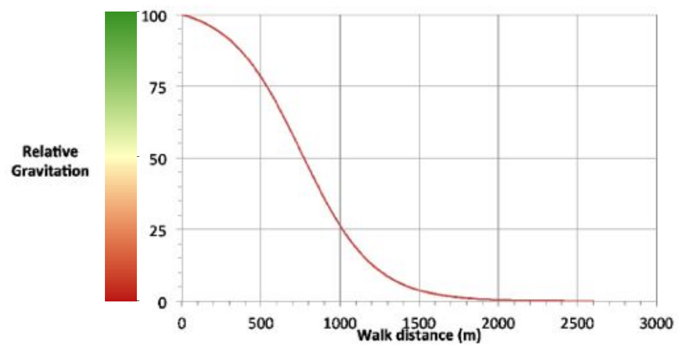
Catering: wide enough no chance of barriers



District border

Service point

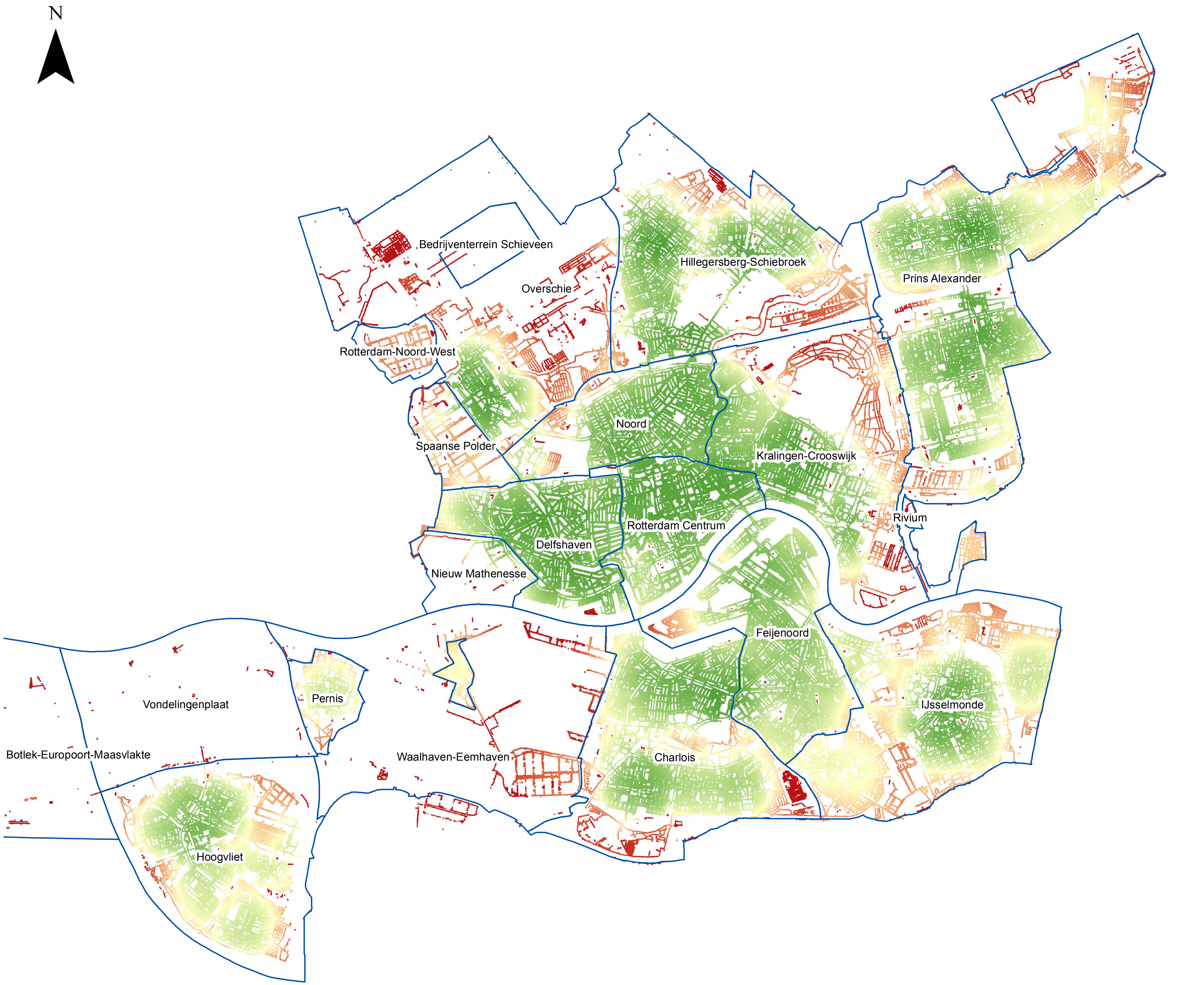
Relative gravitation function (based on TNO, 2004)



Used source data:
- Large scale base map (GBKR 2012)
- Business register (Bedrijvenregister 2011)

Author:	Creation date:	Scale:	Format:
Mark Verschuur	7/22/2013	1:70,000	A3

Annex 4: Mean walking gravitation maps per network scenario

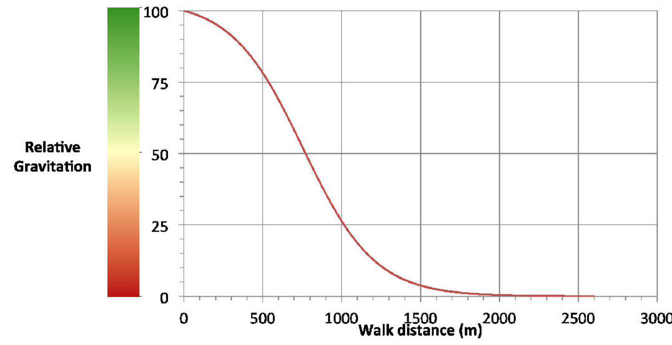


Mean walking gravitation

best-case scenario

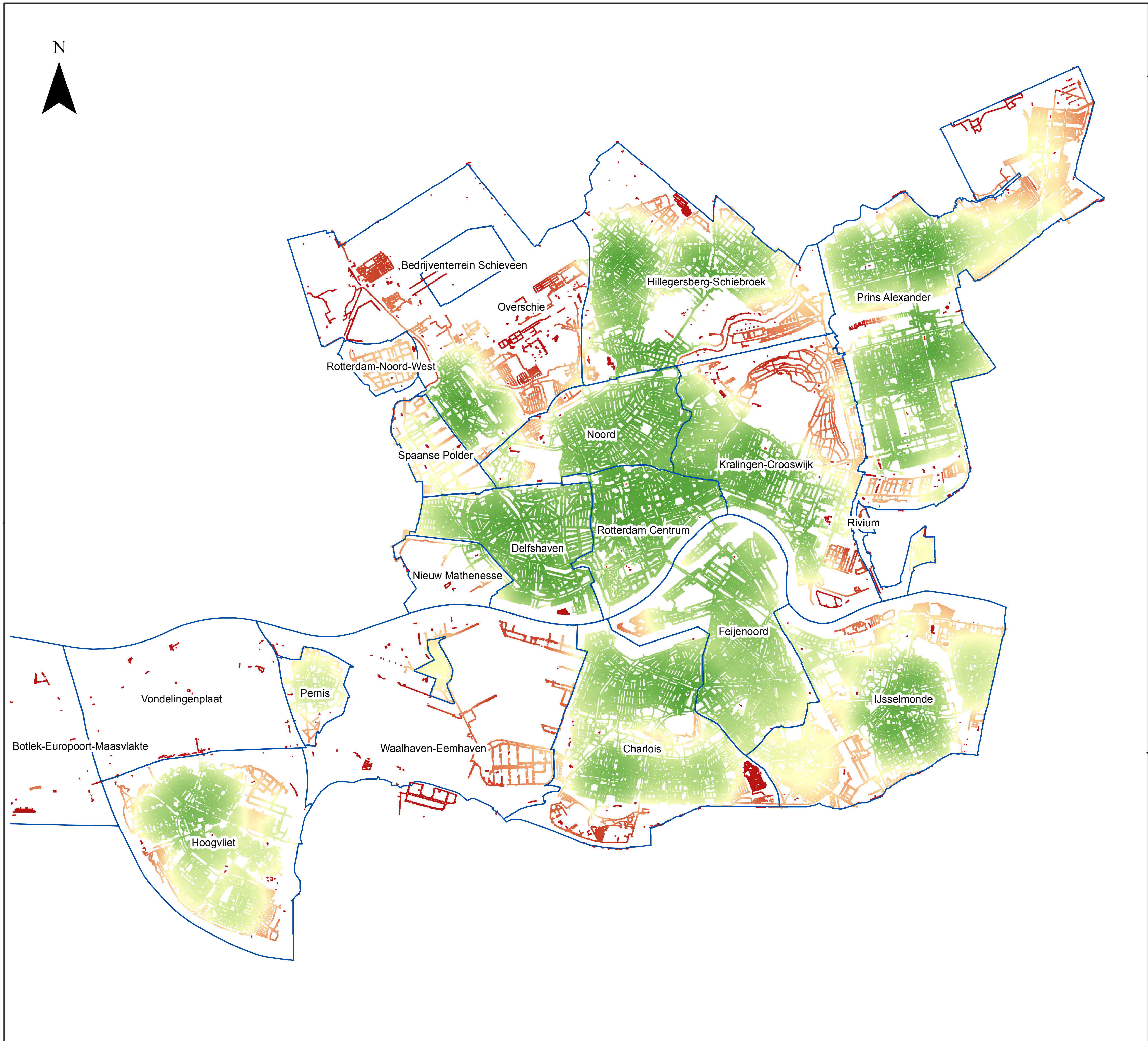
District border

Relative gravitation function
(based on TNO, 2004)



Used source data:
- Large scale base map (GBKR 2012)
- Business register (Bedrijvenregister 2011)

Author:	Creation date:	Scale:	Format:
Mark Verschuur	5/17/2013	1:70,000	A3

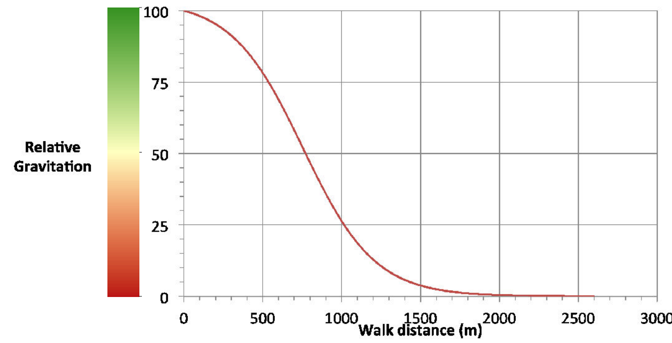


Mean walking gravitation

control scenario

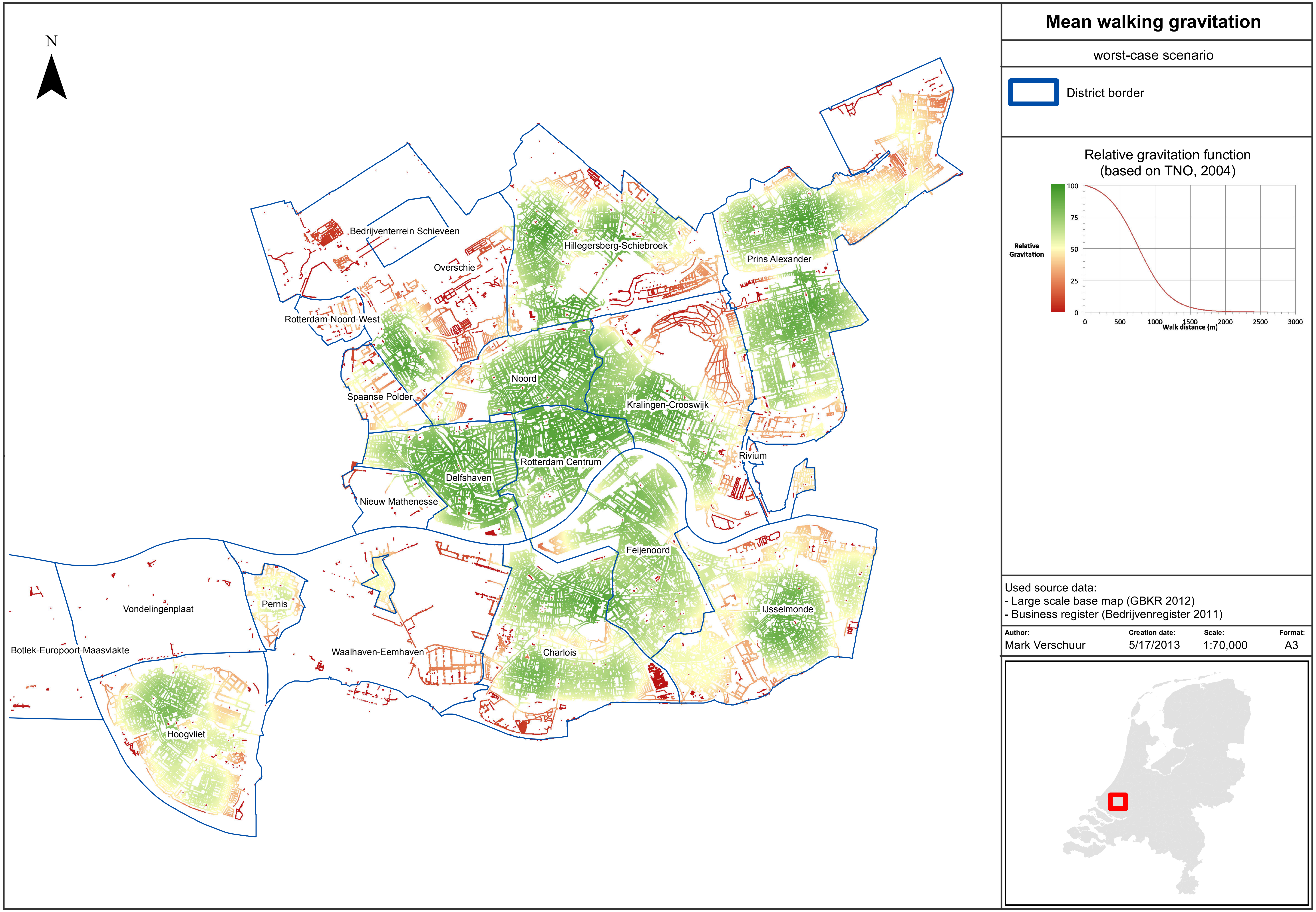
District border

Relative gravitation function
(based on TNO, 2004)



Used source data:
- Large scale base map (GBKR 2012)
- Business register (Bedrijvenregister 2011)

Author:	Creation date:	Scale:	Format:
Mark Verschuur	5/17/2013	1:70,000	A3


Mean walking gravitation
worst-case scenario
District border
Relative gravitation function
(based on TNO, 2004)
Relative Gravitation
100
75
50
25
0
0
500
1000
1500
2000
2500
3000
Walk distance (m)
Used source data:
- Large scale base map (GBKR 2012)
- Business register (Bedrijvenregister 2011)
Author:
Mark Verschuur
Creation date:
5/17/2013
Scale:
1:70,000
Format:
A3
N
Bedrijventerrein Schieveen
Overschie
Hillegersberg-Schiebroek
Prins Alexander
Rotterdam-Noord-West
Noord
Spaanse Polder
Kralingen-Crooswijk
Rotterdam Centrum
Rivium
Delfshaven
Nieuw Mathenesse
Feijenoord
Vondelingenplaat
Pernis
IJsselmonde
Botlek-Europoort-Maasvlakte
Waalhaven-Eemhaven
Charlois
Hoogvliet

Annex 5 (1/2): Relevant facilities for the elderly as described in literature

DESTINATION	WALK SCORE CATEGORY	DESCRIBED BY	DATA SOURCE	SELECTION CRITERIA
(indoor) atm	banks	Veldacademie, 2012a & 2012b	unknown	SELECT * FROM 2011_BRZ_sectie WHERE "SBI_5_omsc" IN ('Spaarbanken','Algemene banken')
bank		TNO, 2004, Veldacademie, 2012a & 2012b, Valdemarsson, M. et.al., 2004, Gant R. 2010	Bedrijvenregister 2011	
bookshop	books	Valdemarsson, M. et.al., 2004	Bedrijvenregister 2011	SELECT * FROM 2011_BRZ_sectie WHERE SBI_5_omsc LIKE '%boek%' AND "SBI_5_omsc" LIKE '%inkel%' OR "SBI_5_omsc" LIKE '%biblio%'
library		TNO, 2004, Gant R. 2010	Bedrijvenregister 2011	
dentist	care*	TNO, 2004	Bedrijvenregister 2011	SELECT * FROM 2011_BRZ_sectie WHERE "SBI_5_omsc" IN ('Algemene ziekenhuizen','Categorale ziekenhuizen','Geestelijke gezondheids- en verslavingszorg met overnachting','Gezondheidscentra','Huizen en dagverblijven voor niet-verstandelijk gehandicapten','Huizen en dagverblijven voor verstandelijk gehandicapten en psychiatrische cliënten','Lokaal welzijnswerk','Maatschappelijk opvang met overnachting','Maatschappelijk werk','Medische laboratoria, trombodediensten en overig behandelingsondersteunend onderzoek','Ondersteuning en begeleiding van gehandicapten','Overig maatschappelijk advies, gemeenschapshuizen en samenwerkingsorganen op het gebied van welzijn','Overige paramedische praktijken (geen fysiotherapie en psychologie) en alternatieve genezers','Praktijken van fysiotherapeuten','Praktijken van huisartsen','Praktijken van medisch specialisten en medische dagbehandelcentra (geen tandheelkunde of psychiatrie)','Praktijken van psychiaters en dagbehandelcentra voor geestelijke gezondheids- en verslavingszorg','Praktijken van psychotherapeuten en psychologen','Praktijken van tandartsen','Praktijken van tandheelkundig specialisten','Preventieve gezondheidszorg (geen arbobegeleiding)','Samenwerkingsorganen op het gebied van gezondheidszorg en overige gezondheidszorgondersteunende diensten','Universitair medische centra','Verpleeghuizen','Verzorgingshuizen','Welzijnswerk voor ouderen','Apotheken','Haarverzorging')
dietician		Veldacademie, 2012a & 2012b	unknown	
family doctor		TNO, 2004 & Veldacademie, 2012a & 2012b	Bedrijvenregister 2011	
hairdresser		TNO, 2004, Veldacademie, 2012a & 2012b, Valdemarsson, M. et.al., 2004	Bedrijvenregister 2011	
hearing care professional		TNO, 2004	unknown	
hospital		TNO, 2004	Bedrijvenregister 2011	
nursing home		TNO, 2004	Bedrijvenregister 2011	
paramedical therapist		Veldacademie, 2012a & 2012b	Bedrijvenregister 2011	
pharmacy / drugstore		TNO, 2004, Veldacademie, 2012a & 2012b, Valdemarsson, M. et.al., 2004	Bedrijvenregister 2011	
physiotherapy		TNO, 2004 & Veldacademie, 2012a & 2012b	Bedrijvenregister 2011	
public medical service		*Valdemarsson, M. et.al., 2004*	*unknown*	
service center / community center		TNO, 2004	Bedrijvenregister 2011	
mailbox	*daily facilities**	*TNO, 2004*	*unknown*	-
public telephone		*Gant R. 2010*	*unknown*	
post office		*TNO, 2004, Veldacademie, 2012a & 2012b, Valdemarsson, M. et.al., 2004, Gant R. 2010*	*unknown*	
sports club / fitniss	exercise*	TNO, 2004	Bedrijvenregister 2011	"SBI_5_omsc" IN ('Bowlen, kegelen, biljarten e.d.','Fitnesscentra','Individuele zaalsport','Kracht- en vechtsport','Overige buitensport','Overige sportaccommodaties','Paardensport en maneges Roei-, kano-, zeil- en surfsport e.d.','Sporthallen, sportzalen en gymzalen','Sportscholen','Sportvelden','Tennis','Veldsport in teamverband (geen voetbal)','Veldvoetbal','Zwem- en onderwatersport','Zwembaden')
swimming pool		TNO, 2004	Bedrijvenregister 2011	
local government office	*govenment**	*Gant R. 2010*	*unknown*	-
supermarket	grocery	TNO, 2004 & Veldacademie, 2012a & 2012b	Bedrijvenregister 2011	SELECT * FROM 2011_BRZ_sectie WHERE "SBI_5_omsc" LIKE '%upermarkten en%'
greenbelts and parks	*parks*	*Veldacademie, 2012a & 2012b*	*unknown*	-

Annex 5 (2/2): Relevant facilities for the elderly as described in literature

DESTINATION	WALK SCORE CATEGORY	DESCRIBED BY	DATA SOURCE	SELECTION CRITERIA
association	*recreation**	*TNO, 2004*	*unknown*	SELECT * FROM 2011_BRZ_sectie WHERE "SBI_5_omsc" IN ('Religieuze organisaties','Kunstgalerieën en –expositieruimten','Musea','Theaters en schouwburgen','Dieren- en plantentuinen, kinderboerderijen')
church		TNO, 2004	Bedrijvenregister 2011	
community center / senior center		*TNO, 2004*	*unknown*	
cultural establishment		*Valdemarsson, M. et.al., 2004*	*unknown*	
drawing lessons / music lessons		*TNO, 2004*	*unknown*	
museum		TNO, 2004, Gant R. 2010	Bedrijvenregister 2011	
petting zoo / farm		TNO, 2004	Bedrijvenregister 2011	
playgrounds		*Veldacademie, 2012a & 2012b*	*unknown*	
public art		*Gant R. 2010*	*unknown*	
theater		TNO, 2004	Bedrijvenregister 2011	
club / café / party room	catering**	TNO, 2004, Valdemarsson, M. et.al., 2004, Gant R. 2010	Bedrijvenregister 2011	SELECT * FROM 2011_BRZ_sectie WHERE "SBI_5_omsc" IN ('Hotel-restaurants','Hotels (geen hotel-restaurants), pensions en conferentie-oorden','IJssalons','Kantines en contractcatering','Restaurants') OR "SBI_5_omsc" LIKE 'Cafetaria%'
restaurant		Valdemarsson, M. et.al., 2004, Gant R. 2010	Bedrijvenregister 2011	
bakery / butcher / greengrocer	shopping	TNO, 2004 & Veldacademie, 2012a & 2012b	Bedrijvenregister 2011	SELECT * FROM 2011_BRZ_sectie WHERE "SBI_5_omsc" LIKE '%inkel%' OR "SBI_5_omsc" IN ('Supermarkten en dergelijke winkels met een algemeen assortiment voedings- en genotmiddelen','Textielsupermarkten','Tuincentra','Warenhuizen')
delicatessen shop		*Valdemarsson, M. et.al., 2004*	*unknown*	
department store		Valdemarsson, M. et.al., 2004	Bedrijvenregister 2011	
florist		Valdemarsson, M. et.al., 2004	Bedrijvenregister 2011	
kiosk		*TNO, 2004*	*unknown*	
liquor store		Valdemarsson, M. et.al., 2004	Bedrijvenregister 2011	
mall / shopping area / passage		*TNO, 2004, Gant R. 2010*	*unknown*	
market		*TNO, 2004*	*unknown*	
public transport stop	transport*	TNO, 2004, Veldacademie, 2012a & 2012b, Valdemarsson, M. et.al., 2004	Open OV	All available public transport stops: train, metro, tram and bus

Annex 6 (1/3): Gravitation scores for neighbourhoods in district: Hillegersberg Schiebroek
Scenario: all pedestrian roads

Age class **50+**

	Gravitation class									
Neighbourhood name	**0-10**	**10-20**	**20-30**	**30-40**	**40-50**	**50-60**	**60-70**	**70-80**	**80-90**	**90-100**
Hillegersberg Noord	1%	0%	1%	4%	0%	9%	34%	25%	26%	0%
Hillegersberg Zuid	0%	0%	0%	0%	1%	4%	1%	16%	65%	13%
Molenlaankwartier	1%	0%	0%	2%	5%	15%	32%	31%	14%	0%
Schiebroek	0%	0%	0%	0%	0%	1%	11%	40%	42%	5%
Terbregge	17%	7%	16%	29%	31%	0%	0%	0%	0%	0%
End total	**1%**	**0%**	**1%**	**3%**	**3%**	**6%**	**19%**	**29%**	**33%**	**4%**

Age class **50-55**

	Gravitation class									
Neighbourhood name	**0-10**	**10-20**	**20-30**	**30-40**	**40-50**	**50-60**	**60-70**	**70-80**	**80-90**	**90-100**
Hillegersberg Noord	1%	0%	2%	5%	1%	8%	18%	32%	34%	0%
Hillegersberg Zuid	0%	0%	0%	0%	0%	3%	1%	18%	66%	12%
Molenlaankwartier	2%	0%	0%	2%	4%	14%	30%	36%	12%	0%
Schiebroek	0%	0%	0%	0%	1%	2%	10%	45%	38%	5%
Terbregge	13%	7%	26%	32%	22%	0%	0%	0%	0%	0%
End total	**2%**	**1%**	**3%**	**4%**	**3%**	**5%**	**12%**	**32%**	**34%**	**4%**

Age class **55-65**

	Gravitation class									
Neighbourhood name	**0-10**	**10-20**	**20-30**	**30-40**	**40-50**	**50-60**	**60-70**	**70-80**	**80-90**	**90-100**
Hillegersberg Noord	0%	0%	1%	6%	0%	6%	25%	31%	30%	0%
Hillegersberg Zuid	0%	0%	0%	0%	2%	4%	1%	15%	65%	14%
Molenlaankwartier	2%	0%	0%	2%	7%	17%	30%	32%	10%	0%
Schiebroek	0%	0%	0%	0%	0%	1%	12%	40%	41%	6%
Terbregge	18%	6%	15%	27%	33%	0%	0%	0%	0%	0%
End total	**2%**	**0%**	**1%**	**3%**	**4%**	**6%**	**15%**	**30%**	**34%**	**5%**

Age class **65-75**

	Gravitation class									
Neighbourhood name	**0-10**	**10-20**	**20-30**	**30-40**	**40-50**	**50-60**	**60-70**	**70-80**	**80-90**	**90-100**
Hillegersberg Noord	2%	0%	1%	3%	1%	7%	31%	27%	28%	0%
Hillegersberg Zuid	0%	0%	0%	0%	2%	4%	1%	16%	64%	12%
Molenlaankwartier	1%	0%	0%	3%	6%	15%	32%	31%	12%	0%
Schiebroek	1%	0%	0%	0%	0%	1%	10%	40%	41%	6%
Terbregge	19%	7%	8%	31%	34%	0%	0%	0%	0%	0%
End total	**2%**	**0%**	**1%**	**3%**	**4%**	**6%**	**19%**	**30%**	**32%**	**4%**

Age class **75-85**

	Gravitation class									
Neighbourhood name	**0-10**	**10-20**	**20-30**	**30-40**	**40-50**	**50-60**	**60-70**	**70-80**	**80-90**	**90-100**
Hillegersberg Noord	0%	0%	0%	3%	0%	11%	45%	18%	22%	0%
Hillegersberg Zuid	0%	0%	0%	0%	2%	4%	3%	16%	61%	13%
Molenlaankwartier	0%	0%	0%	1%	5%	15%	38%	30%	12%	0%
Schiebroek	0%	0%	0%	0%	0%	0%	10%	38%	46%	5%
Terbregge	24%	7%	7%	28%	35%	0%	0%	0%	0%	0%
End total	**1%**	**0%**	**0%**	**2%**	**2%**	**7%**	**25%**	**28%**	**32%**	**3%**

Age class **85+**

	Gravitation class									
Neighbourhood name	**0-10**	**10-20**	**20-30**	**30-40**	**40-50**	**50-60**	**60-70**	**70-80**	**80-90**	**90-100**
Hillegersberg Noord	0%	0%	0%	0%	0%	15%	61%	13%	10%	0%
Hillegersberg Zuid	0%	0%	0%	0%	2%	2%	0%	15%	65%	17%
Molenlaankwartier	0%	0%	0%	1%	3%	10%	30%	21%	35%	0%
Schiebroek	0%	0%	0%	0%	0%	0%	17%	33%	47%	3%
Terbregge	5%	0%	0%	18%	77%	0%	0%	0%	0%	0%
End total	**0%**	**0%**	**0%**	**1%**	**2%**	**7%**	**32%**	**23%**	**34%**	**2%**

Annex 6 (2/3): Gravitation scores for neighbourhoods in district: Hillegersberg Schiebroek
Scenario: wide enough, but chance of barriers

Age class **50+**

	Gravitation class									
Neighbourhood name	**0-10**	**10-20**	**20-30**	**30-40**	**40-50**	**50-60**	**60-70**	**70-80**	**80-90**	**90-100**
Hillegersberg Noord	6%	1%	2%	3%	3%	5%	28%	24%	29%	0%
Hillegersberg Zuid	3%	0%	0%	0%	1%	4%	2%	16%	61%	13%
Molenlaankwartier	7%	3%	0%	1%	6%	19%	38%	20%	5%	0%
Schiebroek	3%	1%	0%	0%	1%	2%	13%	38%	37%	5%
Terbregge	28%	13%	30%	21%	8%	0%	0%	0%	0%	0%
End total	**6%**	**2%**	**2%**	**2%**	**3%**	**6%**	**20%**	**26%**	**30%**	**3%**

Age class **50-55**

	Gravitation class									
Neighbourhood name	**0-10**	**10-20**	**20-30**	**30-40**	**40-50**	**50-60**	**60-70**	**70-80**	**80-90**	**90-100**
Hillegersberg Noord	2%	2%	2%	3%	2%	7%	16%	31%	35%	0%
Hillegersberg Zuid	4%	0%	0%	0%	0%	3%	2%	16%	63%	12%
Molenlaankwartier	10%	2%	0%	1%	6%	14%	37%	25%	4%	0%
Schiebroek	4%	1%	0%	0%	2%	3%	12%	42%	31%	5%
Terbregge	23%	21%	39%	10%	6%	0%	0%	0%	0%	0%
End total	**7%**	**3%**	**4%**	**2%**	**3%**	**5%**	**14%**	**29%**	**30%**	**4%**

Age class **55-65**

	Gravitation class									
Neighbourhood name	**0-10**	**10-20**	**20-30**	**30-40**	**40-50**	**50-60**	**60-70**	**70-80**	**80-90**	**90-100**
Hillegersberg Noord	3%	1%	2%	5%	2%	5%	20%	30%	31%	0%
Hillegersberg Zuid	4%	0%	0%	0%	1%	4%	2%	15%	62%	13%
Molenlaankwartier	9%	4%	0%	1%	7%	17%	36%	21%	4%	0%
Schiebroek	3%	1%	0%	0%	2%	2%	13%	39%	34%	6%
Terbregge	29%	13%	26%	24%	8%	0%	0%	0%	0%	0%
End total	**6%**	**2%**	**2%**	**3%**	**3%**	**6%**	**16%**	**27%**	**30%**	**4%**

Age class **65-75**

	Gravitation class									
Neighbourhood name	**0-10**	**10-20**	**20-30**	**30-40**	**40-50**	**50-60**	**60-70**	**70-80**	**80-90**	**90-100**
Hillegersberg Noord	6%	1%	3%	3%	4%	3%	24%	27%	29%	0%
Hillegersberg Zuid	3%	0%	0%	0%	1%	5%	3%	14%	63%	12%
Molenlaankwartier	6%	4%	0%	0%	7%	19%	35%	24%	4%	0%
Schiebroek	4%	1%	0%	0%	1%	2%	12%	38%	37%	5%
Terbregge	29%	6%	31%	26%	8%	0%	0%	0%	0%	0%
End total	**6%**	**2%**	**2%**	**2%**	**3%**	**6%**	**19%**	**27%**	**29%**	**3%**

Age class **75-85**

	Gravitation class									
Neighbourhood name	**0-10**	**10-20**	**20-30**	**30-40**	**40-50**	**50-60**	**60-70**	**70-80**	**80-90**	**90-100**
Hillegersberg Noord	9%	1%	1%	3%	4%	4%	34%	19%	25%	0%
Hillegersberg Zuid	1%	0%	0%	0%	2%	4%	5%	18%	57%	13%
Molenlaankwartier	3%	2%	1%	1%	4%	20%	49%	16%	4%	0%
Schiebroek	2%	1%	0%	0%	0%	1%	13%	36%	43%	4%
Terbregge	40%	5%	15%	27%	13%	0%	0%	0%	0%	0%
End total	**5%**	**1%**	**1%**	**2%**	**3%**	**6%**	**26%**	**24%**	**29%**	**3%**

Age class **85+**

	Gravitation class									
Neighbourhood name	**0-10**	**10-20**	**20-30**	**30-40**	**40-50**	**50-60**	**60-70**	**70-80**	**80-90**	**90-100**
Hillegersberg Noord	11%	0%	0%	0%	1%	4%	58%	6%	20%	0%
Hillegersberg Zuid	2%	0%	0%	0%	2%	2%	0%	18%	53%	23%
Molenlaankwartier	3%	2%	0%	0%	3%	30%	36%	15%	11%	0%
Schiebroek	1%	0%	0%	0%	0%	0%	18%	32%	46%	2%
Terbregge	5%	0%	5%	64%	27%	0%	0%	0%	0%	0%
End total	**4%**	**0%**	**0%**	**1%**	**1%**	**8%**	**33%**	**20%**	**30%**	**2%**

Annex 6 (3/3): Gravitation scores for neighbourhoods in district: Hillegersberg Schiebroek
Scenario: pedestrian roads are wide enough, no barriers

Age class **50+**

	Gravitation class									
Neighbourhood name	**0-10**	**10-20**	**20-30**	**30-40**	**40-50**	**50-60**	**60-70**	**70-80**	**80-90**	**90-100**
Hillegersberg Noord	1%	0%	3%	2%	5%	19%	19%	25%	26%	0%
Hillegersberg Zuid	0%	0%	0%	0%	2%	2%	1%	18%	64%	12%
Molenlaankwartier	1%	0%	1%	4%	6%	12%	28%	38%	9%	0%
Schiebroek	0%	0%	0%	0%	0%	2%	14%	42%	37%	4%
Terbregge	19%	20%	27%	34%	0%	0%	0%	0%	0%	0%
End Total	**2%**	**1%**	**2%**	**3%**	**3%**	**8%**	**15%**	**32%**	**30%**	**3%**

Age class **50-55**

	Gravitation class									
Neighbourhood name	**0-10**	**10-20**	**20-30**	**30-40**	**40-50**	**50-60**	**60-70**	**70-80**	**80-90**	**90-100**
Hillegersberg Noord	1%	0%	4%	2%	5%	13%	12%	29%	34%	0%
Hillegersberg Zuid	0%	0%	0%	0%	1%	2%	1%	20%	64%	11%
Molenlaankwartier	2%	0%	1%	3%	6%	12%	21%	51%	5%	0%
Schiebroek	0%	0%	0%	0%	1%	4%	12%	49%	30%	4%
Terbregge	14%	32%	29%	24%	0%	0%	0%	0%	0%	0%
End Total	**2%**	**3%**	**4%**	**3%**	**2%**	**6%**	**10%**	**36%**	**29%**	**4%**

Age class **55-65**

	Gravitation class									
Neighbourhood name	**0-10**	**10-20**	**20-30**	**30-40**	**40-50**	**50-60**	**60-70**	**70-80**	**80-90**	**90-100**
Hillegersberg Noord	1%	0%	5%	2%	5%	13%	13%	33%	27%	0%
Hillegersberg Zuid	0%	0%	0%	0%	3%	2%	1%	16%	65%	12%
Molenlaankwartier	2%	0%	1%	4%	8%	14%	23%	42%	5%	0%
Schiebroek	0%	0%	0%	0%	0%	4%	13%	44%	34%	4%
Terbregge	21%	19%	25%	35%	0%	0%	0%	0%	0%	0%
End Total	**2%**	**1%**	**3%**	**4%**	**3%**	**7%**	**12%**	**34%**	**30%**	**4%**

Age class **65-75**

	Gravitation class									
Neighbourhood name	**0-10**	**10-20**	**20-30**	**30-40**	**40-50**	**50-60**	**60-70**	**70-80**	**80-90**	**90-100**
Hillegersberg Noord	2%	0%	3%	2%	5%	17%	15%	29%	27%	0%
Hillegersberg Zuid	0%	0%	0%	0%	3%	3%	2%	17%	64%	11%
Molenlaankwartier	1%	0%	1%	4%	5%	17%	27%	39%	5%	0%
Schiebroek	1%	0%	0%	0%	0%	1%	13%	41%	38%	5%
Terbregge	21%	11%	30%	38%	0%	0%	0%	0%	0%	0%
End Total	**2%**	**1%**	**3%**	**3%**	**3%**	**9%**	**15%**	**32%**	**29%**	**3%**

Age class **75-85**

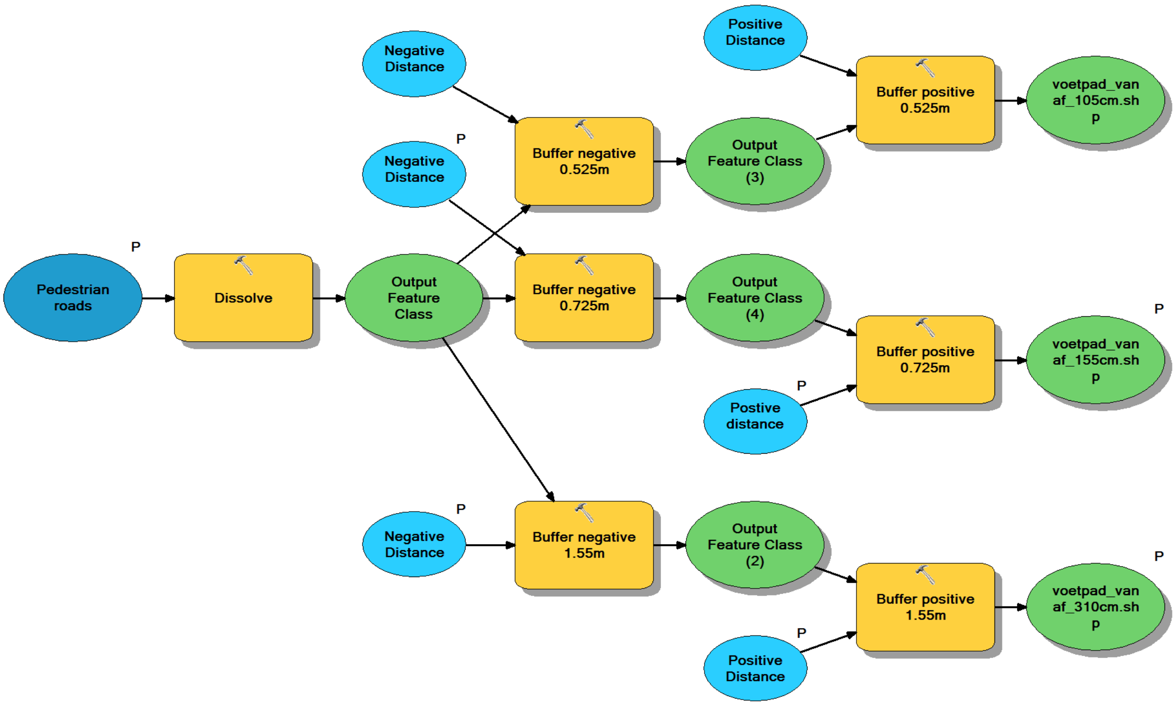
	Gravitation class									
Neighbourhood name	**0-10**	**10-20**	**20-30**	**30-40**	**40-50**	**50-60**	**60-70**	**70-80**	**80-90**	**90-100**
Hillegersberg Noord	0%	0%	2%	1%	5%	22%	26%	20%	24%	0%
Hillegersberg Zuid	0%	0%	0%	0%	3%	3%	3%	19%	59%	12%
Molenlaankwartier	0%	0%	1%	4%	6%	10%	41%	32%	7%	0%
Schiebroek	0%	0%	0%	0%	0%	0%	13%	39%	43%	5%
Terbregge	24%	8%	29%	39%	0%	0%	0%	0%	0%	0%
End Total	**1%**	**0%**	**1%**	**2%**	**3%**	**9%**	**21%**	**29%**	**30%**	**3%**

Age class **85+**

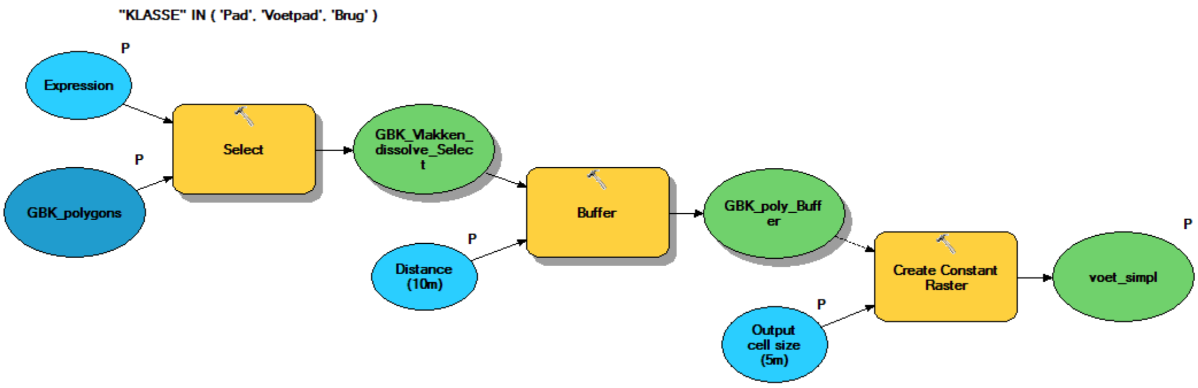
	Gravitation class									
Neighbourhood name	**0-10**	**10-20**	**20-30**	**30-40**	**40-50**	**50-60**	**60-70**	**70-80**	**80-90**	**90-100**
Hillegersberg Noord	0%		0%	0%	4%	37%	33%	6%	19%	0%
Hillegersberg Zuid	0%		0%	0%	2%	2%	2%	17%	55%	23%
Molenlaankwartier	0%		0%	2%	7%	4%	32%	23%	32%	0%
Schiebroek	0%		0%	0%	0%	0%	18%	34%	46%	2%
Terbregge	5%		9%	86%	0%	0%	0%	0%	0%	0%
End Total	**0%**		**0%**	**2%**	**3%**	**12%**	**25%**	**22%**	**35%**	**2%**

Annex 7 (1/2): Used models (ArcGIS 10 model builder)

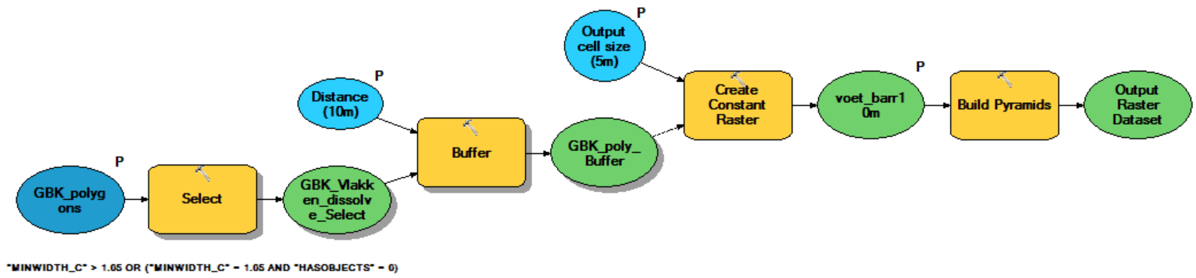
Determining the minimum widths of pedestrian roads:



Generating a transport network including all pedestrian roads:

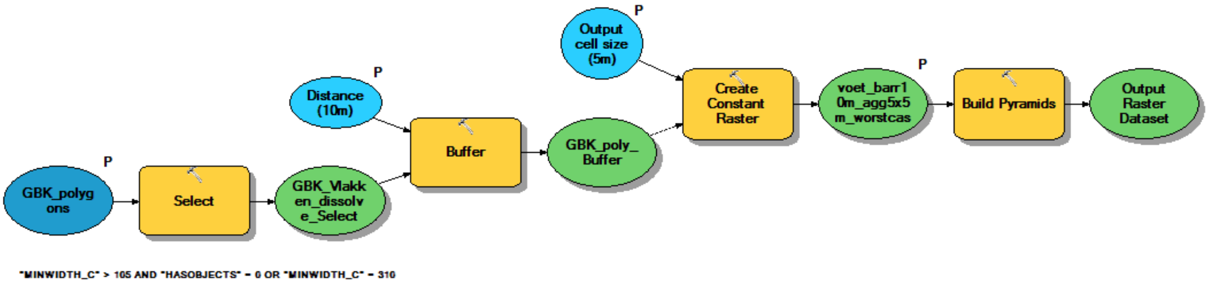


Generating a transport network of pedestrian roads that are wide enough with a chance of barrier objects:

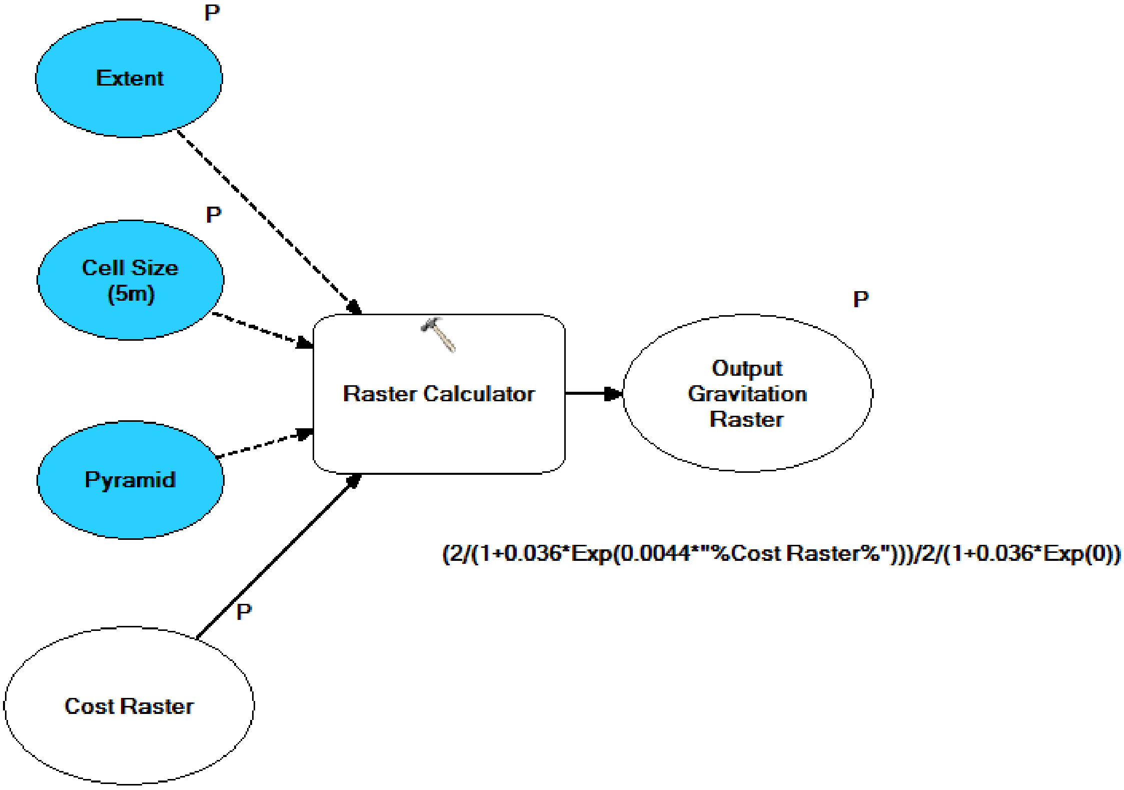


Annex 7 (2/2): Used models (ArcGIS 10 model builder)

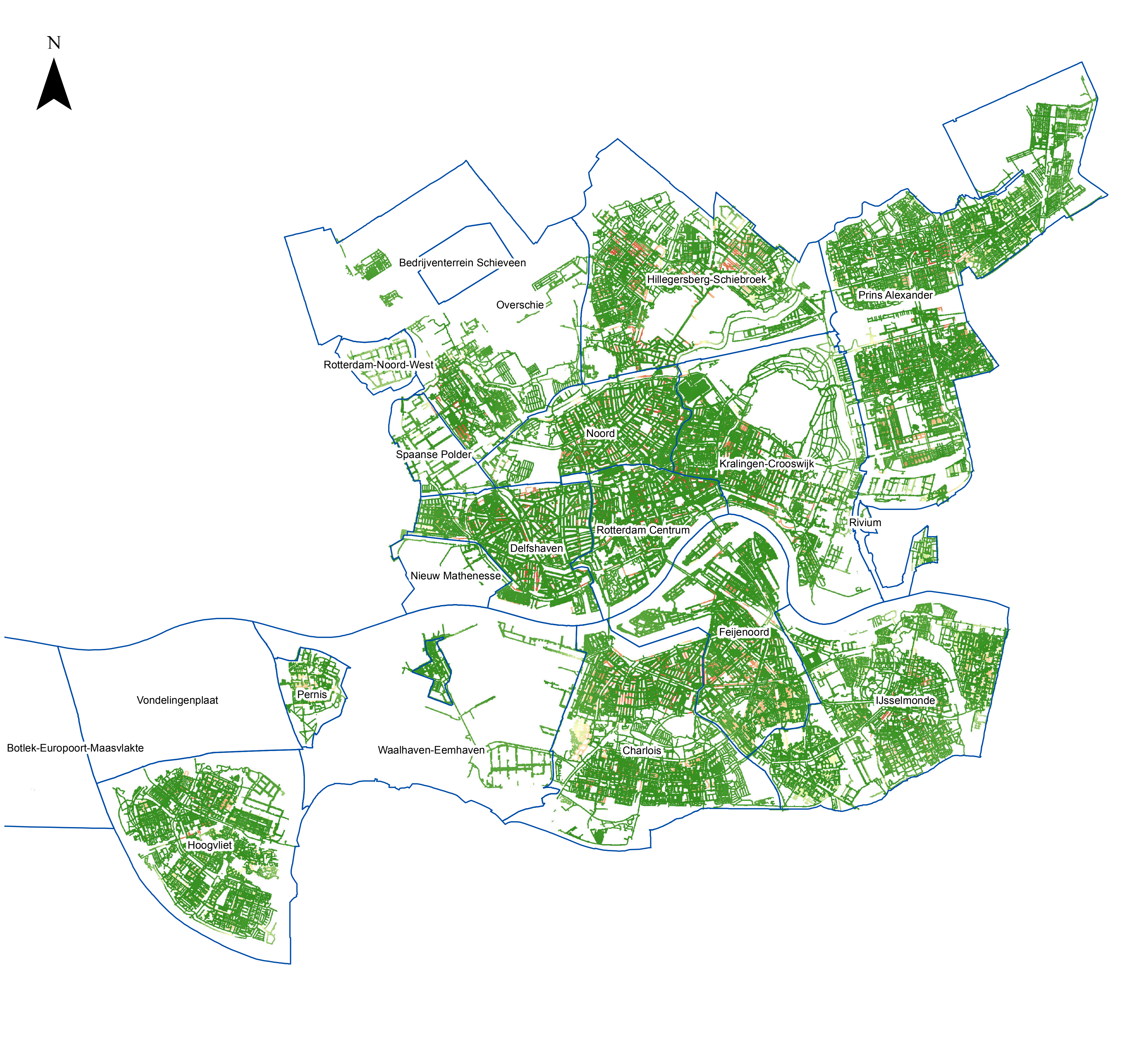
<u>Generating a transport network of pedestrian roads that are wide enough and no barrier objects:</u>



<u>Generating walk gravitation raster based on a cost distance raster:</u>



Annex 8: absolute difference between mean gravitation maps



Absolute difference between mean scenarios

best-case / worst-case scenario

District border

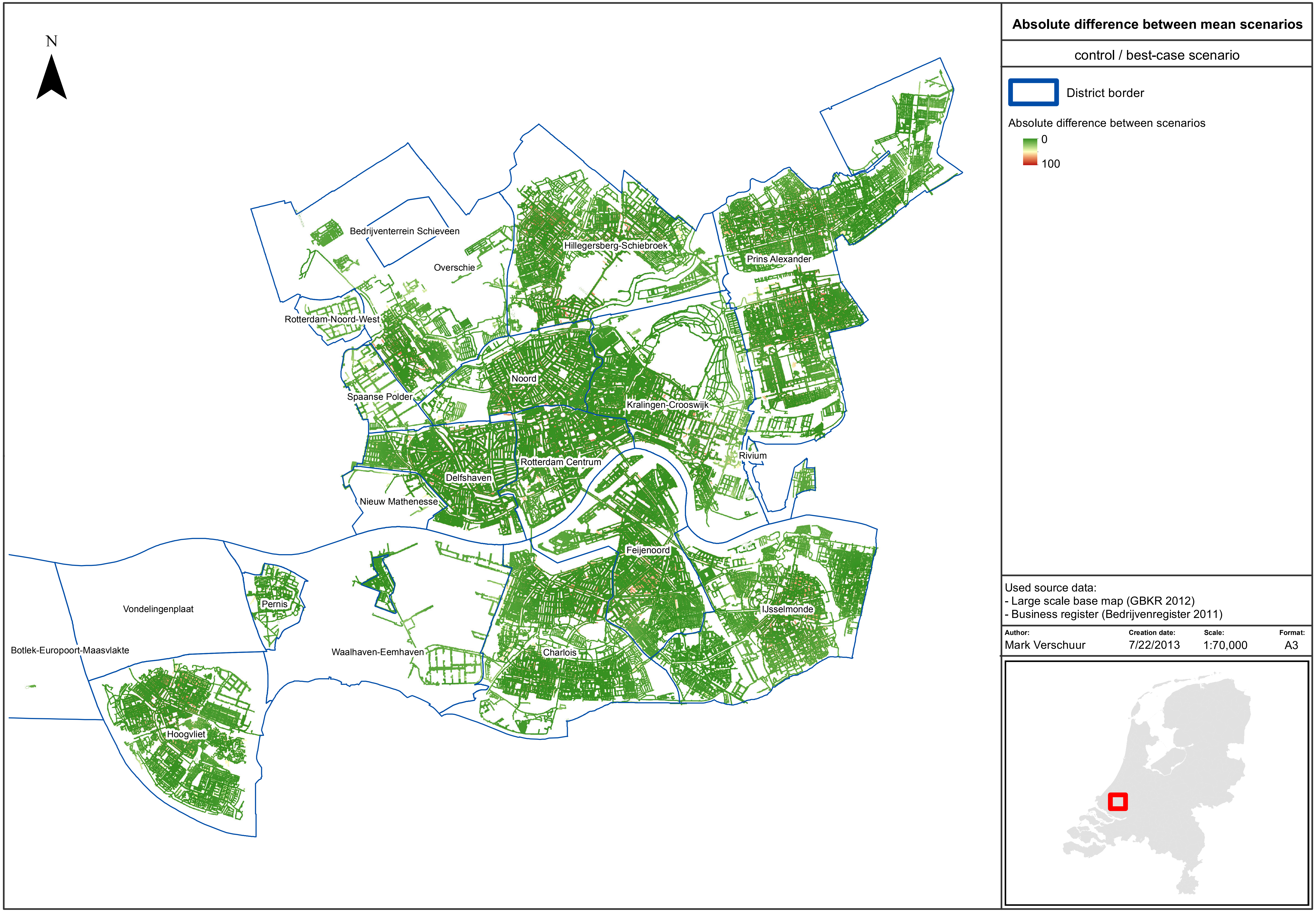
Absolute difference between scenarios

0

100

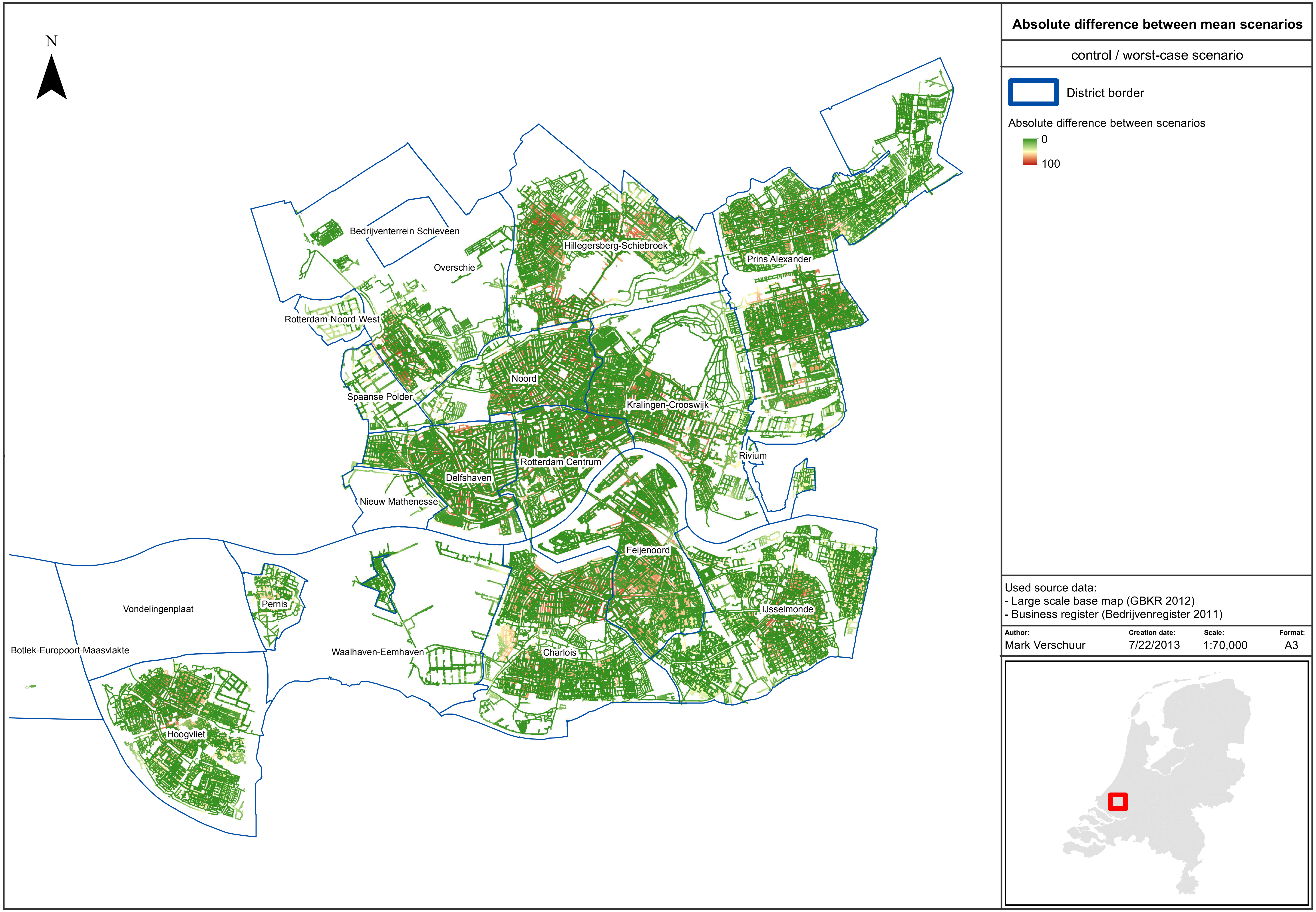
Used source data:
- Large scale base map (GBKR 2012)
- Business register (Bedrijvenregister 2011)

Author:	Creation date:	Scale:	Format:
Mark Verschuur	7/22/2013	1:70,000	A3



Used source data:
- Large scale base map (GBKR 2012)
- Business register (Bedrijvenregister 2011)

Author:	Creation date:	Scale:	Format:
Mark Verschuur	7/22/2013	1:70,000	A3


N
Absolute difference between mean scenarios
control / worst-case scenario
District border
Absolute difference between scenarios
0
100
Used source data:
- Large scale base map (GBKR 2012)
- Business register (Bedrijvenregister 2011)
Author:
Mark Verschuur
Creation date:
7/22/2013
Scale:
1:70,000
Format:
A3
Bedrijventerrein Schieveen
Overschie
Hillegersberg-Schiebroek
Prins Alexander
Rotterdam-Noord-West
Noord
Spaanse Polder
Kralingen-Crooswijk
Rivium
Rotterdam Centrum
Delfshaven
Nieuw Mathenesse
Feijenoord
Vondelingenplaat
Pernis
IJsselmonde
Botlek-Europoort-Maasvlakte
Waalhaven-Eemhaven
Charlois
Hoogvliet

Annex 9: Mean gravitation maps of district Hilllegersberg-Schiebroek

Mean walking gravitation

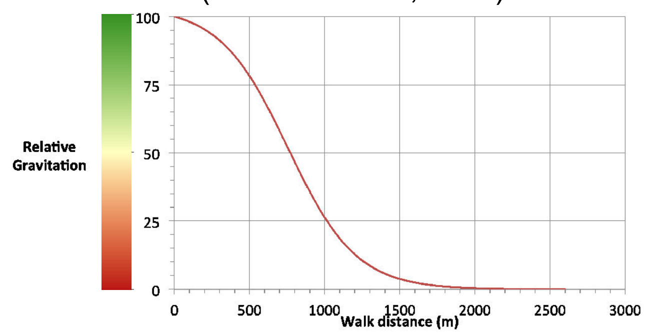
District: Hillegersberg Schiebroek

Best-case scenario

District border

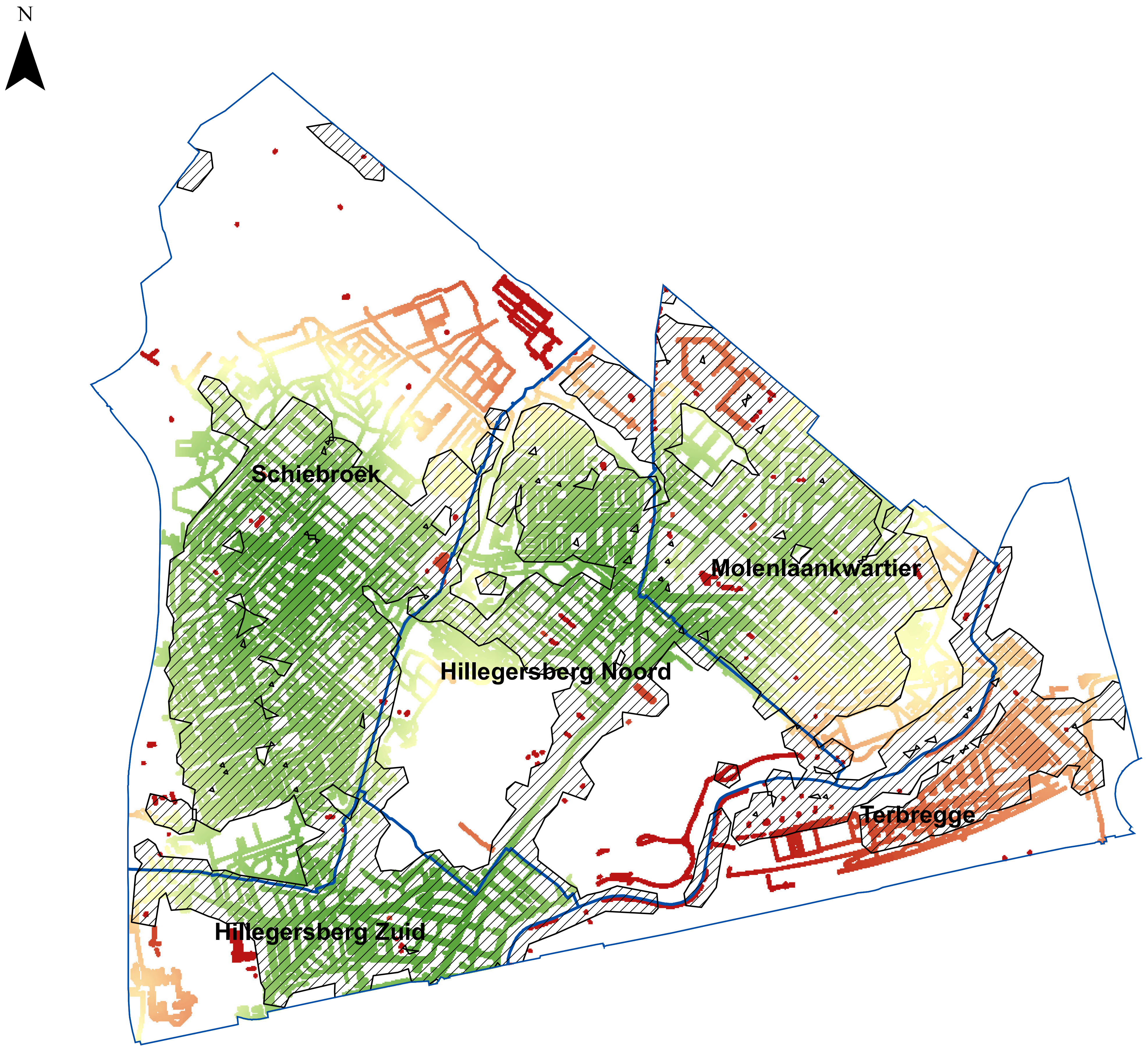
Living area of people of age 50+

Relative gravitation function
(based on TNO, 2004)



Used source data:
- Large scale base map (GBKR 2012)
- Business register (Bedrijvenregister 2011)

Author:	Creation date:	Scale:	Format:
Mark Verschuur	7/22/2013	1:20,000	A3



Mean walking gravitation

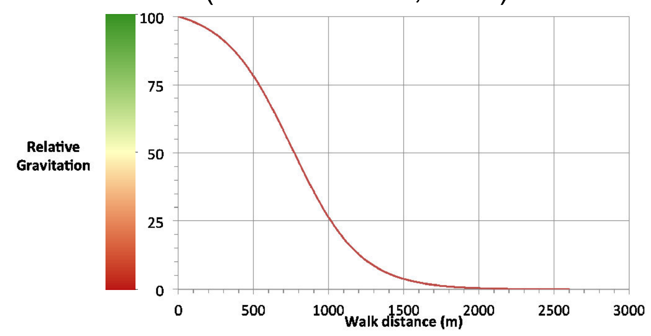
District: Hillegersberg Schiebroek

Worst-case scenario

District border

Living area of people of age 50+

Relative gravitation function
(based on TNO, 2004)



Used source data:
- Large scale base map (GBKR 2012)
- Business register (Bedrijvenregister 2011)

Author:	Creation date:	Scale:	Format:
Mark Verschuur	7/22/2013	1:20,000	A3

Mean walking gravitation

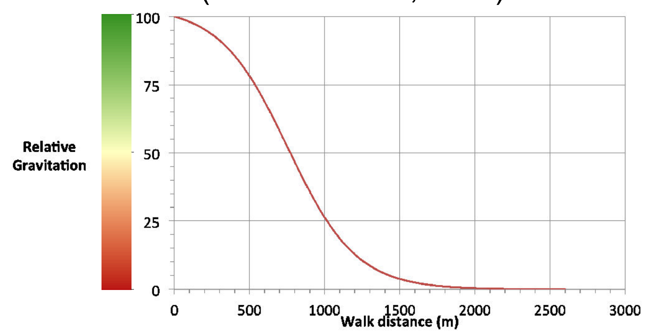
District: Hillegersberg Schiebroek

Control scenario

District border

Living area of people of age 50+

Relative gravitation function
(based on TNO, 2004)



Used source data:
- Large scale base map (GBKR 2012)
- Business register (Bedrijvenregister 2011)

Author:	Creation date:	Scale:	Format:
Mark Verschuur	7/22/2013	1:20,000	A3

Annex 10: Example of analysis on pedestrian road width and potential barriers

Example of analysis on pedestrian road width and barrier objects

- 310cm wide: no barrier objects
- 310cm wide: minimum chance of barrier objects
- 155cm wide: no barrier objects
- 105cm wide: minimum width, no barrier objects
- 155cm wide: chance of barrier objects
- 105cm wide: certainty of barrier objects
- <105cm wide: too narrow
- <150cm wide: too narrow and objects
- Potential barrier object

Used source data:
- Large scale base map (GBKR 2012)
- Business register (Bedrijvenregister 2011)

Author:	Creation date:	Scale:	Format:
Mark Verschuur	5/20/2013	1:1,000	A3