A QUANTITATIVE MODEL TO ANALYSE CITY DEVELOPMENT

A CASE STUDY OF THE IMPACT OF FLOOD AND CONGESTION STRATEGIES ON THE MUNICIPALITY OF ROTTERDAM

MASTER THESIS

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PREFACE

This report will conclude my master Transport and Planning at the faculty of Civil Engineering and Geosciences. The research as described in this report is focused on the quantification of the development of cities in Europe in general. This quantification is used for a case study on the impacts of a flood event, flood adaptation, congestion and congestion measures for the city of Rotterdam.

The subject of the research is inspired by the experiences I had during my master project in Jakarta, which showed me the devastating impacts of flooding and congestion on urban areas. Full knowledge on the long-term impacts of such threats on city development are not known and therefore a quantification of the impacts is useful for decision making.

This thesis could not have been conducted without extensive help of a number of experts.

First of all, I would like to thank the members of my committee for their input, the interesting discussions and for sharing their knowledge and perspectives on the complex system which a city is: prof.ir. F.M. Sanders, dr.ir. R.J. Verhaeghe, dr. B. Wiegmans, dr.ir. F.H.M. Van de Ven, ir. P.B.L. Wiggenraad and A.G.A. Schellekens.

I would further like to thank everyone at ARCADIS who has contributed to the research by discussing the subject with me, helping with the GIS-work and sharing visions and ideas.

Finally I would like to thank my friends and family for their continuous support, reviewing and suggestions. Of course, with a special thanks to my friends from D01.

For me it has been an interesting and inspiring period. The past 9½ months have been a very positive learning experience. The research has contributed to my own vision and ideas on how a city works and how it should develop into the future. I would like to conclude the preface with a quote from Jane Jacobs' book 'The Death and Life of Great American Cities'. This quote describes for me the way we should look at cities:

Everything in the natural world is in flux. When we suppose we see static situations, we actually see processes of beginning and processes of ending occurring simultaneously. Nothing is static. It is the same with cities.

Rogier Pennings

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EXECUTIVE SUMMARY

Cities are continuously threatened by a variety of risks. The size and impact of each risk differs due to differences in geographic location, urban structure and present infrastructure networks. Due to these differences in risks, each city needs city specific risk management. In order to estimate the impacts of the risks, the city as a whole needs to be quantified. This leads to the need for a *quantitative analysis of city processes.*

This study is focused on the impact of precipitation related flooding and recurrent congestion on cities in the European Union. For both flooding and congestion two scenarios are formulated describing a do-nothing scenario (1) and a full measures scenario (2). The outputs of these scenarios can be compared and used to quantify the size of each risk and thereby determine the most efficient risk management strategy. The research question is formulated as: *What are the impacts of flooding, congestion and adaptation measures on the economic vitality of cities?*

The modelling approach used for this model is system dynamics. This approach is chosen because of its ability to model complex and interacting dynamic systems (which a city is). It takes the most important interactions between all important aspects of a city into account. Compared to other model approaches, which focus on the direct impacts, the higher order effects are taken into account in system dynamics. In total, the full city and its interactions are modelled, which leads to a complete picture of the impact of the different scenarios.

Quantitative Model Development

The first part of the research is focused on the development of a quantitative city model. The basis for the new quantitative model is the existing URBAN1 model. This model gives a basic description of the interactions between population, business structures and housing. Due to the presence of each of these components the attractiveness of the other components is influenced. The model has the available land area as a constraint and it has no external influences.

URBAN1 was developed based on cities in North America, which differ from European cities in land use, urban planning and model split. Due to these differences a European model, which is called URBAN2013, is developed. URBAN2013 is based on the classic economic theory elements, which are land, labour and capital.

The first difference between the existing URBAN1 model and URBAN2013 is the split in business sectors. For URBAN2013 the business sectors is split in four different sectors, based on the economic sectors. These sectors are the primary (agriculture and mining), secondary (industry), tertiary (commercial services) and quaternary (non-commercial services) sector. The split in sectors is made due to differences in land use, employment and added value per sector. The primary sector is left out of the scope of the research since it is not present in urban areas.

The *land* area in the model is used by housing, business structures and infrastructure. The latter is a new addition in URBAN2013 and describes the availability of infrastructure in the city. This present infrastructure in turn influences the attractiveness of the urban area for business structures. Land usage is also influenced by flood adaptation and congestion measures.

Labour represents the jobs in the city. These available jobs attract population and the presence of population in turn attracts businesses and thereby supplies jobs. The attractiveness of an urban area for business structures depends on the presence of a sufficient labour force, available land area and the economic development. In time of economic growth more businesses will be created and in time of economic decline more businesses will be dissolved. The economic

development is based on economic waves. These impacts are incorporated in the model to indicate a range of development given the unclear economic future.

A further extension to the model, based on the *capital* component, is the influence of the available governmental funds. This element describes the available funding the municipality has for its amenities, such as infrastructure, quaternary sector facilities and threat measures. The amount of available governmental funds contributes to the attractiveness of the urban area for businesses and population. The attractiveness of the city for business structures is further extended in the model with the presence of related and supporting industries.

The development of the business sectors over time is subject to changes due to efficiency and up scaling. For future developments the role of further globalization and knowledge clusters are taken as important factors for future changes in employment. This leads to a decreases in the tertiary and quaternary sector and an increase in the secondary sector. In the model this is taken into account as the transformation factor.

Other aspects incorporated in the model are the pig-cycle in the tertiary sector, the prioritizing factor (which gives sectors with the highest demand priority) and the influence of land availability on the construction of flood adaptation and congestion measures. The basic model setup is illustrated in Figure 1.

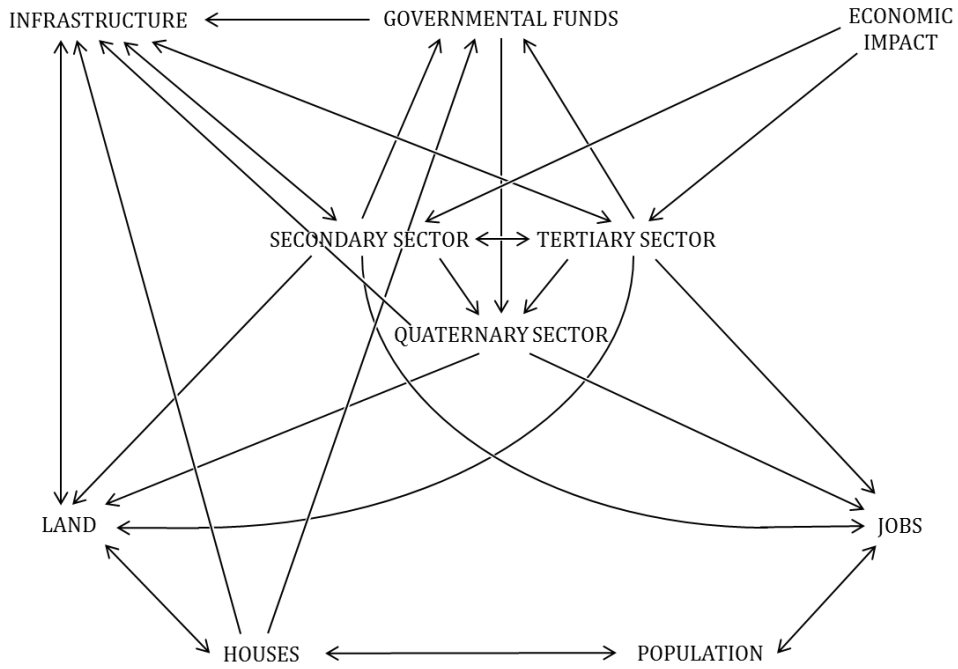


FIGURE 1: THE GENERAL SETUP OF THE URBAN2013 MODEL.

The General Development of the City of Rotterdam

The URBAN2013 model is used for a case study on the impacts of flood and congestion strategies on the municipality of Rotterdam. The model is tuned given the forecasts of population and housing in Rotterdam in 2030. The model start year is 2012 and it runs for a 30 year period.

First the model is used to obtain the basic development of the city of Rotterdam. This general development is used as a reference for the extent of the impacts of the different scenarios. Each scenario is compared to this base case.

The Impacts of Flood Event and Flood Adaptation on Rotterdam

A flood event is assumed as a one-time event. The flooding is based on a 1.200.000 m^3 pluvial flood. The impact of the flooding is based on the location of each sector, the height of each location, the water level and the damage factor. There are two handling scenarios for flooding.

The first scenario (the flood event scenario) describes the impact of a flood without any adaptation measures. This type of flood handling strategy leads to destruction of houses, business structures, infrastructure, deaths, injured and emigration of population, economic losses and a decline in attractiveness of the urban area. The impact of a flood event in the model leads to the destruction of 185 business structures and 205 houses in Rotterdam.

The second scenario (the flood adaptation scenario) is based on the implementation of flood adaptation measures. This scenario provides water storage for the total 1.200.000 m^3 of flood water. Necessities for these measures are land use and the usage of governmental funds for construction, operation and maintenance. The output for both scenarios are given in Table 1. The costs involved for adaptation measures are already incorporated in the model.

TABLE 1: THE RESULTS OF BOTH FLOODING SCENARIOS COMPARED TO THE GENERAL DEVELOPMENT.

	General Model (total)	**Flood Event** (difference with general model)	**Flood Adaptation** (difference with general model)
Population [persons]	19.822.873	-50.526	-50.811
Houses [housing units]	9.531.031	-5.367	6.784
Employment [jobs]	8.612.216	-43.093	-52.865
Secondary sector BS [businesses]	104.546	352	178
Tertiary sector BS [businesses]	586.414	-6.075	1.095
Quaternary sector BS [businesses]	113.292	-184	-2.536
Total loss in added value [million €]		**- 6.833**	**- 5.114**

The flood event scenario leads to a loss in the added value of the business sector of 6.833 million euro over a 30 year period compared to the regular development without flooding. Besides, it leads to a lower population and less employment in the city of Rotterdam. Note that the initial impact in destruction is lower than the consequences caused by the decline in attractiveness of the area.

The flood adaptation scenario leads to a loss in added value of 5.114 million euro compared to a regular development without flooding and flood adaptation measures. It also contributes to a lower population and less employment over the 30 year period because land area is used for adaptation measures instead of for housing and businesses.

A comparison of the flood event and flood adaptation scenarios shows that the flood adaptation scenario has the least negative effect on the added value. The ratio between both scenarios is 1,34 : 1. This leads to the recommendation that (if flooding occurs) flood adaptation measures are the preferable strategy for pluvial flooding in Rotterdam.

The Impacts of Congestion and Congestion Measures on Rotterdam

Congestion is a recurrent structural problem. Two congestion handling strategies are implemented in the model. The first (the congestion scenario) is based on the occurrence of congestion and no implementation of measures to counter its impact. The impacts are an increase in time loss (which currently is 66,1 hours per person per year) and a decline in attractiveness for the different business sectors.

The second scenario is the congestion measures scenario. This scenario is based on the implementation of measures to counter congestion and thereby lower its impact. This leads to a decrease in time loss and an increase in attractiveness of business sectors. It requires land area and governmental funds for construction, operation and maintenance. The output for both congestion scenarios is given in Table 2. The costs involved for the congestion measures are already incorporated in the model.

TABLE 2: THE CONGESTION SCENARIOS COMPARED TO THE GENERAL DEVELOPMENT RESULTS.

	General Model (total)	**Congestion** (difference with general model)	**Congestion Measures** (difference with general model)
Population [persons]	19.822.873	2.761	-23.335
Houses [housing units]	9.531.031	16.877	46.360
Employment [jobs]	8.612.216	-7.854	-49.173
Secondary sector BS [businesses]	104.546	-716	608
Tertiary sector BS [businesses]	586.414	-465	3.176
Quaternary sector BS [businesses]	113.292	247	-3.244
Total loss in added value [million €]		**- 5.619**	**- 3.257**

The congestion scenario leads to a decline in added value and time loss over a 30 year period of 5.619 million euro. Overall, the effects on population and employment are limited. For the congestion measures scenario the loss in added value is 3.257 million euros. It leads to a decrease in employment and an increase in houses, due to decrease in investments which attribute to the attractiveness of the area for businesses (e.g. infrastructure). Due to this lower attractiveness more land area is available for housing.

By comparing the congestion and congestion measures scenarios it follows that the latter has the least negative effect on the added value. The ratio between the scenarios is 1,73 : 1. This indicates that implementing congestion measures is the preferable solution for the city of Rotterdam.

Comparison of the Flood Event and Congestion Scenario

Given both the flood event scenario and the congestion scenario, a comparison of the impacts of both scenarios is made. This comparison is subject to the likeliness of occurring of the different scenarios, but it does provide an image of the extent of the impacts of each scenario on Rotterdam. Note that the flooding is a one-time event and the congestion is a recurrent structural problem. The ratio of the impacts between the flood event and the congestion

scenario is 1,22 : 1. This means that (given the assumptions made) the consequences of a flood event are bigger than the consequences of congestion in Rotterdam.

A comparison of the combination of the flooding and congestion scenarios shows that the loss in added value is the lowest for the combination of flood adaptation and congestion measures (8.100 million euros versus 10.285 to 12.670 million euros). Therefore this combination of scenarios is the most preferable. This indicates that the influence of a combination of scenarios on the city also leads to the same conclusion as made for the flooding and congestion strategies separately.

Conclusion

It can be concluded that both for flooding and congestion the implementation of (adaptation) measures is the most cost efficient strategy. This also holds for the combination of the flooding and congestion scenarios. The results show that for Rotterdam the off-balance situation (which is caused by each scenario) affects the direct outputs, but the self-regulating behaviour of the model adjusts the further development towards the general development (the no scenario situation). This indicates the present adaptive capacity in the city of Rotterdam. The scenarios are not sufficient in size to overcome this adaptive capacity of the city of Rotterdam.

Recommendations

The URBAN2013 model provides a quantitative analysis of a city as a whole. This analysis can be used to quantify the impact of different threats and threat measures. Further refining of the model can be achieved by the following recommendations:

- Combine the city (which is one municipality) with surrounding municipalities, since these share a housing and labour market and thereby influence the development and the economy of the city.
- Introduce a variable density of land use into the land use. This can simulate more effective land usage due to a limited land availability.
- Introduce gentrification in the model. This represents the upgrading (and change of usage) of existing structures.

The research is focused on the impact of two specific threats on a city. Recommendations for further extensions of the research are:

- Perform case studies for different cities. This will contribute to more general conclusions and better comparison of cities.
- Investigate the impacts of intermediate scenarios. Since the scenarios in this research represent two extremes, the most optimal solution can be located between these extremes.
- Extend the number of threats which are researched in the model. This will help quantifying each threat to a city and thereby contribute to a full comparison of the extent of threats. Based on this information the most optimum risk management strategy (with limited available funds) can be determined.

INTRODUCTION

CHAPTER 1

Cities are continuously developing and face threats and opportunities. The risk of occurrence of a threat depends on 'the hazard, the exposure and the vulnerability of each city' (Crichton, 1999). Due to differences in these three between cities, each city has a different risk level towards a threat and therefore risk management will need to differ per city. In order to estimate the impact of risks and to formulate a risk management strategy, a city as a whole needs to be quantified. This quantification provides the basis for the comparison of risk management measures. This leads to *the need for a quantitative analysis of city processes*.

The research is focused on two specific threats to the economic vitality of a city. The reason to focus on two threats is to compare the size of both threats and thereby gain insight in the scale of each threat to a city (in our case Rotterdam). The threats which will be researched are the impacts of a pluvial flood event (1) and the impact of road congestion (2) on the city. The impact of the occurrence of these events will be compared to the impact of the implementation of flood adaptation[1] and congestion measures.

The effects of flood adaptation and congestion measures can provide insight in the most effective protection strategy against each threat[2]. The strategies are either implementing adaptation measures or not implementing these measures and face the consequences of occurrence of these events and pay for the recovery.

The **objective** of this MSc thesis is *to develop a quantitative model to analyse city developments.* This model will be used to quantify the impact of a flood event, flood adaptation, congestion and congestion measures.

The **main research question** is formulated as: *What are the impacts of flooding, congestion and adaptation measures on the economic vitality of cities?*

The **scope** of the research is set as follows:

- The research focus is on the development of an autonomous city model for cities which are located within the European Union and have at least 100.000 inhabitants.
- Solely urbanized area is taken into account.
- The focus is on (climate change related) pluvial flood events and recurrent road congestion.
- For flooding, the focus is on adaptation. Mitigation is outside the scope.
- The focus is on the economic aspects. Governance, social aspects and availability of information are not taken into account primarily.
- A case study is done for the city of Rotterdam.

[1] In this context, adaptation refers to *initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected effects* (IPCC, 2007).

[2] It is important to note that the difference between a flood event and congestion is that a flood event is a onetime incident and road congestion is a structural problem. Therefore, the adaptation measures for a flood event are aimed at reducing the impact of an incident and for road congestion on a structural problem solution.

REPORT STRUCTURE

Chapter 1 describes the objective of the research.

The context of the research is introduced in chapter 2. It describes the characteristics of European cities in general and of Rotterdam in particular.

In chapter 3 the theories on cities and its parts are discussed.

Chapter 4 discusses the existing models on city development. This is followed by the development of the new city model (URBAN2013).

The model results for Rotterdam in general and the scenarios for flooding and congestion are discussed in chapter 5.

In chapter 6 the conclusions and the recommendations of the research are discussed.

EUROPEAN CITIES AND THEIR CHALLENGES

CHAPTER 2

Cities in Europe come in a wide variety. The specific aspects of European cities will be discussed in 2.1. The city of Rotterdam is discussed in 2.2.

2.1 DEVELOPMENT OF EUROPEAN CITIES

A city is a permanent settlement which consists of people, activities, infrastructure and buildings. The first cities in Europe had a regional function. Over time, with technological, social and political developments, the influences of cities on the surrounding area became larger. Due to concentration of industries and the need for labour, cities expanded. With the growth in international trade and the reduction in trade barriers, the threshold of national borders for trade decreased and international and global trade emerged. This led to industries (and cities) competing on the global markets.

Consequences of Globalisation for Cities

A consequence of globalisation is the shift of many (especially unskilled and lower skilled) jobs from (Western) Europe to low-wage countries (Rijksoverheid, 2009). This in turn hits unskilled and low skilled employment industries in (Western) Europe (and other developed economies). Cities with large percentages of low skilled industries are vulnerable to increases in unemployment. Other industries can benefit from the increase in trade (e.g. high-skilled manufacturers and financial institutions), which in turn can generate direct employment (and subsequent tax income and supporting industries employment) within cities. Therefore, the impact on globalisation differs per city.

In the European Union approximately 76% of the population nowadays lives in urban or intermediate areas (Eurostat, 2012). These urban areas consist of one or multiple cities, which are important as economic, cultural and social centres. In total there are over 375 cities with more than 100.000 inhabitants within the EU (EEA, 2009). These cities can be seen in Figure 2.1-1.

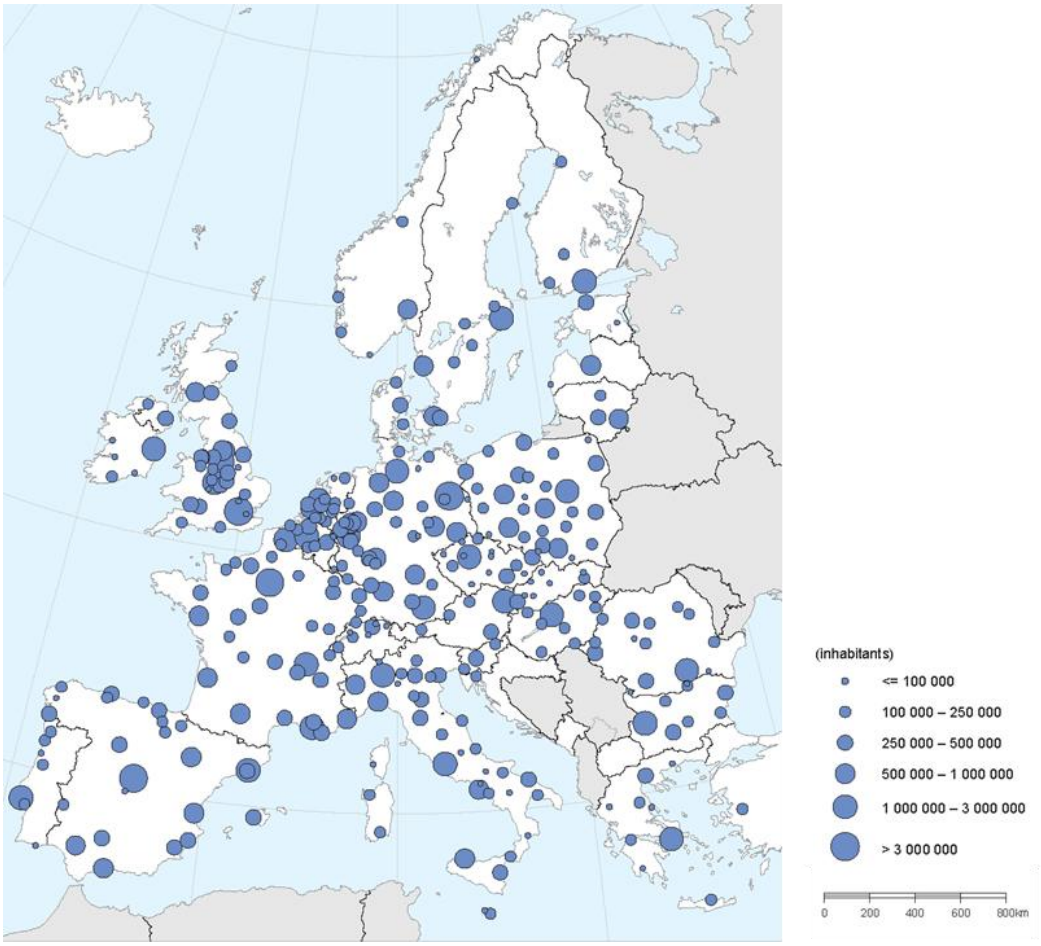


FIGURE 2.1-1: CITIES IN THE EUROPEAN UNION (EUROSTAT, 2008).

The Challenges for European Cities

The challenges facing European cities differ due to differences between these cities such as geographical location, urban structure and networks. The type, scale and risk of these challenges therefore vary per city. Risk types can be classified in either natural risks (geophysical, meteorological, hydrological, climatological and biological (EM-DAT, 2009)) and man-made risks (e.g. technological, financial and social). The handling of these challenges depends on the chosen risk management strategy.

Examples of these challenges are economic decline in Glasgow, flooding in Venice, congestion in Brussels, pollution in Athens and heat waves in Sofia. The size of each of these threats (and thereby each challenge) is different per city, due to differences in location, history, climate, economy, social structure and development.

2.2 CITY DEVELOPMENT CASE: ROTTERDAM

From the 375 European cities the city of Rotterdam is chosen for a case study. The reasons this city is chosen are the availability of data, the participation in the ASEC-project[3] and the lack of a

[3] The Adaptation Strategies for European Cities project is a European Union supported project. The project is performed by a consortium including ARCADIS. The goals of the project are to raise the awareness for climate change in cities, to provide a platform to exchange knowledge and best practices between cities and to supply guidance and tools on adaptation especially for cities (AEA, 2011).

language barrier. This paragraph introduces the city of Rotterdam. First the general characteristics of the city are discussed, followed by a description of the current flood protection and transport systems.

Characteristics of the City of Rotterdam

Rotterdam is a port city located in the province of South-Holland in the Netherlands. The city is located on both banks of the New Meuse river and is strategically located in the Rhine-Meuse-Scheldt delta. The city is by inhabitants the second city of the Netherlands, with 615.762 inhabitants in the municipality and 1.175.875 inhabitants in the metropolitan area (CBS, 2012).

The Port of Rotterdam is the largest in Europe (Port of Rotterdam, 2013) and in the top 10 of the largest ports in the world (AAPA, 2010). Therefore a relatively large proportion of the city's industry and employment is fixated on the port and its associated industries.

The city of Rotterdam and its port area are shown in Figure 2.2-1. The second Maasvlakte (an extension of the port area) is currently being constructed (Gemeente Rotterdam, 2013). The inner city harbours are planned to be redeveloped into residential and commercial areas (Stadshavens).



FIGURE 2.2-1: THE CITY OF ROTTERDAM (RIGHT) AND ITS PORT AREA.

The municipality of Rotterdam occupies an area of 320 km², of which 206 km² is land area (Gemeente Rotterdam, 2012). The housing stock in the city is 297.312 housing units (Gemeente Rotterdam, 2012).

Industry Composition

In total, 320.328 jobs are present in the city of Rotterdam (Gemeente Rotterdam, 2012). The employment is divided over several industry sectors. The port and industrial plants provide 22,9% of the total employment in Rotterdam (Gemeente Rotterdam, 2012). The business services industry provides 18,1% of the employment and the health sector 17,7% of the total employment (due to the presence of the medical cluster, which contains the Erasmus MC and related companies (Gemeente Rotterdam, 2009)). The remainder of jobs is represented in other sectors.

Urban Developments

Urban development for the near future is focused on inner city renewing. The focus of this renewing is a maximization of usage and a more efficient use of land. The vision for the future of

Rotterdam until 2030 is aimed at creating a strong and sustainable economy and an attractive residential climate (to counter negative selective migration) (Gemeente Rotterdam, 2007).

Protection from Flooding in Rotterdam

Much of the Rotterdam area is located below sea level. These areas are kept dry due to the presence of dike rings. The New Meuse can be closed by a movable storm surge barrier (Maeslantkering; located in the New Waterway) to prevent flooding of the city centre and surrounding areas via the New Meuse. The municipality introduced the Rotterdam Climate Initiative to reduce the impact of climate change and strengthen the city's economy. It also introduced the Waterplan 2 in collaboration with the water boards of the area. This plan contains a vision of how to deal with water until 2030.

Transport in Rotterdam

The city of Rotterdam is connected by national and international transport systems. The city is enclosed by a ring road ('*de ruit van Rotterdam*'). The highway network in the area contains several missing links which are currently being constructed or planned. The connection of the port with the hinterland is based on one link. Other modes of transport in the Rotterdam area are train, tram, metro, bus and waterbus.

CONCEPTS AND THEORIES ON CITY DEVELOPMENT

CHAPTER 3

This chapter will discuss concepts and theories on city development. The chapter starts with why cities exist in 3.1. This is followed by the internal city aspects: land (3.2), labour (3.3) and capital (3.4). The external city aspects are discussed in 3.5. A schematization of the city and its parts as these will be discussed is given in Figure 3.0-1.

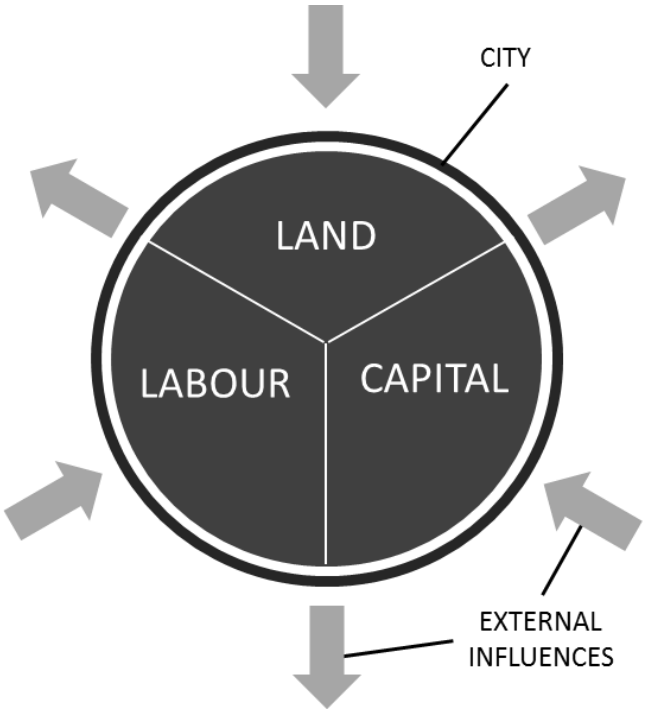


FIGURE 3.0-1: A SCHEMATIZATION OF THE CITY AND ITS PARTS.

3.1 INCENTIVES FOR CITY EXISTENCE

By definition *a city is a permanent settlement which combines people, activities, infrastructure and buildings*. The existence of cities can be related to several theories, such as defensive (military point of view (O'Sullivan, 2008)), the need for human social interaction (sociologist point of view) or the location of employment and jobs (economic point of view) (Brueckner, Lectures on Urban Economics, 2011). A condition necessary for the development of cities is a food surplus.

The development of cities is due to the economic benefits a city offers in comparison to a non-city existence. These benefits are external scale economies in trade and internal scale economies in production, innovation as a result of clustering and the presence of public goods (O'Sullivan, 2008). This business presence generates pecuniary and technological agglomeration economies (Brueckner, Lectures on Urban Economics, 2011). Further sources of agglomeration are benefits in input sharing, labour-market pooling and knowledge spill overs (Rosenthal & Strange, 2008).

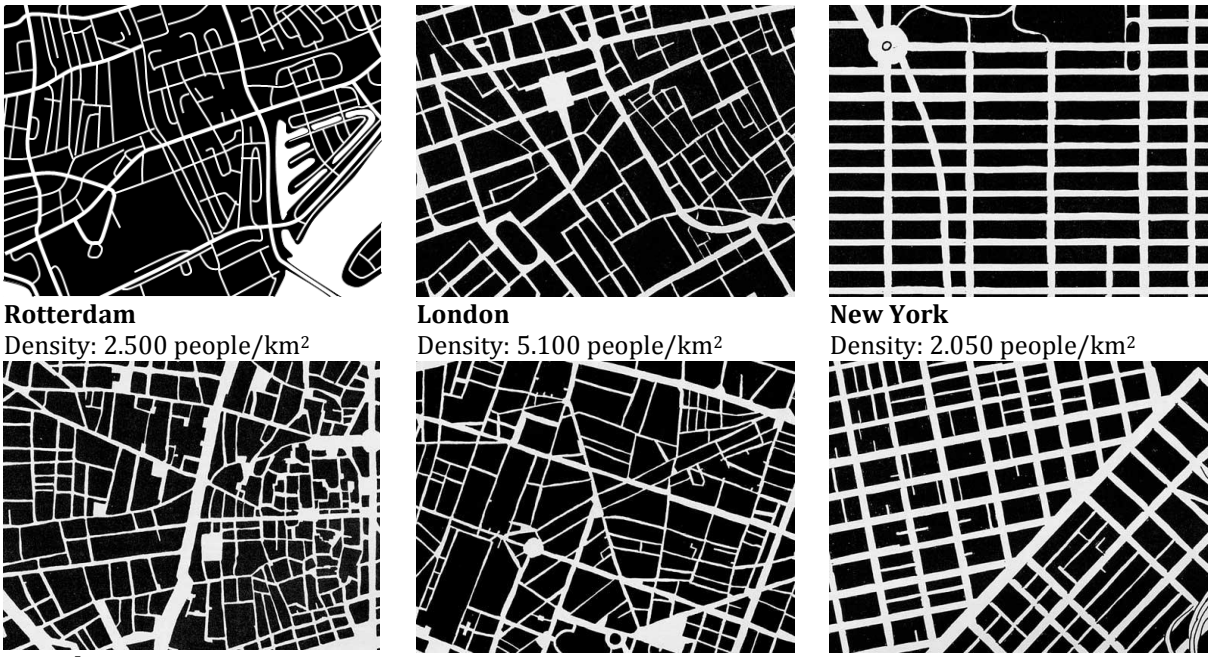
In the developed world, capital and labour are highly agglomerated (Rosenthal & Strange, 2008). These agglomerations are present on limited land areas. Land, labour and capital are considered as the three factors of production in the classical-economic theory[4] and are therefore used as the cornerstones of the urban area in this research. The reason the classical economic theory is taken as basis over other economic theories (e.g. physiocracy, Marxian and the neoclassical theory) is because this theory is based on the available physical resources. These available resources are present in the urban area, identifiable in available data and will fit well into the URBAN2013 model.

3.2 LAND USAGE IN CITIES

Land refers to the surface of the earth and the availability of land is a necessity for the construction of an urban area. The availability of land area differs per geographic area. For cities this can lead to different urban forms, land uses, densities and attractiveness.

Urban Forms

The patterns of land use have diverse economic, social and environmental impacts (VTPI, 2010). Examples of different urban forms (and accompanying) densities are given in Figure 3.2-1.



Rotterdam
Density: 2.500 people/km²

London
Density: 5.100 people/km²

New York
Density: 2.050 people/km²

Barcelona
Density: 4.850 people/km²

Paris
Density: 3.550 people/km²

San Francisco
Density: 2.350 people/km²

FIGURE 3.2-1: DIFFERENCES IN URBAN FORMS (BRICOLEURBANISM, 2008) AND DENSITIES (CITY MAYORS, 2007).

Land Use

The *land use* is how this surface area is used. It can be divided into different categories. A division is made in the built environment (residential, industrial, commercial, institutional, transportation facilities and brownfields (underused facilities)) and the open space (e.g. parks, forests and agricultural) (VTPI, 2010).

[4] Note that in the classical economic theory land and capital are broad concepts. Land includes natural resources which are part of the production process. Capital represents goods which are used to make other goods (e.g. machinery and buildings). Labour represents solely the human effort in production.

For residential, industrial, commercial and institutional areas variation exists in the type of structures (e.g. high rise apartment versus villa and two storey store versus office tower), the number of residents or employees per structure and the usage density. These variation can be a consequence of a lack in supply (e.g. several families in one house due to a limited availability of housing).

Over time, all structures will age, which can lead to under usage of these structures (brownfields). This can be counteracted by either demolition (and new construction on the site) or by regenerating the current structure (possibly for a different type of usage).

The type of land use, the type of structures, the number of residents/employees per structure, the usage density and the aging of structures all influence the land use of a city. These factors are city specific and are incorporated into the URBAN2013 model.

Density of Land Use

The *density* of land uses depends on a variety of factors, such as the availability of land area, land prices and demand. Different urban development patterns exist (e.g. urban sprawl and smart growth), which in turn influence the density, land use mix, scale of buildings and type of transportation (VTPI, 2010). In general high density cities are more sustainable than low density cities, due to limited car usage in comparison to public transport usage and adjacent housing, which saves energy (Gleaser, 2011).

Attractiveness of Land and Structures

The prices for land and/or buildings depend on a number of factors, such as size, facilities, urban amenities (e.g. monuments and architecture), natural amenities (e.g. ocean view or river front), the neighbourhood, safety, presence of businesses and accessibility.

Accessibility is of importance since it influences the travel costs (time and financial). The higher these costs, the more negative this influences the attractiveness and thereby the land price. The influence of congestion on accessibility is negative and therefore it negatively contributes to the attractiveness and the land prices. Figure 3.2-2 (left) shows the schematized example of two housing locations of equal travel time to the central business district (CBD). Due to this equal accessibility (and the assumption all other factors of importance are equal), the land/housing price is equal. Freeway congestion can negatively influence the price of house A due to a longer travel time.

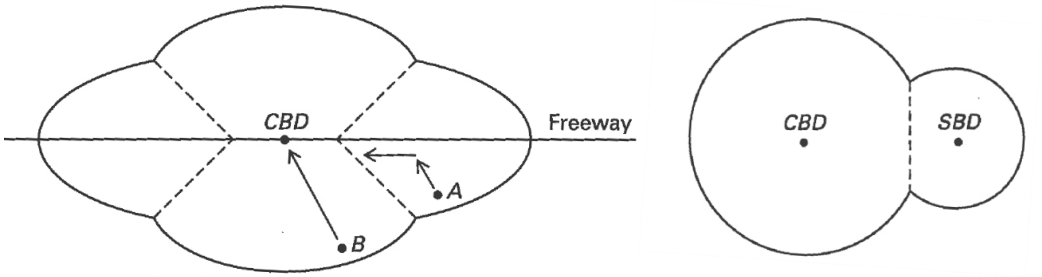


FIGURE 3.2-2: THE IMPACT OF A FREEWAY ON ACCESSIBILITY (LEFT) AND THE SCHEMATIZED PARTITION OF AN URBAN AREA BY A CENTRAL AND A SUB BUSINESS DISTRICT (RIGHT) (BRUECKNER, MODIFICATIONS OF THE URBAN MODEL, 2011).

Cities can be monocentric (as schematized in Figure 3.2-2 (left)) or involve a number of sub centres (as schematized in Figure 3.2-2 (right)). Employment is concentrated in the urban core(s) and residential areas are located outside these clusters.

The presence of sub business districts (SBD) means more distribution of employment over the urban area. Due to this multiple employment locations, in a number of cases people can work closer to home and thereby avoid wasteful commuting.

Conclusion

As described above, cities differ in urban form, densities and land usage. For the research, urban form and densities are city dependent and therefore taken city specific. The division in land use as used in the research is residential, business, transportation (infrastructure) and open areas. A better accessibility lowers travel costs and is therefore beneficial for the urban area. The influence of labour on city dynamics will be discussed in the next paragraph.

3.3 LABOUR IN CITIES

Labour is defined as *the aggregate of all human physical and mental effort used in creation of goods and services.* Labour is essential for businesses development and as income source for the population. Without the presence of a labour force, businesses cannot develop and without the presence of *jobs* (labour), it is (in general) not beneficial for population to settle in a city.

The essence for companies to locate in an urban area is discussed in 3.1. The motivation is based on the presence of other companies and the presence of a labour force (e.g. pecuniary agglomeration economies). This describes part of the attractiveness of an urban area for settlement.

The urban labour market is under influence of demand and supply for labour. Adjustments in these demands and supply are mostly in the form of shocks. These shocks (the scale per shock differs) originate from *internal market forces* (e.g. technology development, public infrastructure investments and increase of worker quality (training)) and *external market forces* (e.g. changes in competition, policy changes and changing resource prices) (Bartik & Eberts, 2006). This demand and supply in the labour market directly influences the attractiveness of an urban area for businesses.

Standard land use models indicate a decline of wage and housing prices with (travel) distance from the (central) business district (Bartik & Eberts, 2006)[5]. Population and company locations are subject to changes that can influence the equilibriums (e.g. the decentralization of labour and residents due to better transportation options).

A lack of labour in regard to the population size can lead to poverty of parts of the population. High poverty rates can lead to an increase in tax burden for the employed part of the population, raise crime rates and affect the quality of schools. A change of residential location for unemployed is costly and other areas need to be able to provide better opportunities for labour. Therefore, the attractiveness for unemployed to relocate has a high threshold, which in turn has a burden on the municipality and its funds (Arnott & McMillen, 2008).

[5] This wage gradient is caused by the lower housing prices the further the distance to the central business district (and therefore a decrease in compensation for rent prices compared to more central locations) and higher transportation costs (which are compensated). An equilibrium for workers in the urban market requires a uniform utility on all locations in the urban area. This, combined with an equilibrium for companies, which requires an equal costs of production throughout the urban area lead to an interaction between the workers utility function and companies costs function. Both functions contain wage and land prices.

The labour force is the part of the population that is of working age and participates (or is willingly to participate) in employment. The percentage labour force is subject to inter alia working ages and population composition.

Conclusion

The presence of labour is an essence of an urban area, since it provides income for residents. The labour market is sensitive to internal and external market forces. For businesses, the presence of a labour force is a must for production of goods and services. The presence of jobs is attractive for the settlement of population and the presence of population (labour force) is positive for the attractiveness for businesses. Labour contributes to the generation of capital, which will be discussed in the next paragraph.

3.4 CAPITAL IN CITIES

Capital is the total of capital goods. In the urban area, capital is considered as the production facilities (businesses). In a broader perspective it is combined with the potential for investments in the city (in the form of governmental funding).

Governmental funding is a necessity for supporting basic urban amenities. It can be provided by regional/national payments, land value tax and other taxes and fees (Ministerie Binnenlandse Zaken en Koninksrijksrelaties, 2013). It finances basic urban amenities such as education, health, governance, transport infrastructure and safety measures. The implementation of governmental funds is city specific.

Businesses create goods and services and offer jobs. A division in the type of businesses can be made on a meso-economic level, which leads to four economic sectors (Kenessey, 1987):

1 - Primary sector	The primary sector is focused on producing food and raw materials. *Examples are agriculture, fishery and mining.*
2 - Secondary sector	The secondary sector processes the raw materials from the primary sector. This sector is also known as industry. *Examples are construction, food processing and metal processing.*
3 - Tertiary sector	The tertiary sector consists of commercial services. The sector is profit-oriented. *Examples are logistics, financial services and retail.*
4 - Quaternary sector	The quaternary sector consists of non-commercial services. This sector contains (semi-)governmental services. The sector is non-profit. *Examples are healthcare, education and emergency services.*

The development of business presence depends on a multitude of factors. This can be because of the presence of resources (for primary and secondary sector businesses; site specific), the presence of sufficient sized markets and users or due to positive living conditions (footloose). Urban areas need a critical mass of industry-specific businesses to attract more and specific businesses (Rosenthal & Strange, 2008).

Attractiveness of the Urban Area

City development depends on the ability of an urban area to attract (and retain) businesses and population. This attraction depends on the attractiveness of the city compared to other cities. For business development (and national competitiveness), the Porter Diamond (see Figure 3.4-1) shows the built up of the competitive advantage for businesses. In relation to the city, it describes the attractiveness of the overall elements as described in Figure 3.0-1 for the business sectors of the city.

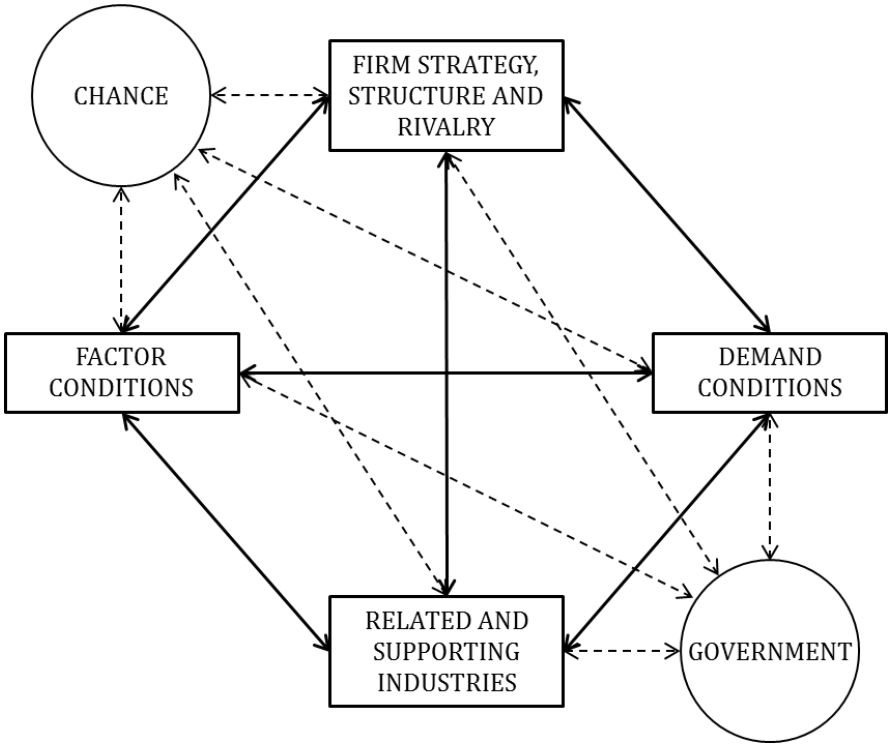


FIGURE 3.4-1: THE PORTER DIAMOND FOR COMPETATIVE ADVANTAGE (PORTER, THE COMPETITIVE ADVANTAGE OF NATIONS, 1990).

Factor conditions	Factor conditions indicate the resources present. These are human, knowledge, capital, physical and infrastructure.
Demand conditions	The presence of a home market, which can contribute to the demand for (innovative) products and advancement in product development.
Related and supporting industries	Related and supporting industries provide cost-effective input and participate in upgrading of in chains and thereby innovation.
Firm strategy, structure and rivalry	The way in which a business is created, organized and managed. This structure is important for its innovation, rivalry and its success.
Government	Government can influence the above mentioned determinants. Intervention can be done on different governmental levels.
Chance	Chance represent the developments outside the control of the businesses and government. Chance can create discontinuities and either lead to positive or negative influence on the competitiveness.

Globalization has led to change in the importance of location choice factors. Outsourcing of (part of) businesses has led to more footloose businesses, which especially has occurred in advanced economies[6]. The importance of clusters of interconnected knowledge-based businesses for location choice has kept level (or even increased). Proximity of businesses leads to a clustering in which the whole is bigger than its parts (Porter, 2000).

The attractiveness of an area for population depends on numerous factors, such as the availability of housing and jobs, quality of education and health services, safety and the absence of negative aspects such as pollution. An urban area needs to attract and maintain population and businesses. The attractiveness has a wide variety of aspects of importance (the push- and pull factors).

Conclusion

Governmental funding is a necessity for basic urban amenities. In the research, the business land use is divided into the four economic sectors. The primary economic sector is not taken into account, due to the fact that this sector is located outside urban area and therefore outside the scope of this research.

The attractiveness of an urban area for businesses depends on the presence of other businesses, the present infrastructure, availability of labour and governmental funds. Due to globalization the influence of clusters on the attractiveness increases. For population, the attractiveness is primarily focused on the availability of jobs and housing.

The impact of the global economy on cities will be discussed in the next paragraph.

3.5 EXTERNAL INFLUENCES ON CITIES

The sensitivity of employment to fluctuations in the national (and global) economy differs per city or area. These city fluctuations do not have to be in line with the national economy, it depends on the characteristics of the city's economy. It can rise or fall at different moments for different reasons (e.g. the car industry in Detroit, which declined heavily due to mismatching supply and demand of the type of vehicles and the software industry in San Jose, which lost employment after the 'dot-com bubble' in 2000). Factors of importance for this variation are the composition of the city's industrial base (the mix in industries), different economic sectors and historical precedent (Coulsen, 2006).

[6] The economy of the EU is considered an advanced economy.

MODEL DEVELOPMENT: URBAN2013

CHAPTER 4

Chapter 4 discusses the model as used in the research. It introduces the existing models on urban development in 4.1, followed by the development of the URBAN2013 model in 4.2. Additions to the model are discussed in 4.3. The validation, sensitivity, verification and tuning of the model is discussed in 4.4.

4.1 EXISTING MODELS ON CITY DEVELOPMENT

Several system dynamics models focused on urban areas exist. This part will discuss three of these models. The models that will be discussed are the URBAN1 model, the URBAN2 model and the Forrester model. The structure of this discussion is from a relative simple model to the more complex one.

Each model has a limited land availability (constraint) and has no external influences. The models assume an unlimited supply availability of people and businesses in the environment as well as a constant valued attractiveness of the environment.

URBAN1

The URBAN1 model (Alfeld & Graham, 1976) describes the dynamic interactions between population, business structures and housing. Each of these three stocks are dependent on several factors for growth and decrease. These are incorporated in the model as multipliers. The multipliers can have a positive or negative effect on the growth of each stock.

The main goal of the URBAN1 model is to provide insight on the role of population, business structures and housing in the different periods of the life cycle of an urban area (growth, transition and equilibrium). The basic setup of the model is given in Figure 4.1-1.

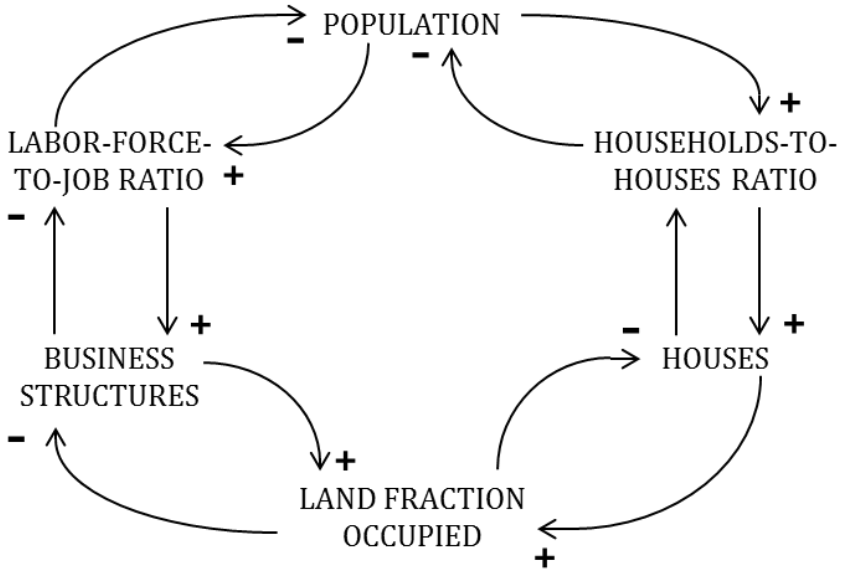


FIGURE 4.1-1: THE MAIN INTERACTIONS BETWEEN POPULATION, BUSINESS STRUCTURES AND HOUSES IN THE URBAN1 MODEL.

URBAN2

The URBAN2 model (Alfeld & Graham, 1976) is an expansion of the URBAN1 model. Each stock is expanded into three parts. For population, a division is made in income groups. Business structures are divided into three obsolescence groups and housing is divided into three income (and obsolescence) related groups. Each group has different relations towards each other group. For example, the number of upper income jobs at new business structures is higher than at deteriorating business structures.

The goal of the URBAN2 model is to give insight on the consequences of policy measures and give a clear view on objectives of policies. The URBAN2 model follows a trajectory (life cycle) with growth, stagnation and equilibrium. The basic setup of the model is given in Figure 4.1-2.

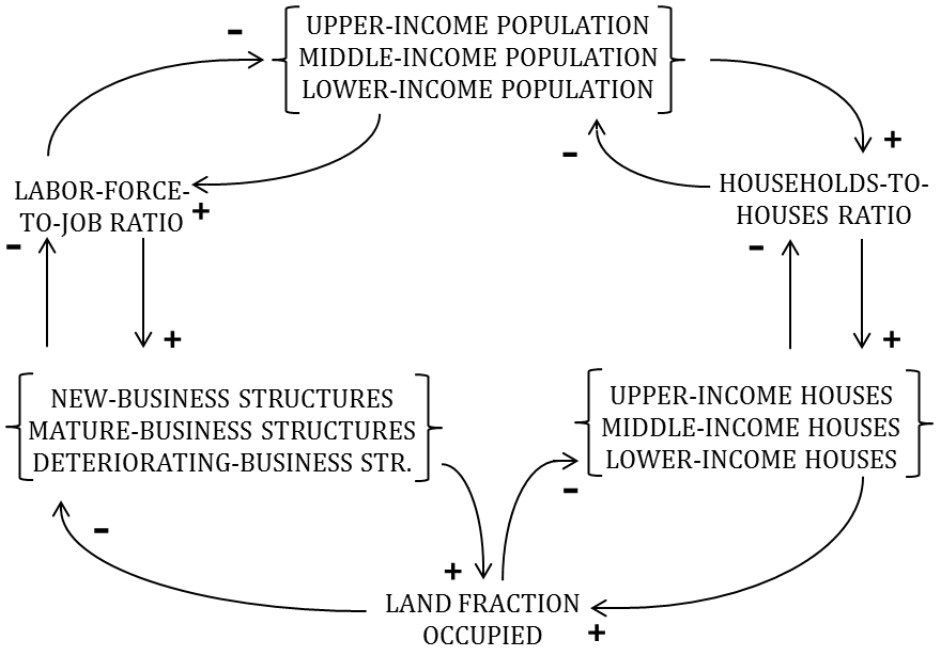


FIGURE 4.1-2: THE MAIN INTERACTIONS BETWEEN POPULATION, BUSINESS STRUCTURES AND HOUSES IN THE URBAN2 MODEL.

Forrester

The Forrester model (Forrester, 1969) is a more extensive model compared to the both URBAN models. The model uses the same basic stocks with three groups each and a same main dynamical structure (although some groups are more flexible and extended). The model has several additions, which are:

- Public expenditure: The expenses made per capita. The higher this amount is, the higher the burden on tax income, but also the larger the positive effect on the attractiveness of the area.
- Tax: The higher the tax income, the larger the stimulation of public expenditure. Higher taxes have a more negative influence on the attractiveness for people and businesses.

- Underemployment: Underemployment is seen in the model as a burden on the city. The more positive the measures for underemployed, the more underemployed will be attracted towards the urban area. Underemployed do not pay taxes and are a burden on public expenditure in the model.

The goal of the Forrester model is to gain insight on the consequences of policy measures. The model follows a life cycle of growth, maturity and stagnation (which leads to an equilibrium).

The existing models all use the same stocks, which are population, business structures and housing. The URBAN1 model is a basic model concerning the interactions between these three. The URBAN2 model is an expansion of the URBAN1 model and describes stocks in multiple parts (either by age or by class). The Forrester model is a more extended model, which not only describes stocks in parts, but also contains public expenditure, tax and underemployment.

The Need for a new Model

The existing models are all based on cities in the United States and this research is focused on European cities. The differences between US and European cities are inter alia the lifetime of buildings, modal split and urban planning.

Cities in the US are in general more focused on private motor vehicle traffic (The Transport Politic, 2010) than European cities, which focus more on public transport (Urban Audit, 2009). Figure 4.1-3 shows the differences in urban densities versus the distance from the city centre. These differences exist due to the abundance of land, low transportation costs and an economy based on services and technology industry (Caulfield, 2007).

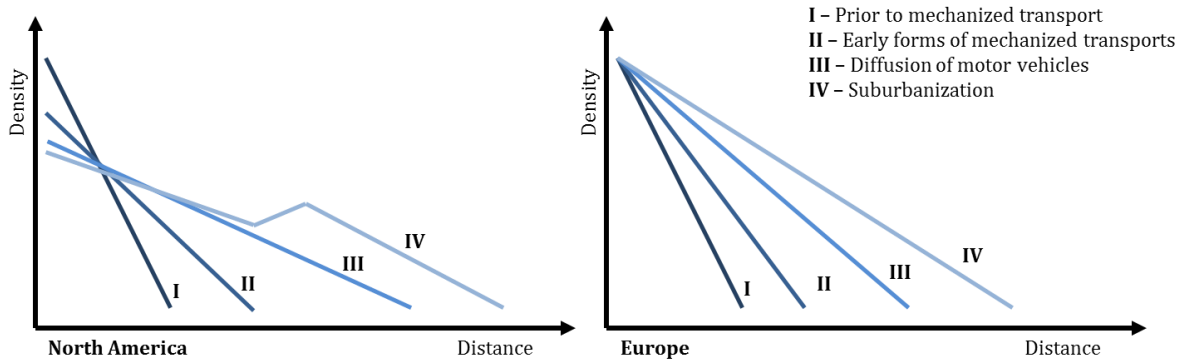


FIGURE 4.1-3: THE EVOLUTION OF URBAN DENSITIES IN NORTH AMERICA AND EUROPE (CAULFIELD, 2007).

Due to these differences the existing models have different starting points than a model focused on European cities should have (e.g. the urban planning). Therefore a model focused on the European cities is developed in the next paragraphs. This new European model will be referred to as URBAN2013.

4.2 DEVELOPMENT OF THE URBAN2013 MODEL

The URBAN1 model is taken as starting point for the development of the URBAN2013 model. New parts (some of which are based on the other existing models) will be fitted onto the model to adjust the model to the needs of the research. A more detailed explanation of the model development can be found in *Appendix A - Theoretical Model Development*.

A differentiation in URBAN2013 from the URBAN1 model is the split of the business structures in different economic sectors (as described in 3.4). This is due to the differences per sector in usage of the land and the corresponding economic output per area. Since the presence of businesses from different economic sectors differs per city, this can have influence on employment, tax income and land use. Table 1 shows the ratio between the different sectors for production and land usage.

TABLE 1: THE RATIOS BETWEEN OUTPUT PER LAND AREA PER ECONOMIC SECTOR.

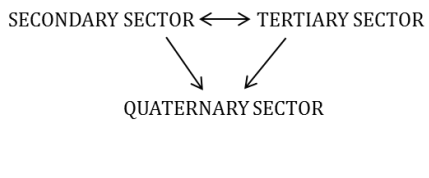
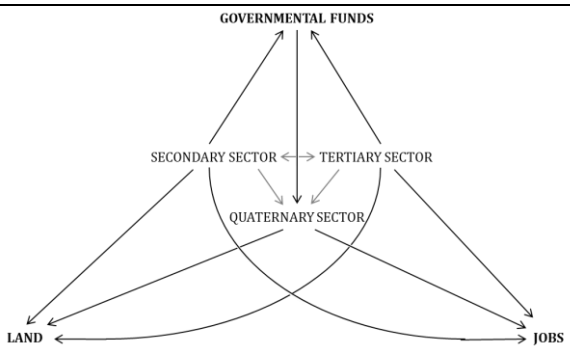
Economic Sector	**Ratio** *(based on data from the Rotterdam case)*
Primary Sector	8834,2
Secondary Sector	14,3
Tertiary Sector	1,0
Quaternary Sector	6,2

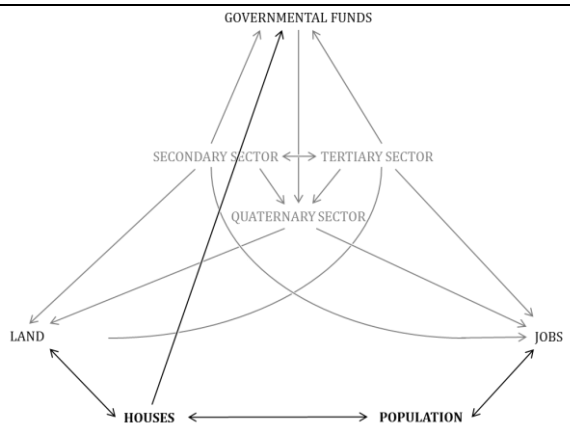
These results indicate that the net output of a hectare of tertiary sector business is 6,2 times higher than the quaternary sector, 14,2 times higher than the secondary sector and 8834,2 times higher than the primary sector. Due to these differences between the output per business sector area, business structures will be divided into groups based on the economic sector.

The primary sector takes place in rural areas (and on water), which are outside the scope of the research. Therefore **the primary sector is not taken into account in the model**.

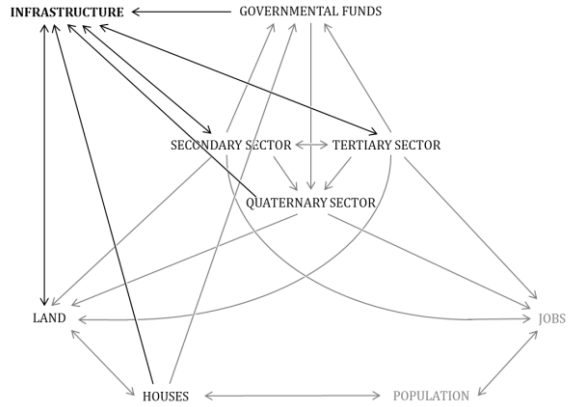
The model development of the city model is described step by step in Table 2.

TABLE 2: THE DEVELOPMENT OF THE CITY MODEL.

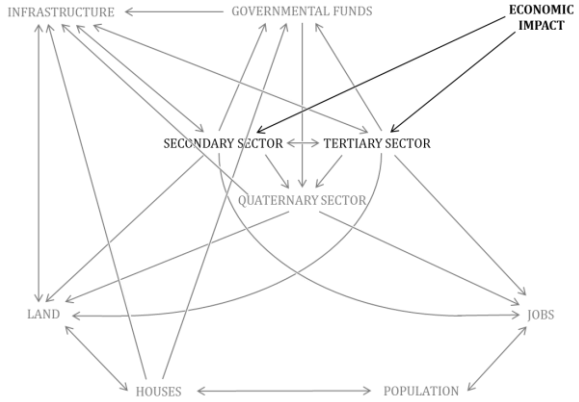
	The secondary and tertiary sector are free-market sectors. The quaternary sector is a (semi-) governmental sector. It provides public goods and services on local tier. It depends on governmental funds and the presence of secondary and/or tertiary sector (and population) for its services.
	The business structures are combined with the cornerstones of the classical economic theory: land, labour and capital. Labour is translated into jobs. Capital is translated in the governmental funds. Although capital is a broad concept, it is solely represented by governmental funds since this is the only relevant capital element for the development of other parts of the URBAN2013 model.



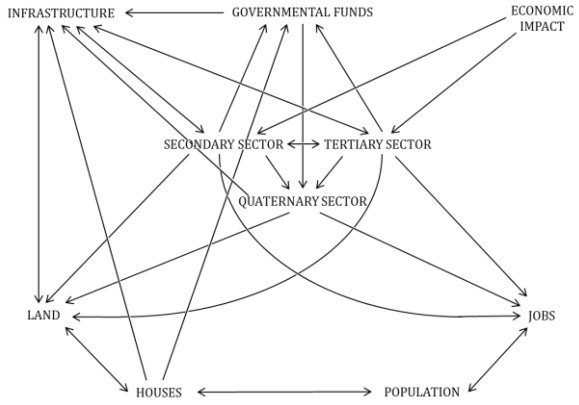
URBAN2013 is further extended with population and housing. The attractiveness of an urban area for population depends on the presence of jobs and houses. The attractiveness for the construction of housing units depends on the available land area and the need for housing from the population. Due to the land value tax a direct relation between houses and governmental funds exist.



Infrastructure concerns all present types of infrastructure in the city (such as transport infrastructure, the electricity network and the sewage system). The presence of infrastructure has positive effects on the attractiveness of the secondary and tertiary business structures due to for example a better accessibility. The scale of present infrastructure depends on the number of present business structures and houses. Infrastructure uses land area. It is assumed that a basic presence of infrastructure per structure is necessary.



The economic impact represents the influence of the global economy on a city. The impact of economic developments is primarily focused on commercial activities. This is due to the fact these activities are (heavily) reliant on demand and supply. The scale of this reliance depends on the type of businesses present.



The URBAN2013 model (as can be seen on the left) has the following additions to the URBAN1 model:

- Business structures is split into the secondary, tertiary and quaternary sector.
- Governmental funds
- Infrastructure
- Economic impact

URBAN2013 does not include different levels of population and levels in obsolescence of structures. This is not incorporated since the available data for European cities on these subjects are limited.

4.3 ADDITIONS TO THE URBAN2013 MODEL

This paragraph describes the elements which are new in the URBAN2013 model (compared to the existing models). These additions are more extensively described given their importance and impact on the model.

4.3.1 ECONOMIC IMPACT

The economic impact describes the influence of the global economy on the urban area. These global economic developments can have a major influence on urban areas (Cohen, 2004) and therefore are of importance for the model. In URBAN2013 the economic impact is represented by a combination of economic cycles. These economic cycles are described below (and visualised in Figure 4.3-1):

- **Inventory cycle** *(Kitchin; period of approx. 40 months)*
  The cycle is believed to be accounted for by time lags in information movements affecting the decision making of commercial firms.

- **Fixed investment cycle** *(Juglar; period of approx. 7-11 years)*
  Fixed investment is investment in physical assets such as machinery, land, buildings, installations, vehicles, or technology.

- **Infrastructure investment cycle** *(Kuznet; period of approx. 15-25 years)*
  The wave is connected with demographic processes and resulting changes in construction intensity over time.

- **Long economic cycle** *(Kondratiev; period of approx. 45-60 years)*
  The cycles consist of alternating periods between high sectorial growth and periods of relatively slow growth. Based on innovation.

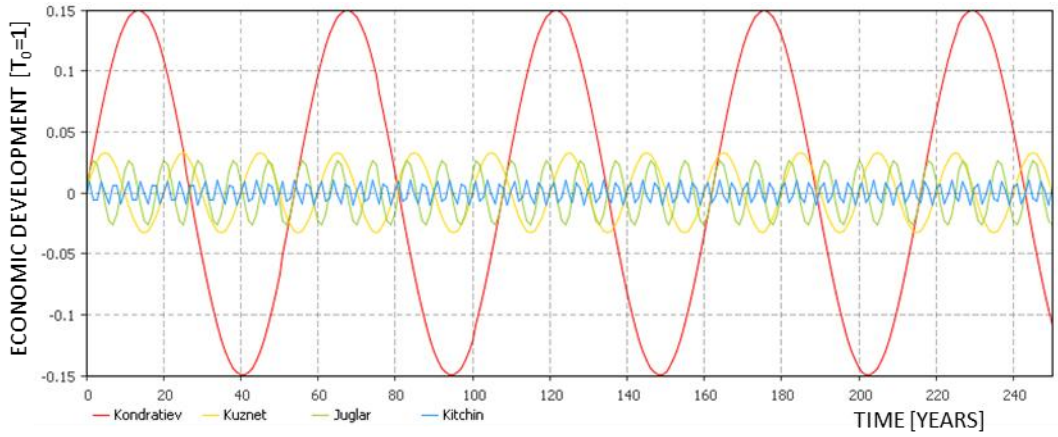


FIGURE 4.3-1: THE ECONOMIC CYCLES.

The economic cycles influence the secondary and tertiary sector in the model. This influence is based on the direct impact on the (global) demand for products and services supplied by these sectors. In times of economic growth, the demand will be higher, which will positively benefit the attractiveness of these sectors. In times of economic decline the opposite will happen.

4.3.2 THE CYCLE IN THE TERTIARY SECTOR

The tertiary sector is subject to fluctuations in supply of real estate availability. This process of fluctuations, also known as a *pork cycle*, originates from the differences between demand and supply at the start of the development time (planning and construction) and the demand and supply after the development is complete (Wheaton, 1999). The period of a real estate cycle is approximately 10 years (Lee, 2011).

The influence of the tertiary cycle in the model is based on a higher demand (in the form of a higher attractiveness of the tertiary sector) followed by a period of decrease in demand (in the form of a lower attractiveness of the tertiary sector). The size of these fluctuations are based on data on the creation and dissolution of tertiary sector businesses compared to other sector businesses in the Netherlands (CBS, 2012).

4.3.3 GOVERNMENTAL FUNDS

The governmental funds describe the available financial resources of the municipality. The governmental funds get these financial resources via national and regional funding and taxes. The usage of these resources differs per municipality and over time due to factors such as maintenance costs, obsolescence and decreases in income.

The governmental funds in the URBAN2013 model is partly based on the *tax* and *public expenditure* functions in the Forrester model (see 4.1). In URBAN2013 the governmental funds are based on the assumption that national and regional contributions are constant. Therefore, the sole influential part in the model is the input via the land value tax, which is contributed via business structures and houses. For Rotterdam, the income via land value tax is 10,8% of the total income (Gemeente Rotterdam, 2012).

The available governmental funds in the model depend on the obsolescence of structures in the model and the present housing and business structures converted per capita. The governmental funds in the model are processed as a ratio (and not an absolute number). This ratio is based on the total yearly income of the municipality of Rotterdam[7].

4.3.4 SECTOR TRANSFORMATION

The sector transformation describes the changes in employment per economic sector. As can be seen in Figure 4.3-2 the ratio of employment per economic sector has changed significantly over time. The sector transformation influences the land use and thereby the output and employment per hectare.

[7] The yearly income of the municipality of Rotterdam is derived from the municipal financial statements (Gemeente Rotterdam, 2012).

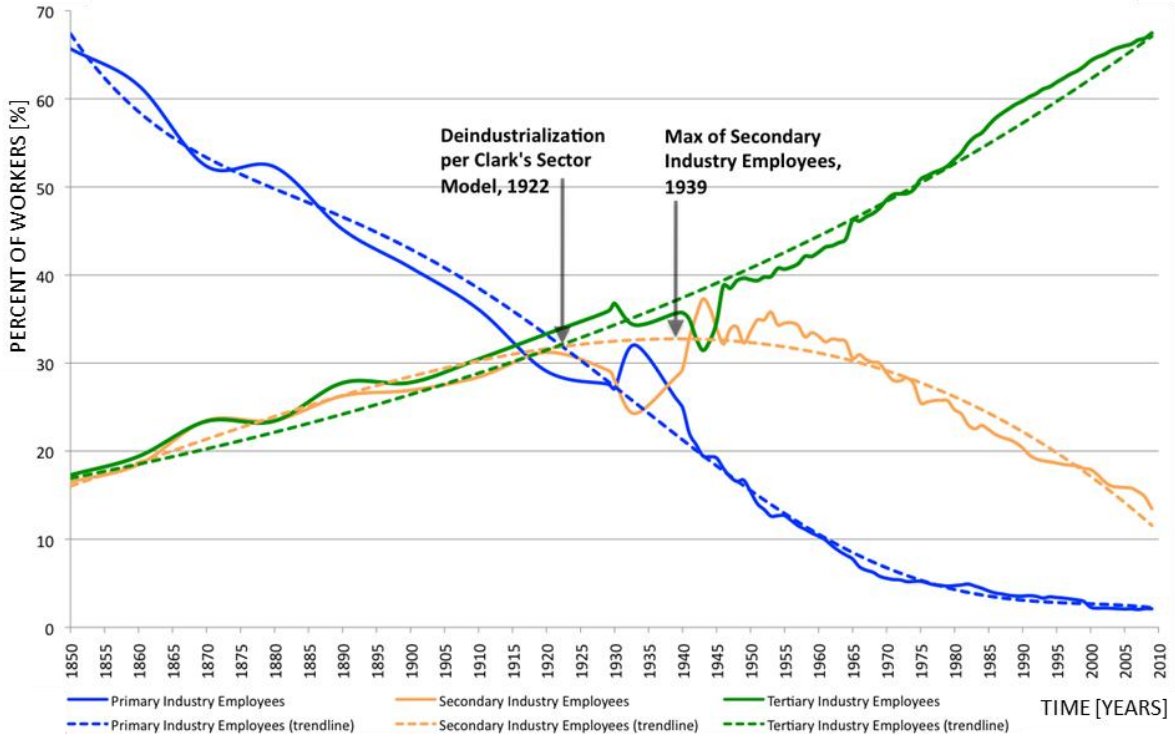


FIGURE 4.3-2: THE DEVELOPMENT OF EMPLOYMENT IN THE DIFFERENT ECONOMIC SECTORS IN THE UNITED STATES FOR A PERIOD OF 160 YEARS (C2ER, 2012).

For the future developments it is expected that the shares of employment per sector will continue to change. Several assumptions are made to describe the development of the sectors into the future. The most important assumptions are:

- ***Further globalization***. The competitiveness of companies will grow on the international field. This leads to more outsourcing to the more cheap employment countries of low-skilled (and also medium and high-skilled) jobs.
- ***Knowledge clusters***. The presence of knowledge clusters in an area will serve as a pull factor for other companies. Due to globalization an increase in specialization will occur, which in turn will be beneficial for the attractiveness (and creation) of knowledge clusters. Besides, knowledge clusters contribute to innovation in sectors, which in turn can provide further development.

These assumptions lead to the developments of each economic sector as described below and visualised in Figure 4.3-3.

- The **primary sector** is not present in the city and it is assumed it will also not be part of the city in the future.
- The decline of the **secondary sector** will halt due to the presence of knowledge clusters in industry (e.g. specialized maritime equipment in Rotterdam) and it will even show growth in the far future.
- The growth of the **tertiary sector** will slow down and turn into decline in the future due to the developments in efficiency and economies of scale (e.g. web shops). The tertiary sector will stabilize after the decrease.
- The growth of the **quaternary sector** will slow down and eventually decrease due to increased efficiency of public services and the privatization of some of these services.

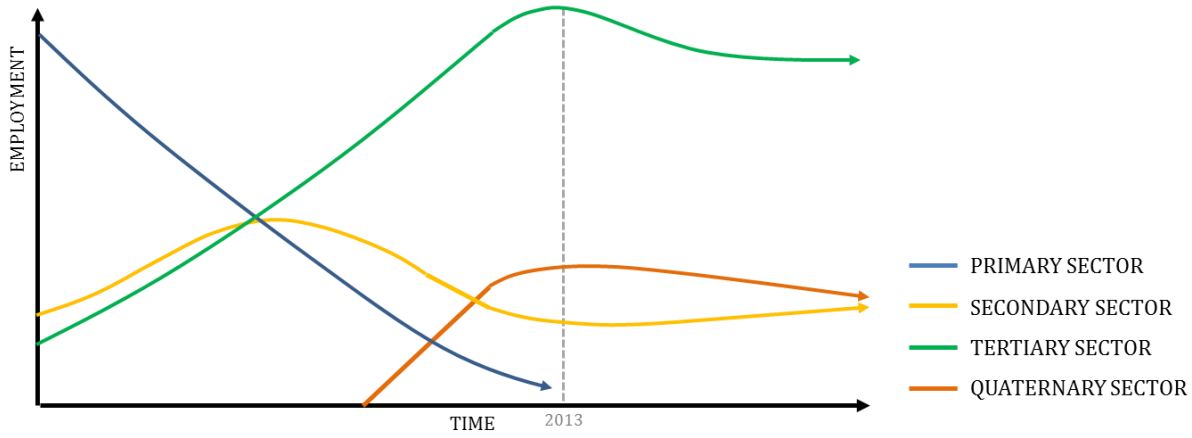


FIGURE 4.3-3: THE DEVELOPMENT OF EMPLOYMENT PER SECTOR AND THE FORECAST INTO THE FUTURE (ON THE RIGHT SIDE OF THE DOTTED GREY LINE).

The developments in sector transformation are incorporated in the model by a transformation factor for each sector. This factor influences the growth and decline of each sector over time, based on the assumptions as mentioned above.

4.3.5 AVAILABILITY OF LAND FACTOR

The availability of land factor describes the influence of land availability on the construction of new structures. This factor is in this model of importance for the implementation of flood adaptation measures and congestion measures. The factor describes the costs made for the acquisition of land for these measures.

These land costs differ due to the demand for land area. If the much of the land area is occupied, little land will be available for construction. This will lead to higher land prices, which in turn will lead to higher costs for land area for the implementation of measures. This is incorporated in the model by the availability of land factor, which directly influences the expenditure of the governmental funds for the measures.

4.3.6 PRIORITIZING FACTOR

The prioritizing factor is used to influence the development of each sector (business and housing) in a way that the sector with the highest demand has priority in development and thereby in claiming the available construction area.

It is assumed that if the demand in one sector is much higher than in other sectors, most of the development will be done in this high demand sector. However, not all development will be done in this sector, since project developers will have different strategies in development and therefore it is assumed that development in the other (less demanded) sectors will also occur, although in a lower priority number.

The prioritizing factor solely influences the type of development and not the total need for development. The factor respects the demand ratios (which means that the relative demand does not change). It is incorporated in the model by using the ratios in demand.

4.3.7 ATTRACTIVENESS OF THE URBAN AREA

The attractiveness for businesses in the URBAN2013 model differs from the attractiveness in the URBAN1 model. The attractiveness in URBAN1 was based solely on the available land area and the available labour force. The attractiveness in URBAN2013 is based on the Porter diamond on competitive advantage (as described in 3.4). The factors taken into account are:

- **Related and supporting industries:** The presence of other businesses is taken into account in the model.
- **Demand conditions:** The development of the global economy influences the attractiveness of the secondary and tertiary sector.
- **Factor conditions:** These are taken into account by the availability of labour and the presence of infrastructure.
- **Government:** The availability and usage of governmental funds.

Not taken into account are:

- **Firm strategy, structure and rivalry:** These factors are firm and sector dependent. Since this differs per firm and market, this aspect is not taken into account due to the lack of available data.
- **Chance:** Chance is not taken into account in the attractiveness, since there is no data available for the influence of chance on each business sector.

For population, the attractiveness is based on the availability of jobs and housing units and does not differ theoretically form the URBAN1 model.

4.4 VERIFICATION, SENSITIVITY, VALIDATION AND TUNING OF URBAN2013

The theoretical model as described in 4.2 and 4.3 is constructed in the AnyLogic software program for system dynamics. A complete description of how the city model is implemented in the software is given in *Appendix B – Software Model*. All parameters and start values are also given in this appendix.

The software package used for the research, AnyLogic University, does not contain the Monte Carlo Experiment. Therefore the modelling of the economic impact cannot be done (which would use a combination of the economic waves, a randomizer and the Monte Carlo Experiment). The economic impact in URBAN2013 is therefore assessed by three scenario's (positive, neutral and negative economic development). A full description of the economic impact implementation on the model is given in *Appendix C - Economic Impact*.

This paragraph will further discuss the validation, sensitivity, verification and tuning of the URBAN2013 model implemented in the software.

VERIFICATION OF THE MODEL

The objective of this research is *to develop a quantitative model to analyse city developments.* The model therefore needs to produce measurable units of output to determine the impact of flood and congestion on present city infrastructures. The model output contains the number of business structures and houses, the present infrastructure and the size of the population. With this output the model can be used to compare and quantify different scenarios and therefore the model suits its design requirements.

SENSITIVITY OF THE MODEL

The sensitivity of the model indicates the effect of uncertainty (in the input) on the output of the model. The sensitivity analysis function is not available in the software package used and therefore a precise sensitivity analysis in regard to the different parameters cannot be made.

Alternatively, the sensitivity of the model is therefore checked by implementing changes in the input parameters and comparing the output of each of these. The results of this check for sensitivity do not show any excessive sensitivity in the parameters used in the model and therefore the model is assumed as robust.

VALIDATION OF THE MODEL

The model is validated by implementing changes in a parameter value and comparing the output for these different parameter values. This output is compared with the expected behaviour of the model. If these match, the model behaves as expected and is therefore considered valid. The model validation is done for the relevant parameters. The behaviour is checked using 7 parameters (population, housing, secondary, tertiary and quaternary sector business structures, infrastructure and the land fraction occupied). A full description of the validation can be found in *Appendix D - Validation*. The behaviour of the model is in line with the expectations and therefore the model is assumed as valid.

TUNING OF THE MODEL

To improve the reliability of the model, it is tuned in order to fit the forecasts. For this tuning it is necessary that part of the input of the model needs to be adjustable.

The start values, rates and normal values used in URBAN2013 are directly taken from available data and therefore considered as the actual values. The tuning of the model can be done by adjusting the multiplier tables. These tables are incorporated from the existing URBAN1 and URBAN2 models. Since these existing models are based on cities in the United States, they are different for European cities (as described in 4.1) and therefore the multipliers are changed. The adjustable multipliers in the model are:

- Attractiveness of Housing Multiplier
- Attractiveness of Jobs Multiplier
- Housing Land Multiplier
- Housing Availability Multiplier
- Business Land Multiplier
- Business Labour Force Multiplier

For the tuning limited information of future development is available. Forecasts on population development to 2030 (Gemeente Rotterdam, 2012), housing development to 2030 (Gemeente Rotterdam, 2012) and the household size development to 2025 (Gemeente Rotterdam, 2009) exist. It is assumed that these forecasts are irrefutable and therefore these are used for the tuning of the model.

For the tuning the household size development is used as an input, since it is not a direct output in the model and can be inserted as an input which changes over time. The population forecast and the housing development are taken as the main forecasts for the tuning of the model.

TUNING ACCEPTANCE

The results of the model are accepted if the total difference between the model value and the forecast in 2030 is smaller or equal to 5,0% of the difference between the start parameter and the 2030 parameter. The desired output ranges for population and housing units are given in Table 3 and Table 4.

TABLE 3: THE CURRENT POPULATION, POPULATION FORECAST FOR 2030 AND THE REQUIRED RANGE OF THE MODEL OUTPUT.

	Start value (2012)	**Forecast (2030)**	**Range Model**
Population [people]	616.456	660.000	657.823 to 662.177

TABLE 4: THE CURRENT HOUSES, THE FORECAST FOR 2030 AND THE REQUIRED RANGE OF THE MODEL OUTPUT.

	Start value (2012)	**Forecast (2030)**	**Range Model**
Houses [housing units]	293.614	316.281	315.148 to 317.414

TUNING PROCESS

The tuning process is an iterative process. In each iteration step the multipliers are adjusted to improve the match of both the population and houses in the model with the forecasts. The decision which multiplier needs to be adjusted is taken on the basis of the differences in deviation of both parameters, since each multiplier has a different scale of influence on both parameters. The iteration process stops when both the population development and the housing development output of the model are within 5,0% range of the 2030 forecasts. The results for population and housing are given in Figure 4.4-1 and Figure 4.4-2.

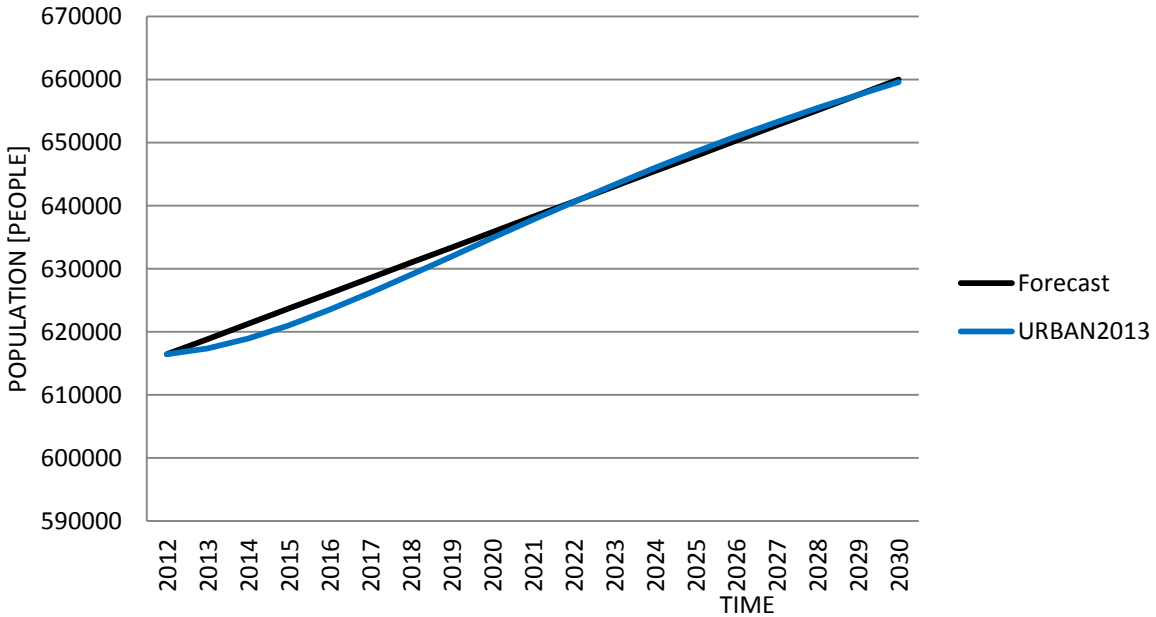


FIGURE 4.4-1: THE DEVELOPMENT OF THE POPULATION IN THE MODEL AND THE POPULATION FORECAST.

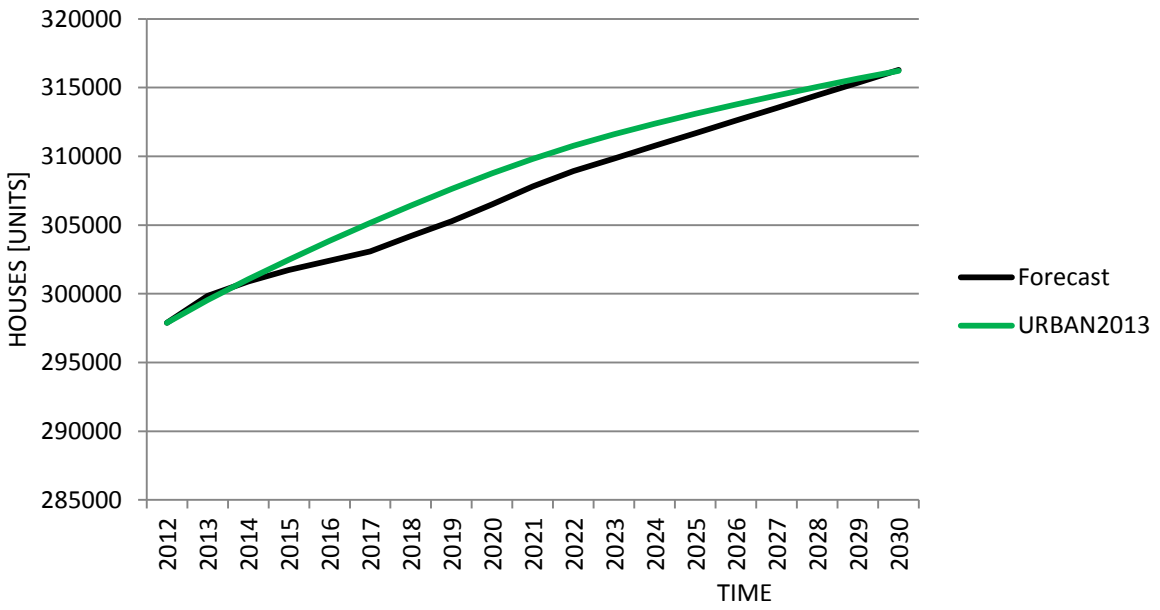
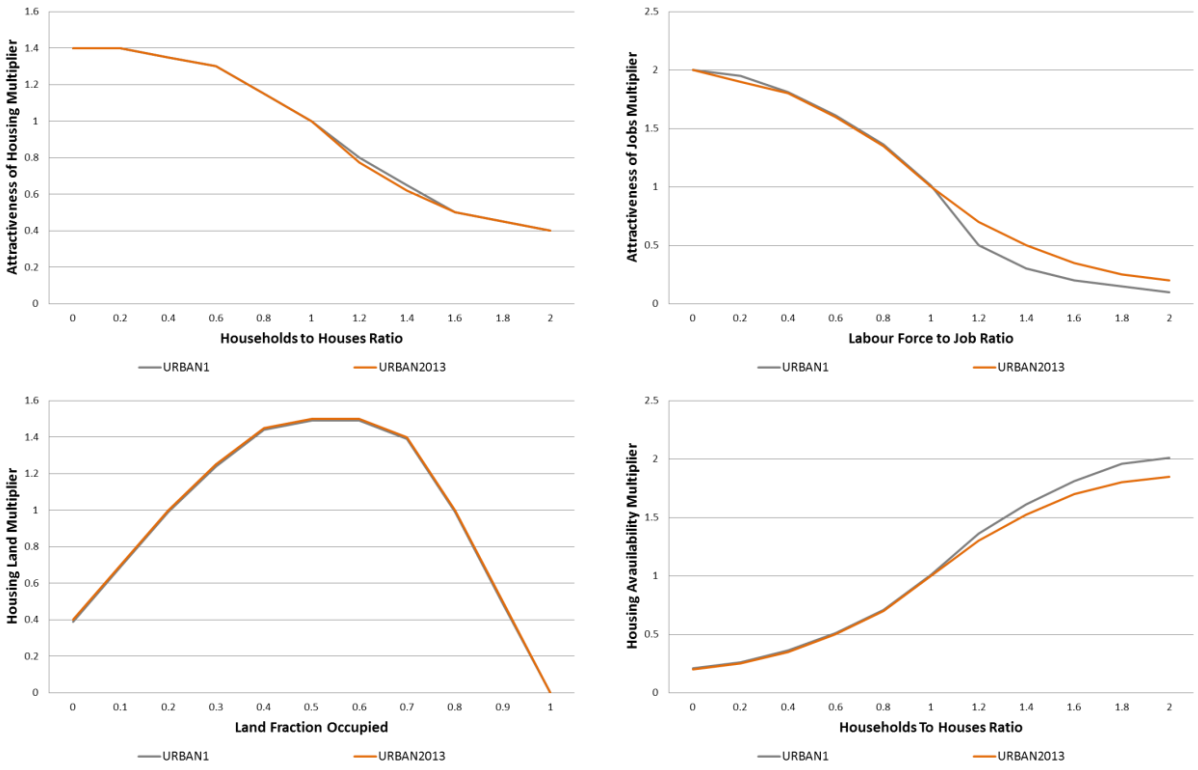


FIGURE 4.4-2: THE DEVELOPMENT OF HOUSING UNITS AND THE HOUSING UNIT FORECAST.

For population the difference between the model and the forecast in 2030 is 0,9%. For housing this difference between the model and the forecast in 2030 is 0,2%. Both are within the range as described and therefore the tuning of the model is acceptable.

Multiplier Graph Adjustments

For the tuning the multiplier tables have been adjusted. These adjustments are visualised in Figure 4.4-3. The multiplier tables get an input in the form of a ratio. The output of the multiplier is taken by inserting the input on the x-axis of the graph and taking the output from the y-axis of the graph.



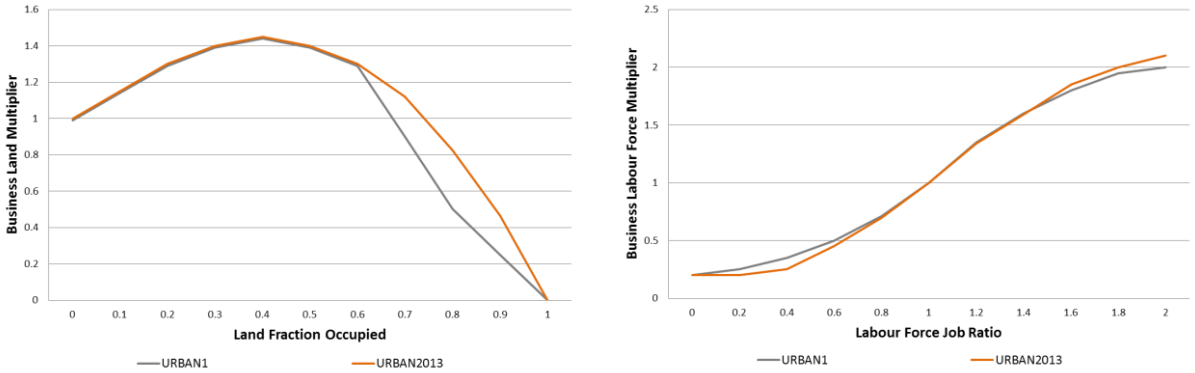


FIGURE 4.4-3: THE ADJUSTMENTS IN THE MULTIPLIER GRAPHS.

As can be seen in Figure 4.4-3 the *Business Land Multiplier* is amplified on the right part of the graph. This adjustment has been made since the assumptions in the original URBAN models were based on cities in the United States with urban sprawl and no or limited spatial planning. Since spatial planning in Europe is more regulated, the land use will therefore be more efficient, which leads to a higher multiplier for businesses in case most of the available land area is occupied.

The URBAN models are also adjusted by using city specific data. The main reasons for these adjustments are the more accurate data and the differences between US-cities (on which the existing models are based) and European cities such as Rotterdam.

ANALYSIS OF THE IMPACTS OF FLOODING AND CONGESTION

CHAPTER 5

With the URBAN2013 model completed, provided with the necessary additions and tuned, the model results can be analysed. The results of the general URBAN2013 model are used as the base case for the analysis of the impacts of flooding and congestion.

For both flooding and congestion two scenarios (handling strategies) are investigated. One strategy is aimed at doing nothing (the baseline scenario) to prevent the flood or congestion from occurring and the other is aimed at preventing the flood or congestion completely by implementing prevention measures.

The comparison with the base case is made on six elements. These elements are population, houses, employment and the secondary, tertiary and quaternary sector business structures. Table 5 shows the setup of the comparison which is done in this chapter.

TABLE 5: THE COMPARISON OF THE FOUR SCENARIOS.

	URBAN2013	**Extensions**			
Scenarios	*General Development*	*Flood Event*	*Flood Adaptation*	*Congestion*	*Congestion Measures*
Population	100%				
Houses	100%				
Employment	100%				
Secondary Sector BS	100%				
Tertiary Sector BS	100%				
Quaternary Sector BS	100%				
Comparison	100%	***Comparison of the results***			

The general development of Rotterdam is discussed in full in 5.1 to give a complete picture of the city in the URBAN2013 model. This is followed by the description and implementation of the four scenarios (the flooding scenarios in 5.2 and the congestion scenarios in 5.3). The comparison of the scenarios is made in 5.4.

Each scenario will be discussed following a standard setup. This setup provides the necessary results for the comparison of the impact of each scenario and discusses additional elements. The additions are of interest due to their influence in each scenario. These additional elements are the infrastructure present, the land fraction occupied and the governmental funds multiplier.

5.1 ANALYSIS OF THE DEVELOPMENT OF ROTTERDAM

The analysis of the development of Rotterdam is based on the general city model combined with the Rotterdam specific data. This data is obtained via the *Gemeente Rotterdam* and the *Centraal Bureau voor de Statistiek* in the Netherlands.

The life cycle of a city in the existing system dynamics models describes several phases. These phases are schematized in Figure 5.1-1.

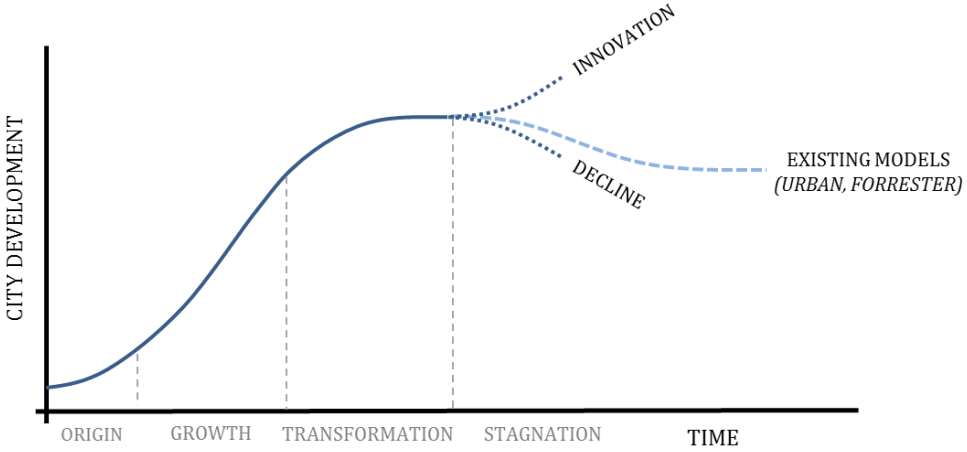


FIGURE 5.1-1: A SCHEMATIZATION OF THE LIFE CYCLE OF A CITY (BASED ON LECTURES CT5750).

The development of the urban area in the existing models all follow the four phases as indicated in the figure until a final equilibrium situation is reached. Urban areas have the possibility to continuously develop and innovate so the stagnation phase, with its decline, will be delayed or even prevented. This depends on many specific factors, such as the available resources, the type of economic activities, its geographic position and the economic structure (mono-economic versus multi-economic).

Figure 5.1-2 presents the historical development of the population of the city region of Rotterdam from 1868 until 2012 (the solid line) combined with the model output from 2012 until 2262 (the dotted line). The shape of the graph shows resemblance with the shape of Figure 5.1-1, showing a growth, transformation and stagnation phase. The peak period is located at approximately the year 2060.

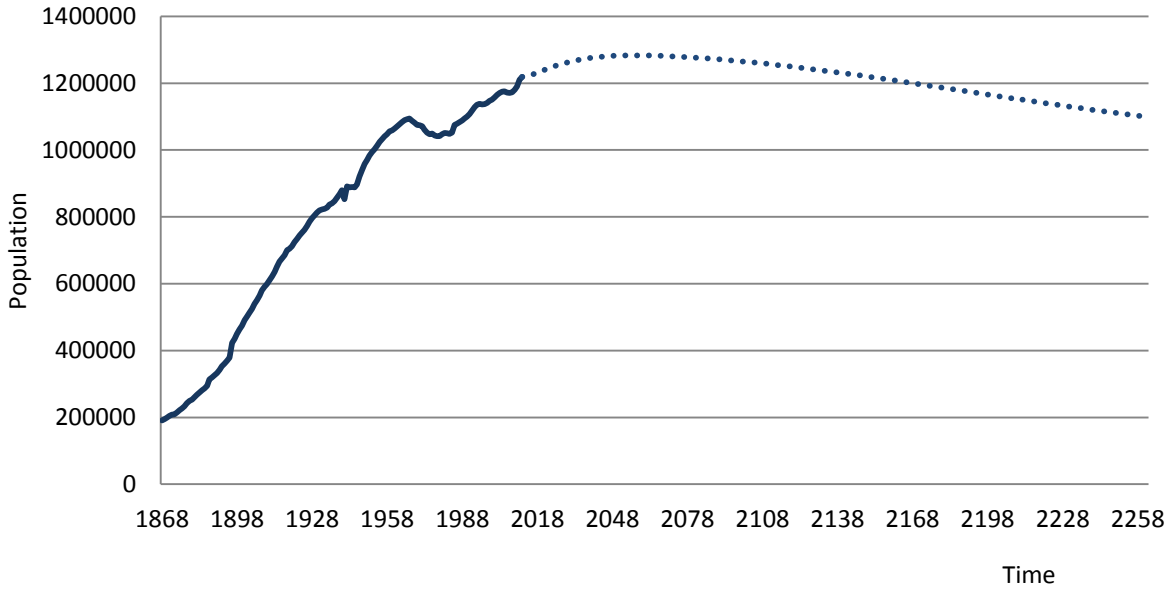


FIGURE 5.1-2: THE DEVELOPMENT OF THE POPULATION OF ROTTERDAM FROM 1868 UNTIL 2262.

The bumpy shape in the first part of the graph is due to several historical developments such as:

- The bombardment of Rotterdam in the Second World War (1940) and the subsequent reconstruction period (1940-1965).
- The national spatial planning policies, such as the *Eerste Nota Ruimtelijke Ordening* (1960) and the *Tweede Nota Ruimtelijke Ordening* (1966).
- The periods of high population growth in the Netherlands (e.g. labour immigration in the 1960s).

The start of the model (2012) is beyond the founding of the city of Rotterdam. Therefore the model starts later on in the life cycle. By inserting historical data[8] Figure 5.1-3 is created. This figure shows the development of Rotterdam starting from 1900. It can be seen that the URBAN2013 model gives a shape as described in the life cycle of a city (see Figure 5.1-1).

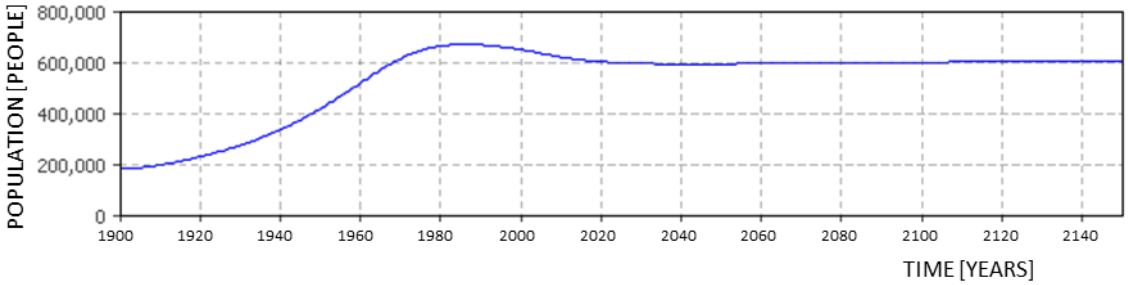


FIGURE 5.1-3: THE POPULATION DEVELOPMENT FOR URBAN2013 STARTING IN 1900.

The peak in population in Figure 5.1-2 is the year 2060 and in Figure 5.1-3 it is the year 1985. This difference in peak time is explained by the different starting principles, the impact of historical developments and annexations of neighbouring municipalities over time (e.g. Pernis (1934) and Rozenburg (2010)).

The development of the governmental funds multiplier over the 250 year period is shown in Figure 5.1-4. The multiplier has a positive contribution if the value is higher than one and a negative contribution if lower than one. For the first 80 years, the multiplier has a stable positive influence on the development. After this period the decline sets in. This decline is caused by obsolescence of the structures in the city. The period of decline takes approximately 30 years. The multiplier goes from a positive contributing multiplier to a negative contributing multiplier. After this period the multiplier stabilizes.

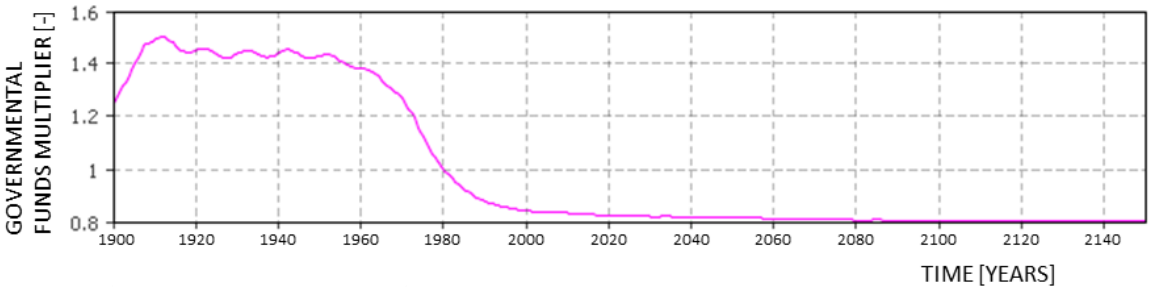


FIGURE 5.1-4: THE DEVELOPMENT OF THE GOVERNMENTAL FUNDS MULTIPLIER STARTING IN 1900 FOR A 250 YEAR PERIOD.

The sinusoid shape in the beginning of the graph is caused by the relative big influence of the tertiary sector cycle on the city development. Over time, the share of influence of the tertiary sector cycle diminishes which causes the sinusoid shape to disappear.

[8] The availability of historical data is limited. Therefore part of it is derived by extrapolating available data.

ROTTERDAM GENERAL DEVELOPMENT RUNS

The model runs start in the year 2012 and are done for a 30-year period. This period is chosen since it provides a sufficient time period to analyse the impacts of the flooding and congestion scenarios on a city. Therefore, in the remainder of this chapter, a timescale of 30 years is used in all graphs instead of the previously used timescale of 250 years.

POPULATION

The development of the population in Rotterdam is indicated in Figure 5.1-5. It shows a continuous growth for the 30-year period.

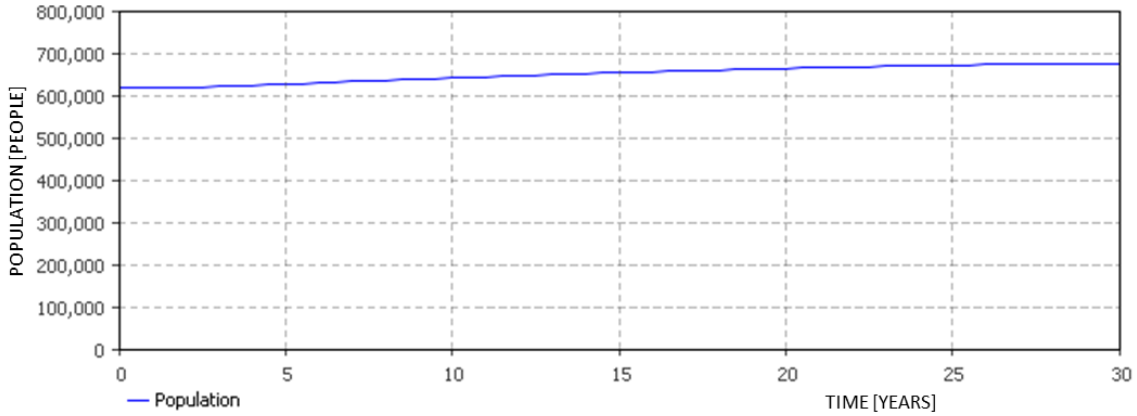


FIGURE 5.1-5: THE POPULATION DEVELOPMENT IN ROTTERDAM.

HOUSING

The development of the number of housing units present in Rotterdam is indicated in Figure 5.1-6. It shows an increase for the 30 year period. The increase becomes smaller over time and nears a peak at the end of the period.

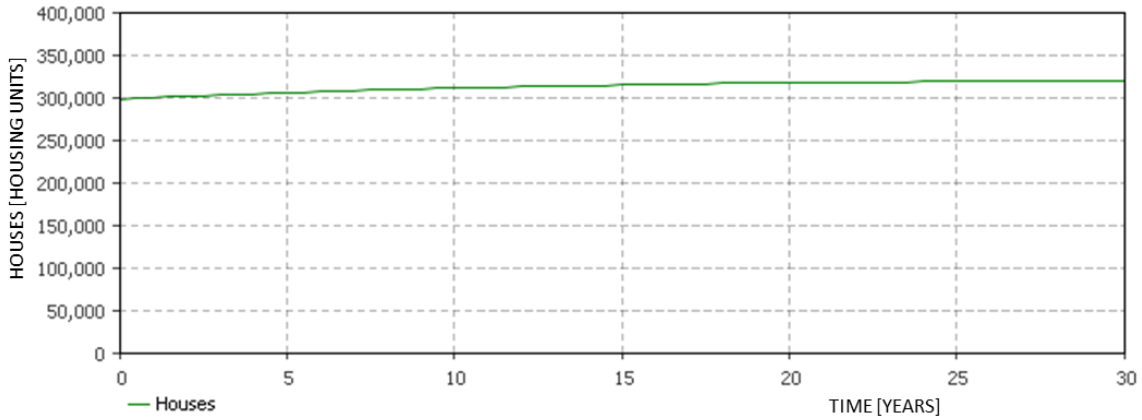


FIGURE 5.1-6: THE HOUSING DEVELOPMENT IN ROTTERDAM.

EMPLOYMENT AND BUSINESS STRUCTURES

The development of the employment in Rotterdam is indicated in Figure 5.1-7. The total employment grows until it nears a peak at the end of the 30-year period.

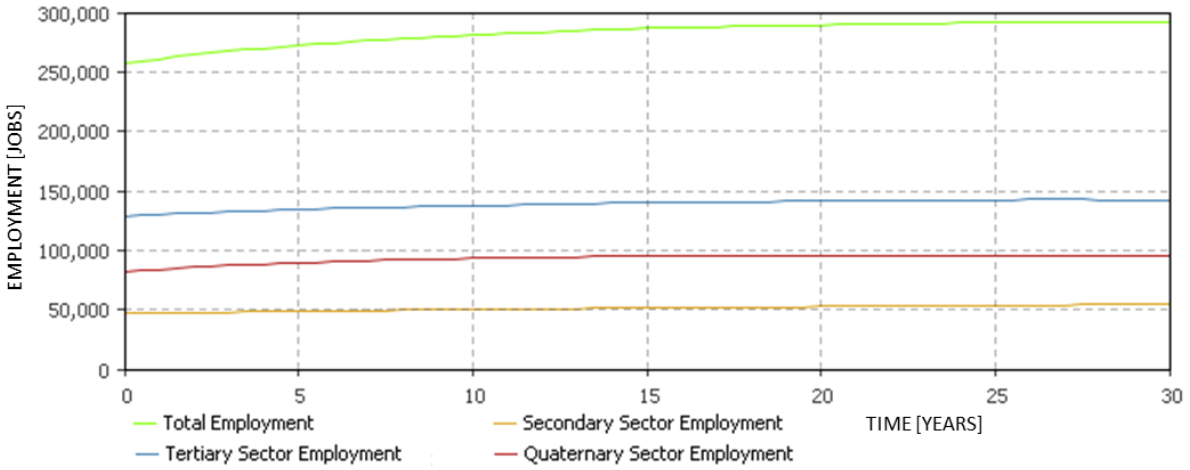


FIGURE 5.1-7: THE DEVELOPMENT OF EMPLOYMENT IN ROTTERDAM.

The development of the business structures in Rotterdam is shown in Figure 5.1-8. The business structures present describe a similar pattern as described by the employment. The total number of business structures grows until it nears a peak at the end of the 30-year period.

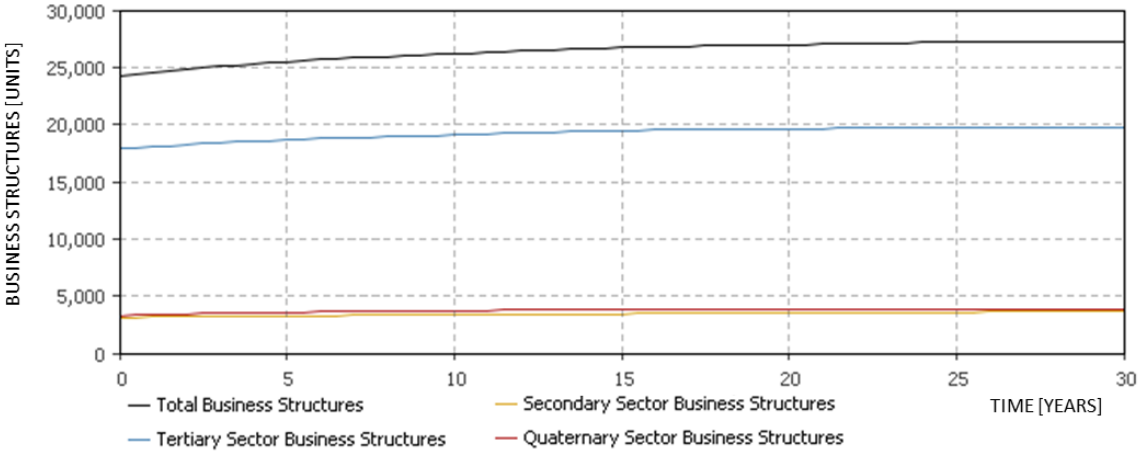


FIGURE 5.1-8: THE DEVELOPMENT OF THE BUSINESS STRUCTURES IN ROTTERDAM.

INFRASTRUCTURE

The development of the infrastructure in Rotterdam is illustrated by Figure 5.1-9. It indicates an initial growth followed by a peak around year 20-25 and the start of a decline afterwards. Infrastructure is influenced by the pressure for construction land and the decline of available governmental funding.

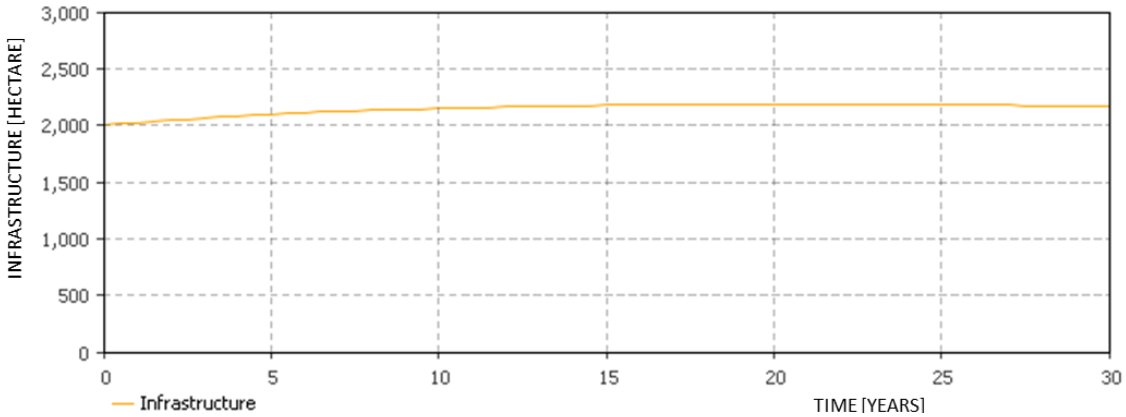


FIGURE 5.1-9: THE DEVELOPMENT OF THE PRESENT INFRASTRUCTURE IN ROTTERDAM.

LAND FRACTION OCCUPIED BY URBAN AREA

The development of the total land usage in Rotterdam is indicated in Figure 5.1-10. The land fraction occupied starts at 85% and grows until an equilibrium at approximately 95% land occupation is reached.

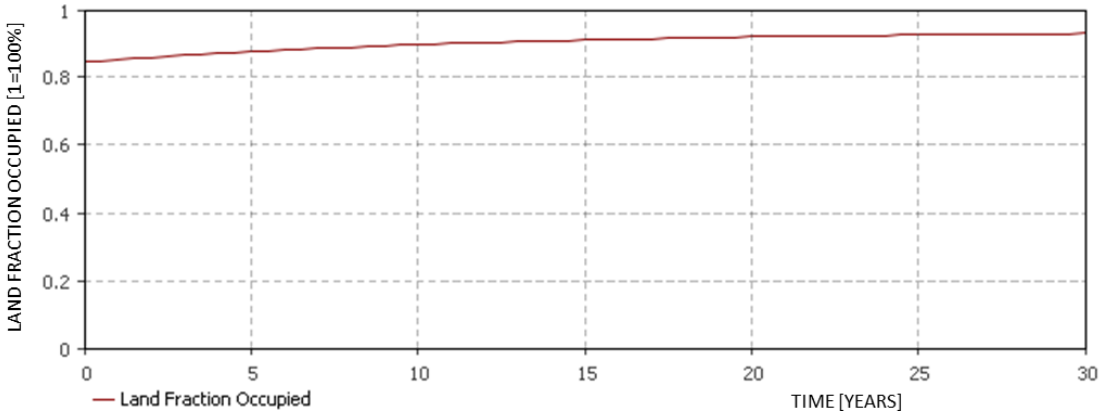


FIGURE 5.1-10: THE DEVELOPMENT OF THE LAND FRACTION OCCUPIED IN ROTTERDAM.

GOVERNMENTAL FUNDS

The development of the governmental funds in Rotterdam is indicated in Figure 5.1-11. The governmental funds initially (in time of city growth) show a positive impact on the development (higher than 1). Around year 15 the positive impact of the multiplier turns into a negative impact (lower than one), due to a decline in growth and obsolescence (and thereby higher maintenance costs) of structures and infrastructure. Since the city of Rotterdam in 2012 already nears its full land usage, the end of the growth period in the urban life cycle is already near.

By comparing this picture to the shape of the governmental funds multiplier in Figure 5.1-4 (note the different time scales), it can be seen for Figure 5.1-11 that it describes a transition in the availability of governmental funds from the positive impact towards a negative impact.

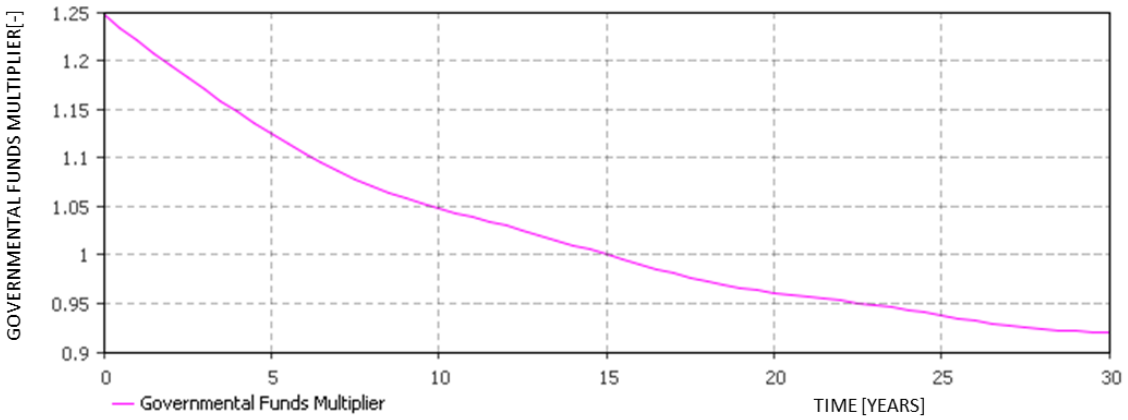


FIGURE 5.1-11: THE DEVELOPMENT OF THE GOVERNMENTAL FUNDS MULTIPLIER IN ROTTERDAM.

ROTTERDAM IN THE LIFE CYCLE OF A CITY

Given the results of the Rotterdam model runs it can be derived that Rotterdam is currently located in the transformation phase of the urban life cycle. This can be seen by the decrease in growth rate of the population, houses, employment and business sectors, the high land fraction occupied and the decrease of the governmental funds multiplier.

5.2 URBAN2013 EXTENSION: FLOODING

The URBAN2013 model is extended for both a flood event and flood adaptation. This paragraph first discusses the setup of the flood event and flood adaptation scenarios and subsequently gives a comparison of the scenario outcomes.

5.2.1 SCENARIO FLOOD EVENT

The setup of the flood event scenario consists of three parts. These describe the stepwise construction of the extent of the flooding, its impacts and the implementation in URBAN2013. The parts are:

1. Flood event scenario
2. Impact of a flood event on a city
3. Implementation in the URBAN2013 model

FLOOD EVENT SCENARIO

The type of flood event simulated in both scenarios is focused on pluvial flooding (flooding due to precipitation). The flood scenario is based on the projections made by the municipality of Rotterdam. The expectation is that in 2015 a shortage of 600.000m^3 water storage will exist. (Rotterdam Climate Initiative, 2010). These shortage projections are based on *no inundation in a 1 in 100 years period*.

Based on expert consultation[9] the shortage in water storage for this scenario is doubled to create the effect of heavy precipitation. The doubling is based on the assumption that a further increase in precipitation in the near future is likely. This assumption is based on the historic records of precipitation development in the Netherlands (KNMI, 2011).

The scenario therefore describes a 1.200.000m^3 pluvial flood in the municipality of Rotterdam in 2015. This scenario is used as a onetime event and will not occur periodically in the model, since the projections are based on no inundation in a 1 in 100 years period.

THE IMPACTS OF A FLOOD EVENT ON A CITY

A flood event has a variety of impacts on a city. The type of impacts are divided into three groups, which are the property impact, the economic impact and the impact on the population.

Property Impact

The property impact describes the destruction of buildings and infrastructure by high water levels. The damage to buildings and infrastructure can be calculated by introducing damage factors. These factors give the percentage of damage caused by a certain water level in a building or on the infrastructure (Genovese, 2006).

Since the amount of flood water (which cannot be stored and therefore causes the flood) is known, this is combined with a height map and a sector map (which indicates which areas are occupied by which sector) of Rotterdam. This gives the percentage of affected sectors and the water levels per sector. Table 6 shows the impact of the flood event on the different sectors multiplied with the damage factors. It can be seen that the tertiary business sector is the most vulnerable sector to a flood event. For a more extended description of the property impact, see *Appendix E1 - Analysis Flood Scenarios*.

[9] Expert consultation with Frans van de Ven (TU Delft) and Eric Schellekens (ARCADIS).

TABLE 6: THE PERCENTAGES OF DAMAGED STRUCTURES AND INFRASTRUCTURE IN THE SCENARIO.

Sector	Percentage demolished
Secondary sector business structure	0,008%
Tertiary sector business structure	0,996%
Quaternary sector business structure	0,131%
Housing sector	0,068%
Infrastructure	0,080%

Economic Impact

The economic impact describes the loss in production capacity of businesses. These losses are caused by destroyed goods and lost production means. This in turn leads to the loss of potential revenue for the businesses. This loss is not taken into account directly in the model, but calculated for the difference of added value per business sector in the comparison of the scenarios. The impact of a flood event on the city finances are caused by recovery costs, loss of business structures and houses (which would otherwise pay taxes) and the relief effort costs. The relief effort costs are based on a comparison with the costs made for the hurricane Katrina relief effort (Kok, 2006). The total relief effort costs are 3,4 million euro.

Impact on the Population

The impact on the population describes the decrease in population due to deaths, the injured and emigration. The number of deaths caused by the flood event scenario is 0,13, which is rounded to 0. This is based on the comparison of this flood event scenario with a reference flood event in Nimes, France (Falkenhagen, 2010). Injured are left outside the scope due to a lack in available data on pluvial flood related injuries.

Emigration can be temporary until the area is rebuild (e.g. Wilnis) or permanent in case of resettlement (e.g. New Orleans). The emigration can either be forced (due to destruction of housing and businesses) or motivated (due to a lack in attractiveness of the urban area). This decline in attractiveness is caused by the sentiment of insecurity in a (recently) affected area.

The impact on attractiveness of an urban area with flood risk is based on the differences in real estate prices in flood-prone and flood-free areas. Directly after a flood event the attractiveness of flood prone areas has decreased. Over time, this decrease reduces to approximately its pre-flood event condition (Eves, 2002).

The areas hit by the flood are also assumed as a flood prone areas in the model. Due to this flood event, the attractiveness of these areas declines, which influences the attractiveness in these specific areas.

THE FLOOD EVENT IN THE URBAN2013 MODEL

The flood event is incorporated in the model as shown in Figure 5.2-1. The property impact is indicated by the links with the different business sectors, houses and infrastructure. The population impact is indicated by the link with the population. The economic impact is not directly incorporated in the model, but can be derived from the differences between the flood event outcome and the general URBAN2013 outcome.

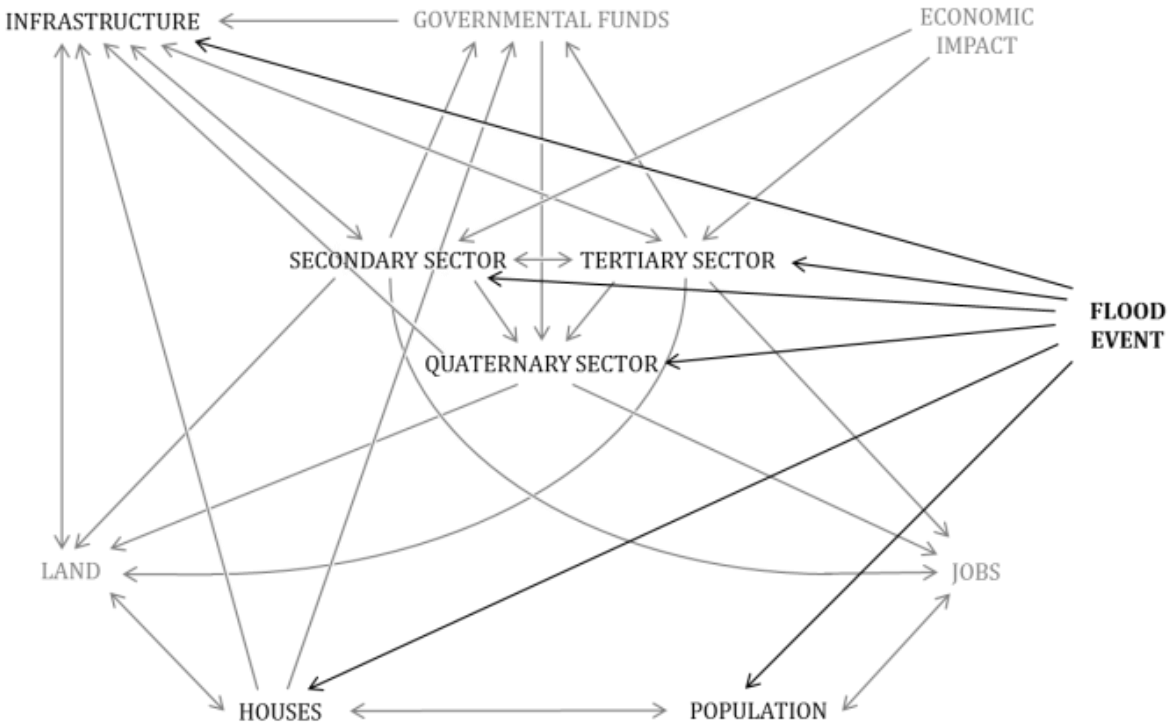


FIGURE 5.2-1: THE INFLUENCE OF A FLOOD EVENT ON THE URBAN2013 MODEL.

5.2.2 SCENARIO FLOOD ADAPTATION

The flood adaptation scenario is set up in three parts. These describe the extent of the adaptation measures taken, its impacts and the implementation in the model:

1. Flood adaptation scenario
2. Impact of flood adaptation on a city
3. Implementation in the URBAN2013 model

FLOOD ADAPTATION SCENARIO

The flood adaptation scenario is the strategy of preventing the flood event from occurring. In this scenario adaptation measures are implemented to prevent the impacts of the pluvial flood. In total these measures need to be able to store 1.200.000 m^3 of water by 2015.

The flood adaptation scenario is based on the construction of adaptation measures (e.g. water plazas, green roofs and elevated structures) to counter the flood event. The types of adaptation measures applied depend on the available land area and site specific characteristics.

THE IMPACTS OF FLOOD ADAPTATION ON A CITY

The implementation of the adaptation measures will have a variety of impacts on the city. It will cause extra land use for the constructions, construction costs and subsequently operation and maintenance costs.

Land Usage

The influence of the available land area for the implementation of adaptation measures is described in the model by the transformation factor. This factor is based on the increase in costs which are caused by the limited available land area and the coinciding extra needed structures (e.g. the construction of a pond versus an underground water storage). The increase in costs are given in Table 7. For the intermediate land fraction occupied values a linearity is assumed.

TABLE 7: THE COSTS OF LAND AREA[10].

Costs	**No/limited land occupation** *(LFO ≈ 0)*	**Full land occupation** *(LFO ≈ 1)*
Land [€/m²]	10	500

Construction Costs

The implementation of measures can be done by either solely constructing the new measures or by combining the measures with renewing (e.g. inserting larger sewage pipes during the renewing process) and new building constructions (e.g. by implementing green roofs). By combining these measures a cost reduction can be achieved. For the model it is assumed that all renewing can be combined with implementing adaptation measures and can be done free of costs and free of extra land use. The efficiency of the implementation in renewing projects is assumed as 5%[11]. This means that for each renewed structure 5% of the land area can be efficiently used as water storage. An overview of the costs per m³ water storage is given in Table 8. For the intermediate land fraction occupied values a linearity is assumed.

TABLE 8: THE COSTS FOR FLOOD ADAPTATION MEASURES[12].

Costs	**No/limited land occupation** *(LFO ≈ 0)*	**Full land occupation** *(LFO ≈ 1)*
Adaptation measures [€/m³]	10	250

The time needed for the implementation is derived via expert consultation[13]. The total time (which includes strategy, short and long term plans, political decision making and implementation) takes between 3 and 4,5 years. For the model, it is assumed that given the importance of the measures and the current developments adaptation measures with the full capacity of 1.200.000 m³ will be completed by 2015 (in 3 years).

Operation and Maintenance Costs

The yearly operation and maintenance costs for the adaptation measures are assumed as 6,5% of the total construction costs (Emerson PlantWeb, 2003).

THE FLOOD ADAPTATION IN THE URBAN2013 MODEL

Flood adaptation influences the same elements as the flood event, but it prevents the consequences of a flood event due to a lower flood water level. For this scenario the impact of a flood event will be reduced to zero due to the implementation of sufficient adaptation measures. Therefore the impact on the flood event elements are not taken into account. These adaptation measures are financed by governmental funds and use land area, as indicated by the links in Figure 5.2-2.

[10] Expert consultation with Ger Sterks, ARCADIS.
[11] A 5% efficiency means a water storage of 500m³ per hectare. This assumption is based on expert consultation with Frans van de Ven, TU Delft.
[12] Expert consultation with Ger Sterks, ARCADIS.
[13] Expert consultation with Bert Smolders, ARCADIS.

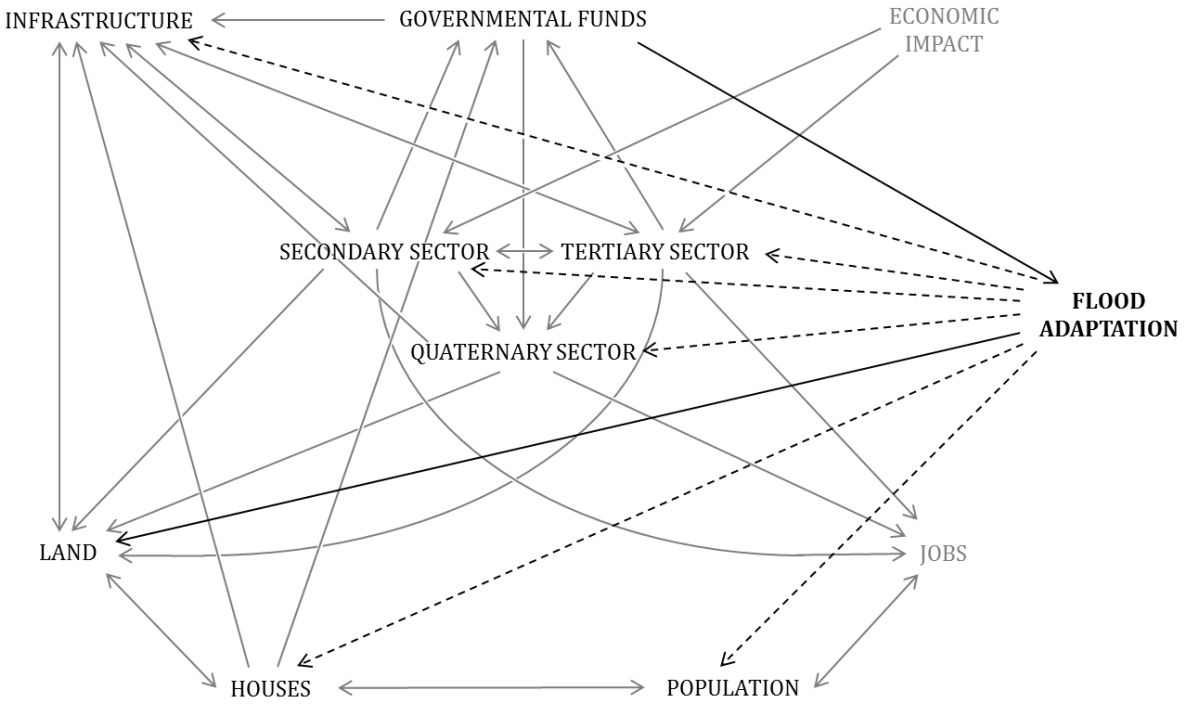


FIGURE 5.2-2: THE INFLUENCE OF FLOOD ADAPTATION ON THE URBAN2013 MODEL.

5.2.3 COMPARISON OF THE FLOOD EVENT AND FLOOD ADAPTATION MODEL RUNS

The graphs in this section indicate the development of the area (with the occurrence of a flood event and flood adaptation) with colored lines. The development without a flood event or flood adaptation (the so-called *general development* as discussed in 5.1) is indicated by a grey line. The differences between these lines indicate the influence of the scenarios on the development of the city.

POPULATION

Figure 5.2-3 shows the development of the population for the flood event scenario, the flood adaptation scenario and the general development. The figure shows for both the flood event and the flood adaptation a smaller growth over time compared to the general development of the URBAN2013 model. The cause for this difference is (for the flood event scenario) the decline of the tertiary sector (with high employment per ha) caused by the flood event. The newly free area (due to the flood event damage) is reused, but in a different composition where more land is used by sectors with a lower employment per ha. This different composition of reuse is caused by the demand of the different sectors at the time of and after the flood event.

For the flood adaptation a small lag behind the general URBAN2013 model exists. This lag is caused by the lower availability of land (due to the usage of the land for adaptation measures) and the smaller growth of quaternary sector business structures.

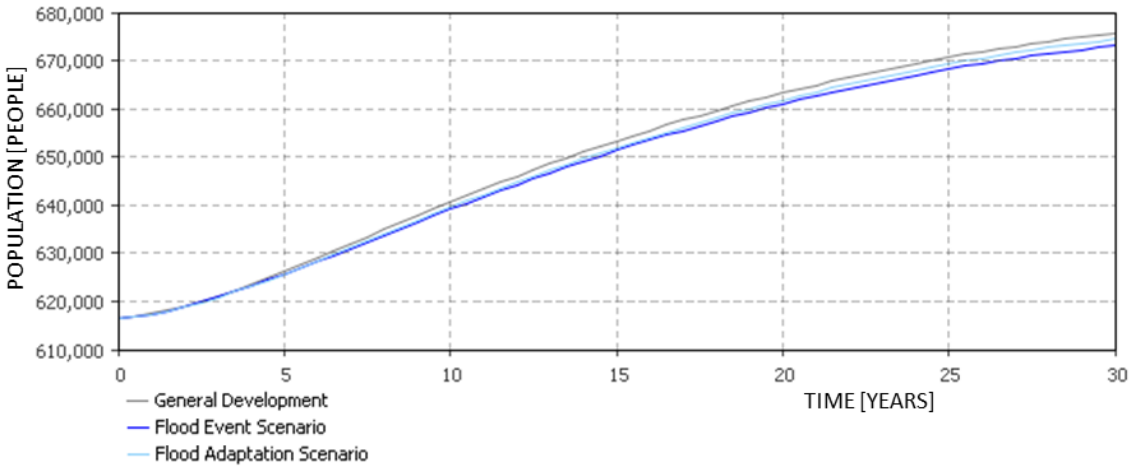


FIGURE 5.2-3: THE DEVELOPMENT OF THE POPULATION OF ROTTERDAM.

HOUSING

The development of the number of housing units present is shown in Figure 5.2-4. The figure shows an almost equal development of housing units over time for the flood event and the general model. The small difference can be explained by the reduced attractiveness for the construction of new housing due to a lower employment (caused by the shift in land usages of the affected area) and the lower attractiveness of flood-prone areas.

The implementation of adaptation measures leads to an increase in housing units. This is due to a lower demand for quaternary sector business sectors (caused by the lower available governmental funds), which leads to more available construction area for housing.

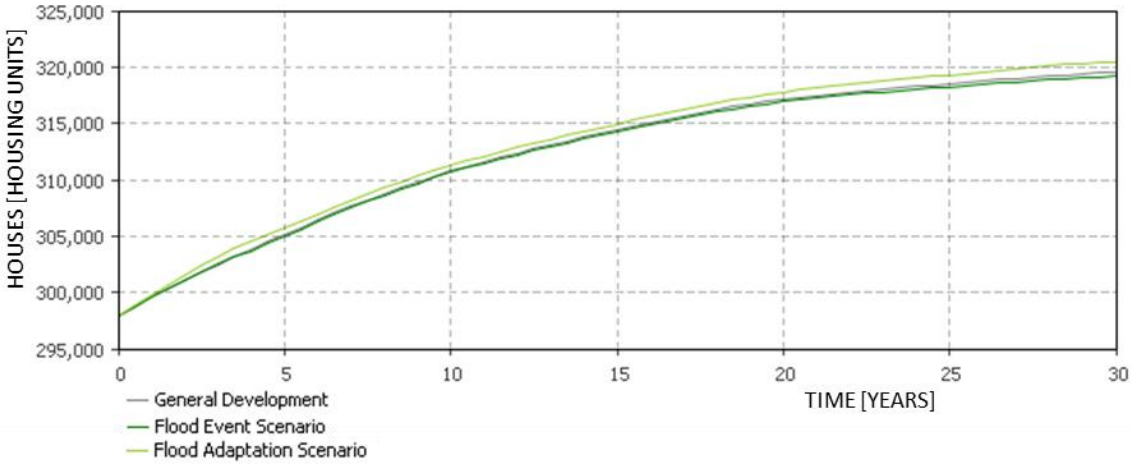


FIGURE 5.2-4: THE DEVELOPMENT OF THE NUMBER OF HOUSING UNITS.

EMPLOYMENT AND BUSINESS STRUCTURES

Figure 5.2-5 indicates the development of the employment over time. It can be seen that for both the flood event and the flood adaptation scenario the growth is lower than the general development model. For the flood event scenario this lower employment is caused by the changes in land usage of the affected areas and the lower attractiveness of the flood prone areas.

For flood adaptation, the decline is caused by the lower growth of the quaternary business sector (due to the lower availability of governmental funds) and the lower availability of land area due to the land usage of adaptation measures.

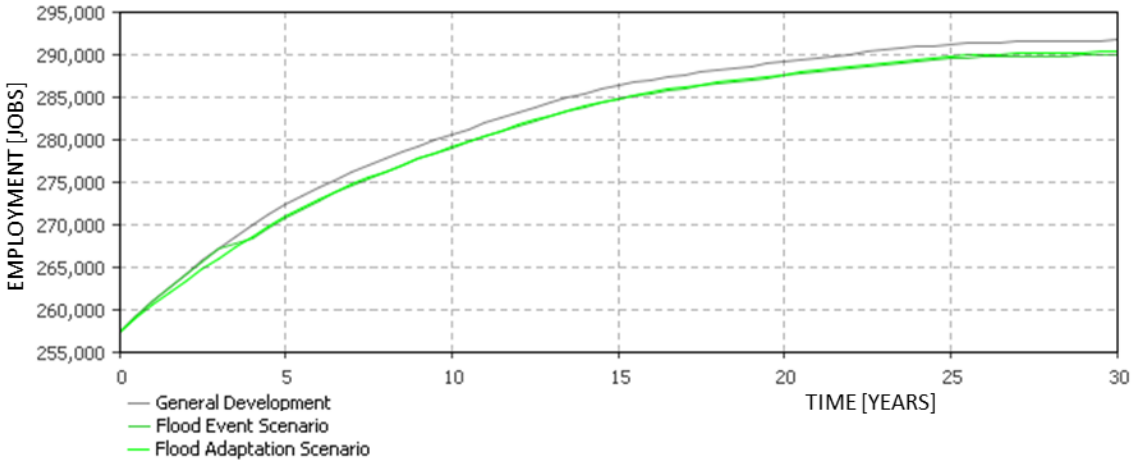


FIGURE 5.2-5: THE DEVELOPMENT OF THE EMPLOYMENT.

The impact of the flood event on the secondary sector business structures can be seen in Figure 5.2-6. The secondary sector shows an increase compared to the general development (as can also be seen in Table 6). This differences exists due to the changes in land usage of the affected areas.

The impact of the flood adaptation scenario on the secondary sector business structures is limited in comparison to the general development. The small difference can be attributed to the lower quaternary sector and infrastructure construction (due to lower governmental funds) and the subsequent more available land area for the secondary sector (as well as for housing and the tertiary sector).

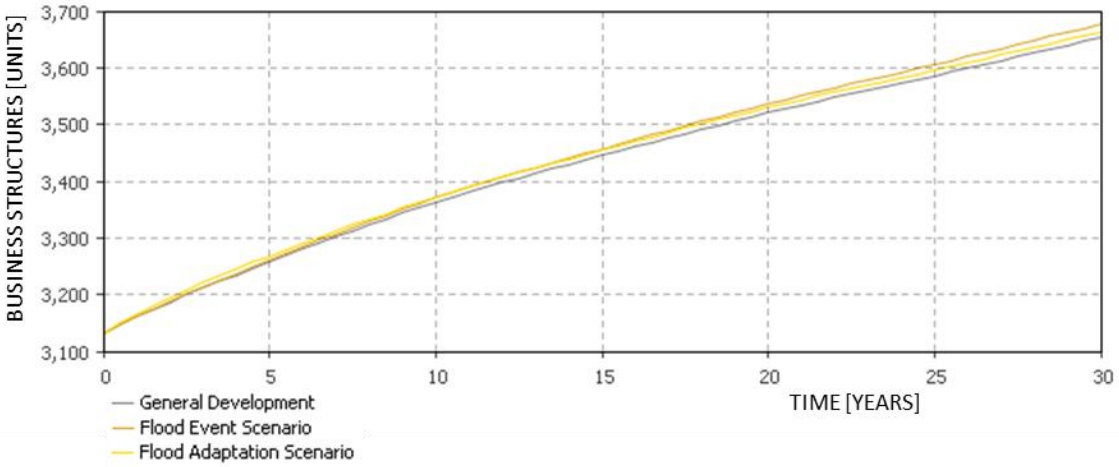


FIGURE 5.2-6: THE DEVELOPMENT OF THE NUMBER OF SECONDARY SECTOR BUSINESS STRUCTURES.

The impact of the flood event on the tertiary sector business structures can be seen in Figure 5.2-7. The sudden decline in structures due to the flood event is clearly visible. This lag remains present over time. This is due to new developments from other sectors on the vacated area.

The tertiary sector in the flood adaptation scenario shows a small increase compared to the general URBAN2013 run. This is due to the lower available governmental funds and thereby the decrease in investments in the infrastructure and the quaternary sector. This leads to less demand from both infrastructure and the quaternary sector for land use. In turn, this gives more space for the other sectors.

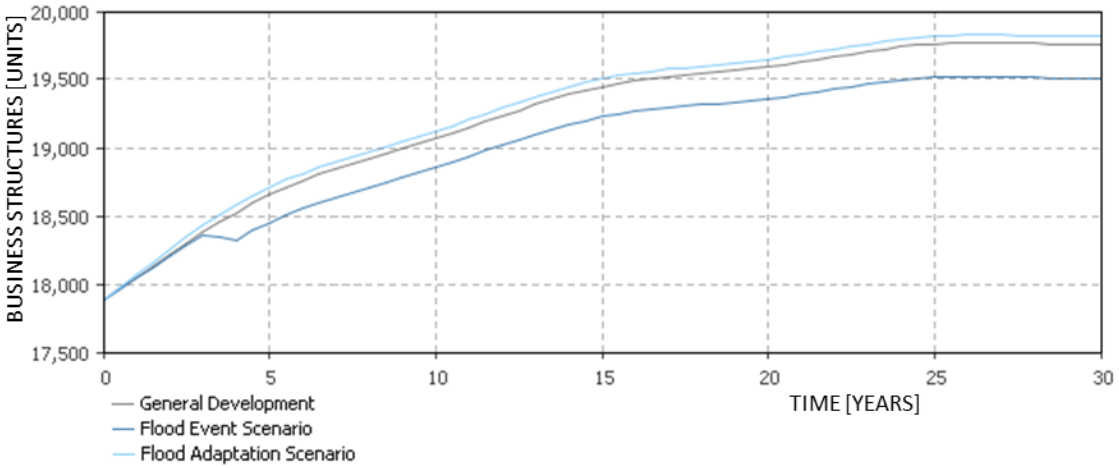


FIGURE 5.2-7: THE DEVELOPMENT OF THE NUMBER OF TERTIARY SECTOR BUSINESS STRUCTURES.

The impact of the flood event on the quaternary sector business structures can be seen in Figure 5.2-8. The flood event scenario has little influence on the development of the quaternary sector business structures. A small percentage is destroyed by the flood event (see Table 6).

The flood adaptation scenario shows a smaller increase of quaternary sector business structures over time. This smaller growth is due to the decrease in available governmental funds (especially the first three years due to the construction of the adaptation measures). Due to this construction, less governmental funding is available for new developments in the quaternary sector (and also for the infrastructure).

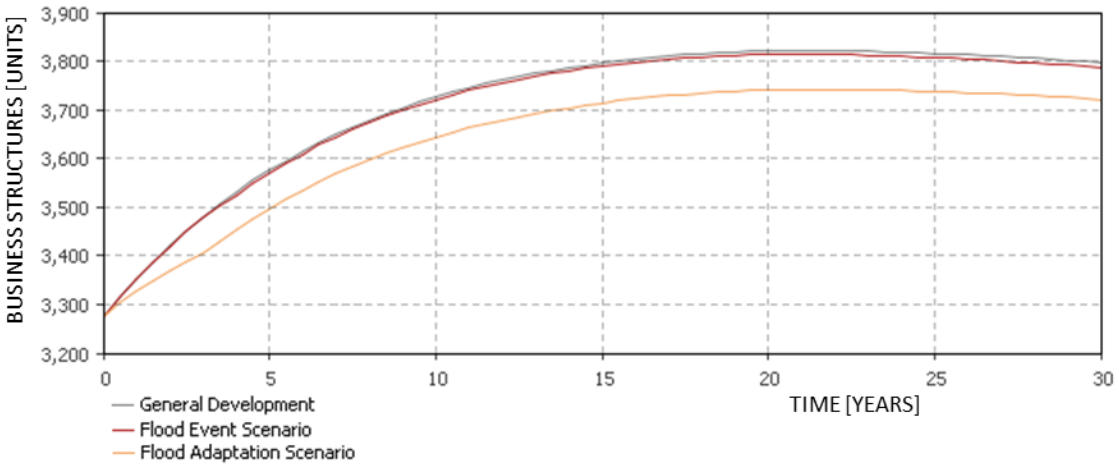


FIGURE 5.2-8: THE DEVELOPMENT OF THE NUMBER OF QUATERNARY SECTOR BUSINESS STRUCTURES.

INFRASTRUCTURE

The impact of the flood event on the infrastructure development can be seen in Figure 5.2-9. The flood event scenario has little influence on the development of the infrastructure. A small percentage is destroyed by the flood event (see Table 6).

The flood adaptation scenario shows a smaller increase of infrastructure development over time. This smaller growth is due to the decrease in available governmental funds (especially the first three years due to the construction of the adaptation measures). Due to this construction, less governmental funding is available for new developments in other infrastructure (and also for the quaternary sector business structures). The flood adaptation scenario combined with the land use for flood adaptation measures gives the higher land usage. This 'extra' land usage describes the land area needed for the adaptation measures.

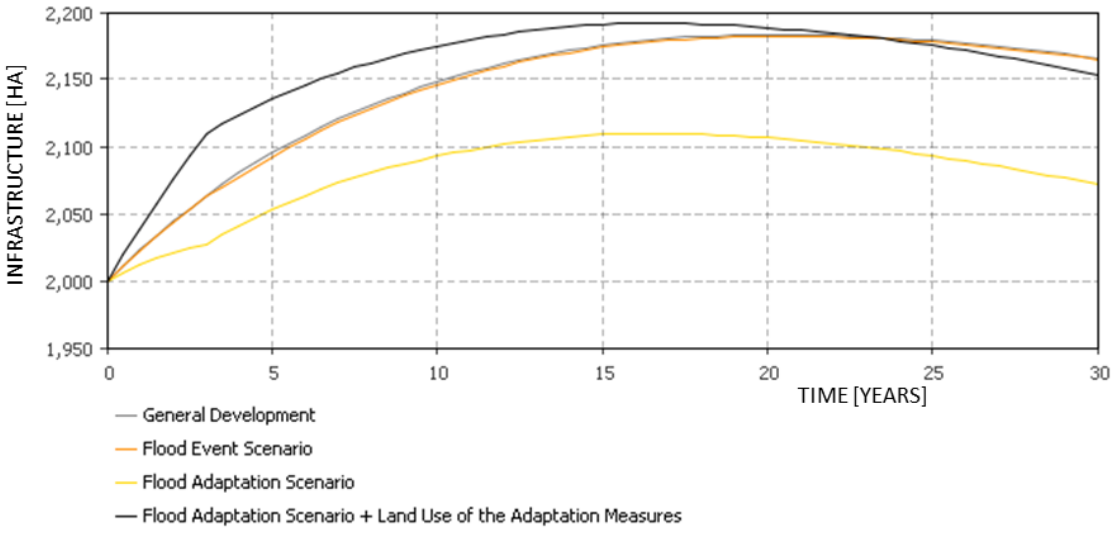


FIGURE 5.2-9: THE DEVELOPMENT OF THE INFRASTRUCTURE.

LAND FRACTION OCCUPIED BY URBAN AREA

Figure 5.2-10 shows the development of the land fraction occupied over time. As can be seen in the figure, both the flood event and the flood adaptation scenario cause little change over time, compared to the general development in the URBAN2013 model. For a more extended explanation of the land usage of the scenarios, see *Appendix E1 - Analysis Flooding Scenarios*.

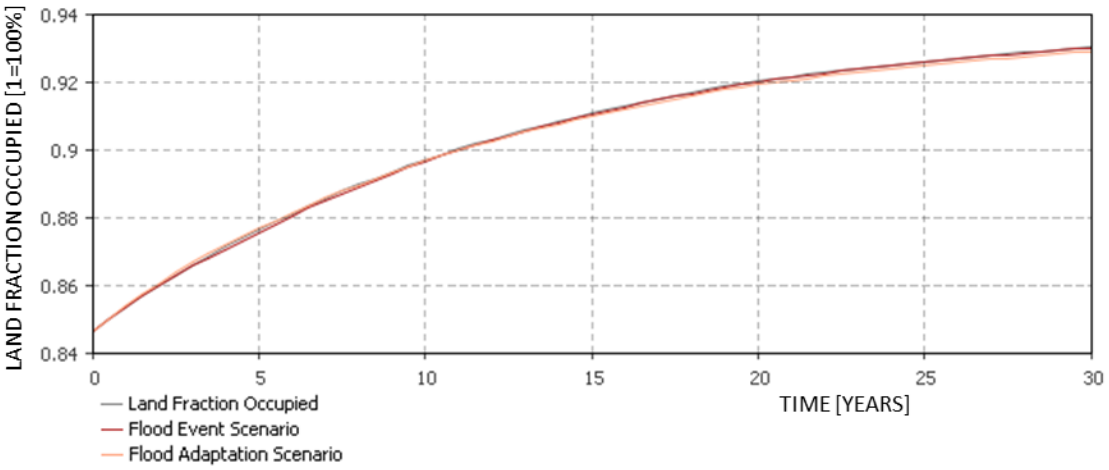


FIGURE 5.2-10: THE DEVELOPMENT OF THE LAND FRACTION OCCUPIED.

GOVERNMENTAL FUNDS

The development of the governmental funds for both scenarios is shown in Figure 5.2-11. The impact of the flood event scenario on the governmental funds is limited. The relief effort costs are not visible in the graph, since these make up only 0,2% of the total available governmental funds.

The impact of the flood adaptation scenario on the governmental funds multiplier shows a large gap with the flood event scenario. This gap is caused by the construction costs (over the first three years) of the adaptation measures. After the construction period, the operation and maintenance costs cause the difference in available governmental funds. Due to this lower availability of governmental funds, the development of the quaternary sector and the infrastructure is lower than in the general development of the URBAN2013 model. This in turn

will influence the governmental funds dependent infrastructure and quaternary sector. In total, the governmental funds multiplier for the flood adaptation scenario is significantly lower than the general development and the flood event scenario.

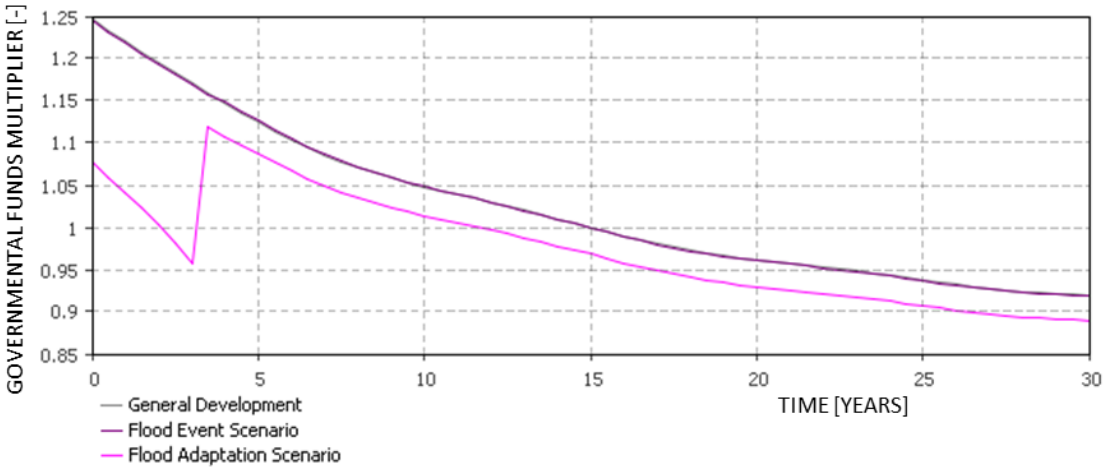


FIGURE 5.2-11: THE DEVELOPMENT OF THE GOVERNMENTAL FUNDS MULTIPLIER.

THE RESULTS OF THE FLOOD SCENARIOS

Table 9 describes the results of both scenarios compared to the general model development. The results are the summation of each output over a period of 30 years. Therefore each value describes the presence of population/employment/structures in years (e.g. the value for the secondary sector business structures describes the total number of businesses years present). For example, the flood event scenario leads to a decrease of 0,5% in employment and the flood adaptation scenario leads to a 0,19% increase in secondary sector business structures.

TABLE 9: THE RESULTS OF BOTH FLOODING SCENARIOS COMPARED TO THE GENERAL DEVELOPMENT.

	Absolute			**Percentage**	
	General Model (total)	**Flood Event** (difference with general model)	**Flood Adaptation** (difference with general model)	**Flood Event** (difference with general model)	**Flood Adaptation** (difference with general model)
Population [persons]	19.822.873	-50.526	-50.811	-0,25%	-0,26%
Houses [housing units]	9.531.031	-5.367	6.784	-0,06%	0,07%
Employment [jobs]	8.612.216	-43.093	-52.865	-0,50%	-0,61%
Secondary sector BS [businesses]	104.546	352	178	0,34%	0,17%
Tertiary sector BS [businesses]	586.414	-6.075	1.095	-1,04%	0,19%
Quaternary sector BS [businesses]	113.292	-184	-2.536	-0,16%	-2,24%

5.3 URBAN2013 EXTENSION: CONGESTION

The URBAN2013 model is extended for both congestion and congestion measures. With congestion solely recurrent congestion on the road network in the city is taken into account. This paragraph first discusses the setup of both scenarios and subsequently gives a comparison of the scenario outcomes.

5.3.1 SCENARIO CONGESTION

The setup of the congestion scenario consists of three parts. These describe the extent of the congestion, its impacts and the implementation in URBAN2013. These parts are:

1. Congestion scenario
2. Impact of congestion on a city
3. Implementation in the URBAN2013 model

CONGESTION SCENARIO

The scenario for congestion is derived from the '*Welvaart en Leefomgeving*' study (CPB, 2006). The *Global Economy* scenario is used in this research and it describes a growth in congestion in the Netherlands caused by further globalisation and trade growth (see also *Appendix E2 - Analysis Congestion Scenarios*). This scenario describes an increase in congestion hours of 70% by 2040 (using 2002 as a base year). It is important to note that the scenario for congestion does not fully matches the developments since 2002 in congestion in the Netherlands. Currently the development of congestion is lower. It is assumed that this mismatch is due to the current economic crisis.

For the scenario the current congestion situation in the Netherlands is the start value and the assumption is made that the congestion growth is linear. The current congestion situation describes an average congestion time of 66,1 hours per person per year in Rotterdam (INRIX, 2013). Since the 'Welvaart en Leefomgeving' study has 2002 as a start year, the overall congestion growth is adjusted to the starting year of the model: 2012. This leads to an increase in congestion hours of 51,6%[14] in 2040, which means an annual growth of 1,2 hours per person per year.

THE IMPACT OF CONGESTION ON A CITY

Road congestion hampers people and goods transport and it leads to higher emissions and nuisance. This can lead to economic damage due to time losses and to a decrease in the attractiveness of an area for business.

Time Losses due to Congestion

The valuation of travel time is based on the opportunity cost principle. This opportunity cost principle means that the value of lost time is taken as the value of time of the activity that otherwise would have been undertaken (Verhaeghe, 2009). This loss is not taken into account directly in the model, but calculated separately for the congestion scenario and added to the total added value in the comparison of the scenarios.

[14] Based on the assumption of a linear congestion growth. Calculated by 0,7*((2040-2012)/(2040/2002))=0,516. For the annual growth this result is divided by 28 (=2040-2012).

Decline in Attractiveness due to Congestion

The attractiveness of the secondary and tertiary sector businesses reduces due to congestion because of reduced accessibility and time loss (Metropolitan Planning Council, 2008). The attractiveness of housing will differ given the location of the housing unit in the city. Better accessible houses will become more attractive and less accessible housing will become less attractive (Brounen, Neuteboom, & Xu, 2008). Other negative effects for both businesses and housing are pollution and noise nuisance.

The impact of congestion on the urban area affects the attractiveness of the secondary and tertiary business sectors. The ratio of the sensitivity of congestion on the attractiveness of secondary and tertiary sector businesses is based on the importance of the accessibility for these business. This importance is derived from the factors of choice for the selection of business locations. For the secondary sector businesses, the importance of the accessibility is 50,0% and for the tertiary sector this importance is 44,3% (Pellenbarg, 2006). The secondary sector is therefore more sensitive for congestion than the tertiary sector.

The impact of congestion on the attractiveness of businesses is based on the impact an increase in congestion has on the productivity of these businesses. A decrease in accessibility of approximately 10% would decrease productivity by 1% (Hartgen, 2009). Due to a lack of available data the assumption is made that this 1% productivity decrease will also cause a 1% decline in attractiveness for the business sectors. This 1% decline is further balanced over the sensitivity of the secondary and tertiary sector as described above.

THE CONGESTION IN THE URBAN2013 MODEL

The occurrence of congestion is incorporated in the model as shown in Figure 5.3-1. Road congestion influences the accessibility of the area and thereby the attractiveness of the area for the secondary business sector, the tertiary business sector and the population due to time losses and pollution. Vice versa, the presence of business structures and population leads to road usage, which in turn may lead to road congestion. Road congestion depends on the present transport infrastructure, which explains the link with the infrastructure in the URBAN2013 model.

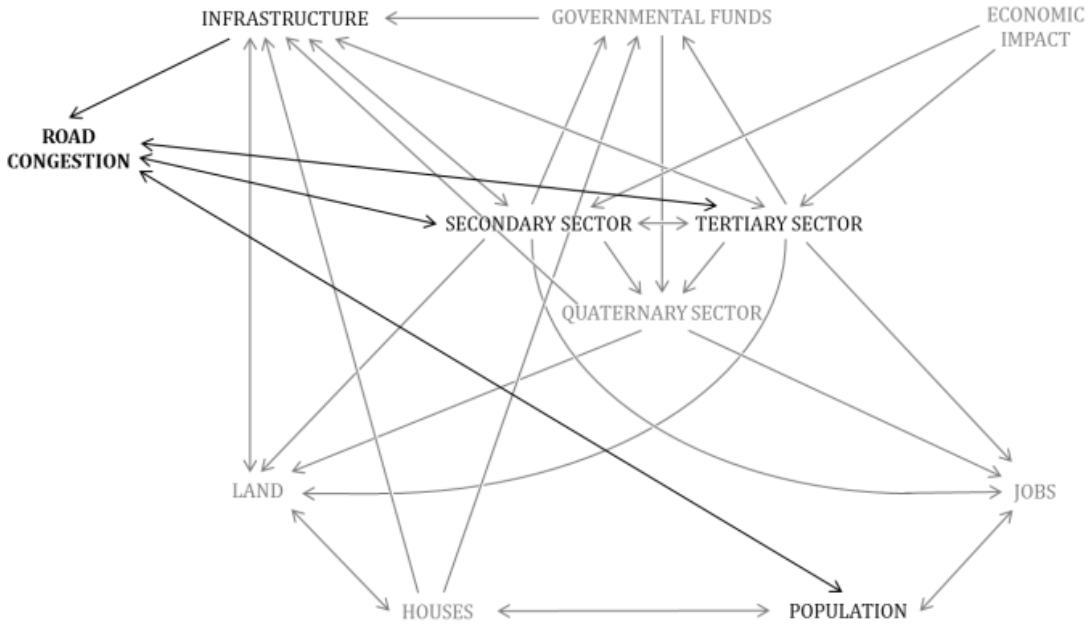


FIGURE 5.3-1: THE INFLUENCE OF CONGESTION ON THE URBAN2013 MODEL.

The input of the population, secondary sector and tertiary sector on the road congestion are incorporated in the model via the congestion scenario.

It is important to note that economic growth and decline influence congestion. This is due to the direct influence the global economic development has on commuting and business travel (Ministerie Verkeer en Waterstaat, 2009). Since the economic impact cannot be taken directly into the model, this link is not incorporated in the model.

5.3.2 SCENARIO CONGESTION MEASURES

The congestion measures scenario is set up in three parts. These parts describe the extent of the congestion measures, its impacts and the implementation in the URBAN2013 model. These parts are:

1. Congestion measures scenario
2. Impact of congestion measures on a city
3. Implementation in the URBAN2013 model

CONGESTION MEASURES SCENARIO

The congestion measures scenario is based on reducing the consequences of congestion (as described in 5.3.1) to zero. Congestion reduction can be based on a number of measures, such as roadway expansion, smart growth land use policies, improvement of alternative modes and pricing reforms (VTPI, 2013). The impacts and costs of these measures vary. In this research no distinction is made in which type of strategy is implemented. This is done since the types of measures applied depend on the available land area and site specific characteristics.

IMPACT OF CONGESTION MEASURES ON THE CITY

A variety of measures to limit the impact of congestion exist. Depending on the type of measures implemented, these will cause land usage, construction and/or implementation costs and operation and maintenance costs. For this scenario a combination of the different measures is assumed. Therefore the costs in land usage, construction/implementation and operation and maintenance are taken as averages from the different type of measures.

Land Usage

The construction of new transport infrastructure as congestion measure will require land area. The land usage for the measures are derived from reference projects[15]. A yearly extension of 0,85% of the transport land use is sufficient for to cope with the yearly congestion growth. The costs for the acquisition of land area is shown in Table 10.

TABLE 10: THE COSTS FOR CONGESTION MEASURES[16].

Costs	**No/limited land occupation** *(LFO ≈ 0)*	**Full land occupation** *(LFO ≈ 1)*
Land [€/m²]	10	500

[15] Due to a limited availability of data the land usage of the congestion measures is based on reference projects in the United States (Hartgen, Fields, & Poole, 2006). It is assumed that the land use per measure is equal for both cities in the United States and cities in Europe.
[16] Expert consultation with Ger Sterks, ARCADIS.

Construction and Implementation Costs

The construction and implementation costs for the congestion measures are based on reference research on congestion reduction in cities in the United States (Hartgen, Fields, & Poole, 2006). The costs of construction and implementation for are based on the average costs for this in the reference project and the ratio in congestion increase compared to the scenario. The construction and implementation costs are approximately 39,2 million euro per year.

Operation and Maintenance Costs

The yearly operation and maintenance costs for the adaptation measures are assumed as 6,5% of the total construction costs (Emerson PlantWeb, 2003).

THE IMPACT OF CONGESTION MEASURES IN THE MODEL

The impact of congestion measures in the model is shown in Figure 5.3-2. Adaptation to road congestion has the same dependencies as solely road congestion. One additional link is introduced, indicating the influence of the available governmental funds on the congestion measures. The higher this relative availability of funding, the more can be invested in adaptation measures (and vice versa for lower available funding).

The impact of congestion is taken into account in the model based on the ratio between the total economic congestion costs and the costs of applying congestion measures combined with a lowered level of congestion.

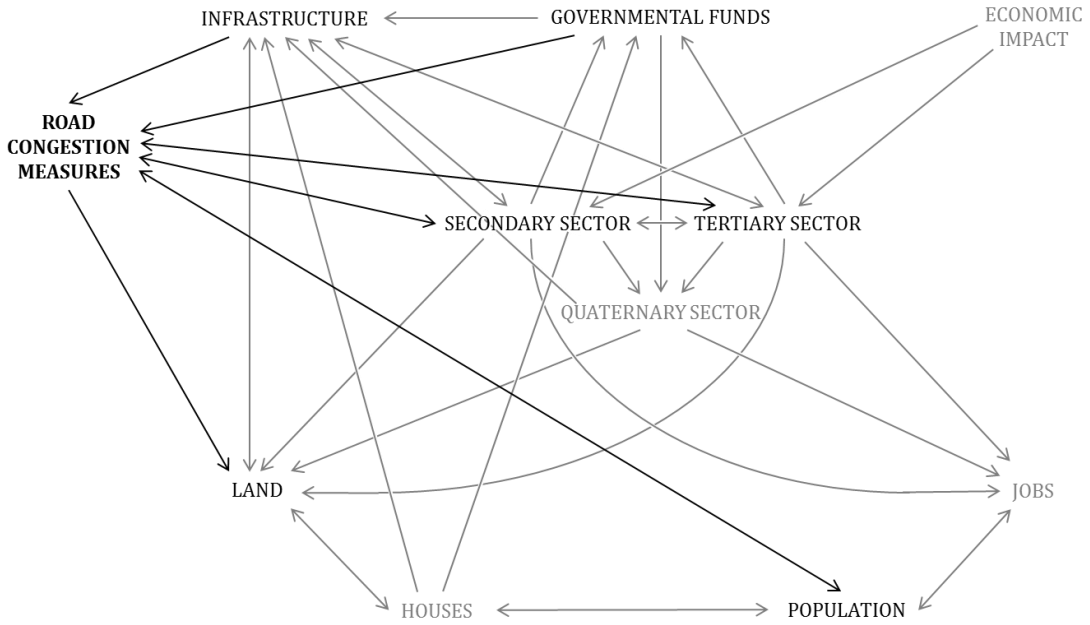


FIGURE 5.3-2: THE INFLUENCE OF CONGESTION MEASURES ON THE URBAN2013 MODEL.

5.3.3 COMPARISON OF THE CONGESTION SCENARIOS MODEL RUNS

The graphs in this section indicate the development of the area (with the occurrence of *congestion* and *congestion measures*) with colored lines. The development without congestion or congestion measures (the so-called *no event* situation) is indicated by a grey line. The differences between these lines indicate the influence of the scenarios on the development of the city. Note that for the following graphs close ups are used to indicate the differences in development for the scenarios and the general model. This means that the y-axis does not start at 0.

POPULATION

Figure 5.3-2 shows the development of the population over time. The differences between both congestion scenarios and the general development of the URBAN2013 model are limited.

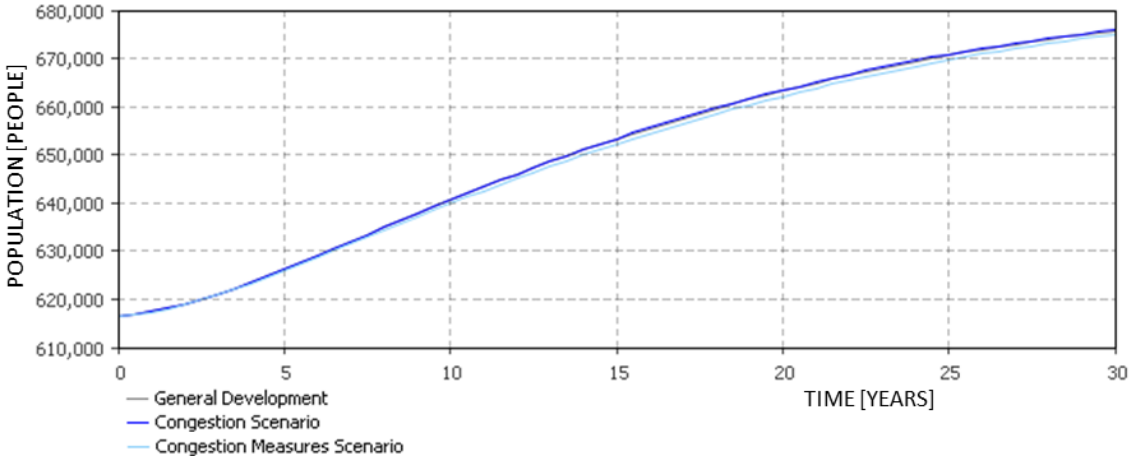


FIGURE 5.3-3: THE DEVELOPMENT OF THE POPULATION.

HOUSES

The development of the number of housing units is shown in Figure 5.3-4. In both the congestion and congestion measures scenario, the growth of the number of housing units increases over time compared to the general development. For the congestion scenario, this is due to the lower attractiveness of the secondary and tertiary sector business structures and the subsequent more available land area for housing construction.

For the congestion measures scenario, the difference can be explained by the lower governmental funds (due to the costs of the congestion measures) and the subsequent lower development of the quaternary sector and the infrastructure. This lack in development supplies the other sectors (including housing) with more available land for the construction of new structures.

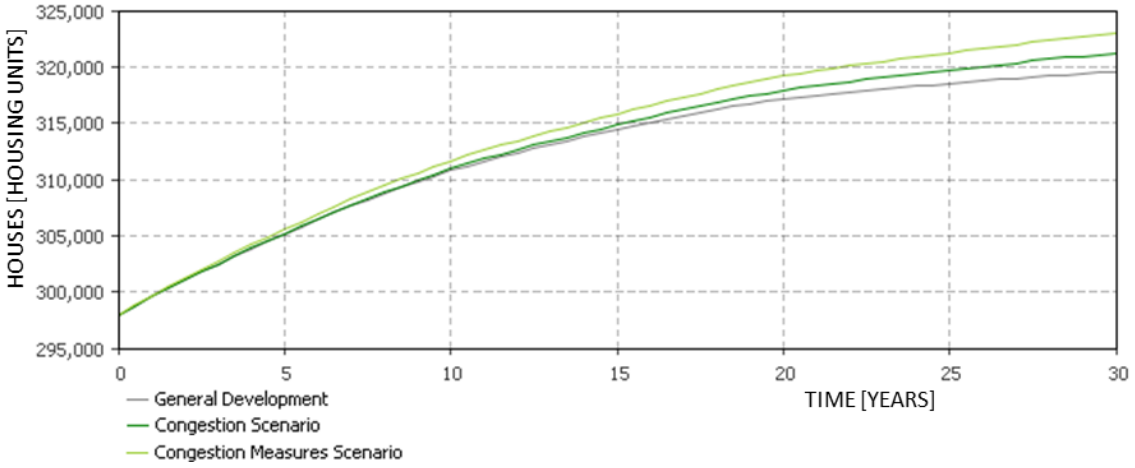


FIGURE 5.3-4: THE DEVELOPMENT OF THE NUMBER OF HOUSING UNITS.

EMPLOYMENT AND BUSINESS STRUCTURES

Figure 5.3-5 shows the development of the employment in both scenarios. For the congestion scenario, a limited decrease in growth occurs over time. This decrease is due to the lower growth of the secondary and tertiary sector business structures, due to the lower attractiveness caused by the congestion.

The congestion measures scenario shows a decline in employment. This decline is caused by the lower land area availability (due to the land needed for congestion measures) and the lower growth of the quaternary sector (due to the lower governmental funds). The employment in the congestion measures scenario is lower than in the congestion scenario.

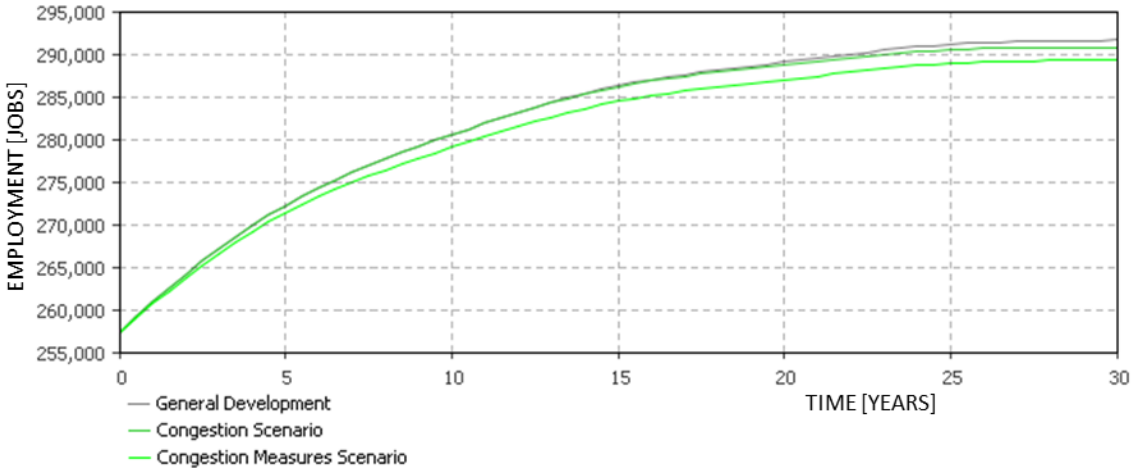


FIGURE 5.3-5: THE DEVELOPMENT OF THE EMPLOYMENT.

The development of the secondary sector business structures over time is shown in Figure 5.3-6. In the congestion scenario, the development of the secondary sector business structures grows at a lower rate than the general development. This is due to the negative impact of congestion on the attractiveness of the secondary sector.

The secondary sector increase in the congestion measures scenario is more than the general development. This increase is caused by the lower land usage by the quaternary sector and the infrastructure. This lower land usage is caused by the lower available governmental funds and thereby the lower increase of these sectors and the subsequent higher land availability for the other sectors.

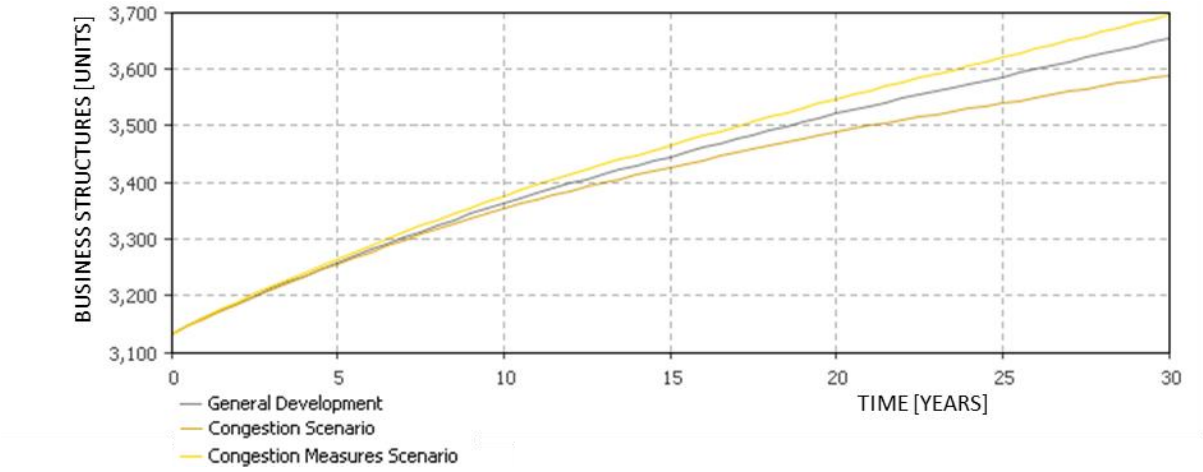


FIGURE 5.3-6: THE DEVELOPMENT OF THE NUMBER OF SECONDARY SECTOR BUSINESS STRUCTURES.

Figure 5.3-7 shows the development of the tertiary sector business structures over time. In the congestion scenario the development of the sector grows less fast. This is due to the negative impact of congestion on the attractiveness of this sector.

The number of tertiary sector business structures in the congestion measures scenario increases steeper than in the general development. This increase is caused by the lower land usage by the quaternary sector and the infrastructure. This lower land usage is caused by the lower available governmental funds and thereby the lower increase of these sectors and the subsequent higher land availability for the other sectors. Therefore the tertiary sector in the congestion measures scenario increases at a higher rate than the general development and the congestion scenario.

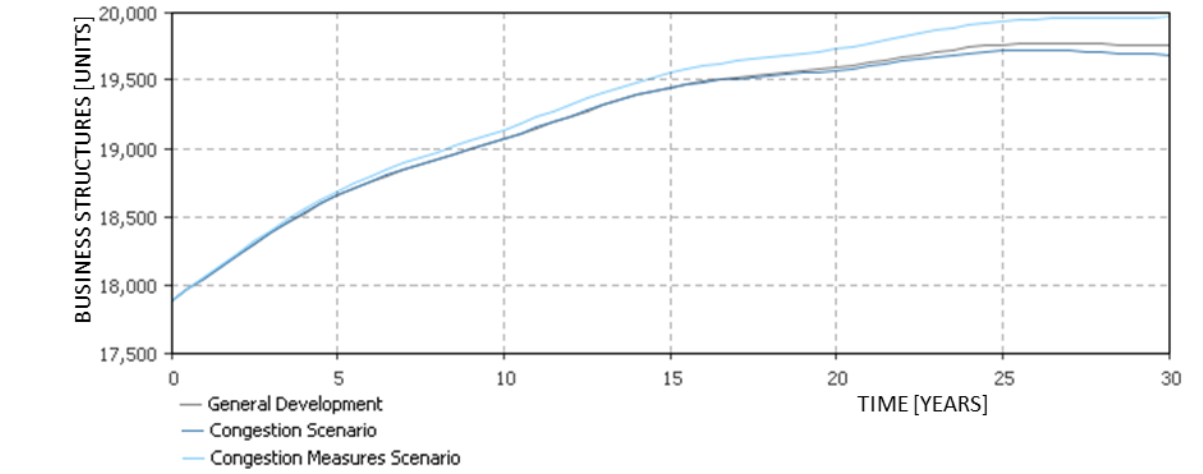


FIGURE 5.3-7: THE DEVELOPMENT OF THE NUMBER OF TERTIARY SECTOR BUSINESS STRUCTURES.

Figure 5.3-8 shows the development of the quaternary sector business structures. For the congestion scenario the sector increases slightly. This is due to the higher land availability for the quaternary sector, since the growth of the secondary and tertiary sector business structures will be lower due to the negative impact congestion has on the attractiveness of these sectors.

The development of the quaternary sector in the congestion measures scenario is lower than the general development. This is due to the lower available governmental funds (caused by the congestion measures expenses). The congestion measures scenario therefore shows a lower increase than both the general development and the congestion scenario.

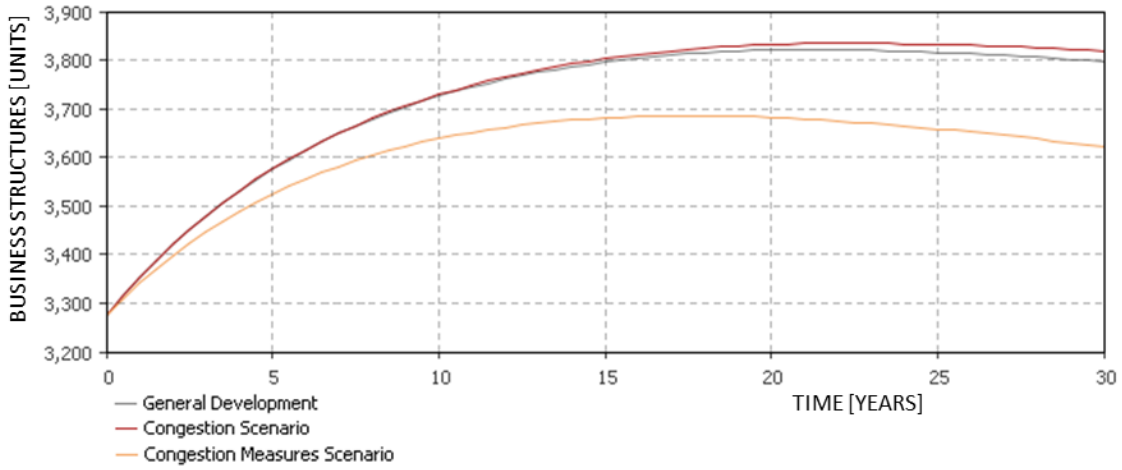


FIGURE 5.3-8: THE DEVELOPMENT OF THE NUMBER OF QUATERNARY SECTOR BUSINESS STRUCTURES.

INFRASTRUCTURE

The development of the infrastructure is shown in Figure 5.3-9. The differences between the general development and the congestion scenario are limited.

The infrastructure development in the congestion measures scenario shows a lower increase than the general development and the congestion scenario. This is due to the lower available governmental funds (due to the yearly expenses for the congestion measures). Note that the congestion measures are not taken into account in this line. By combining these measures the total land area used for infrastructure becomes higher than it is in the general development.

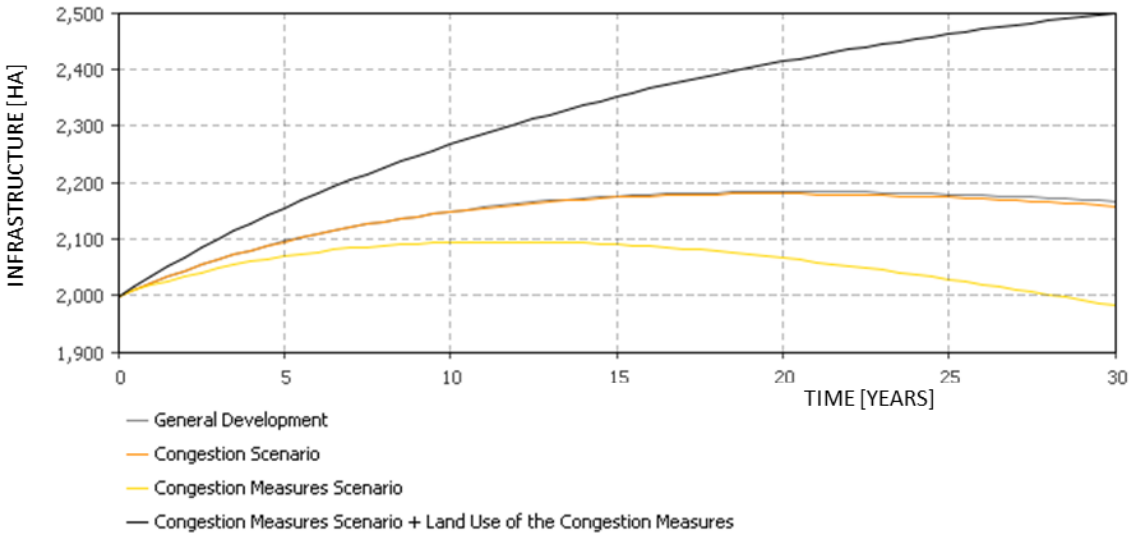


FIGURE 5.3-9: THE DEVELOPMENT OF THE INFRASTRUCTURE.

LAND FRACTION OCCUPIED BY URBAN AREA

Figure 5.3-10 shows the influence of both scenarios on the land fraction occupied. As can be seen in the figure, differences between these scenarios and the general development are limited. For a more extended explanation of the land usage of the scenarios, see *Appendix E2 - Analysis Congestion Scenarios*.

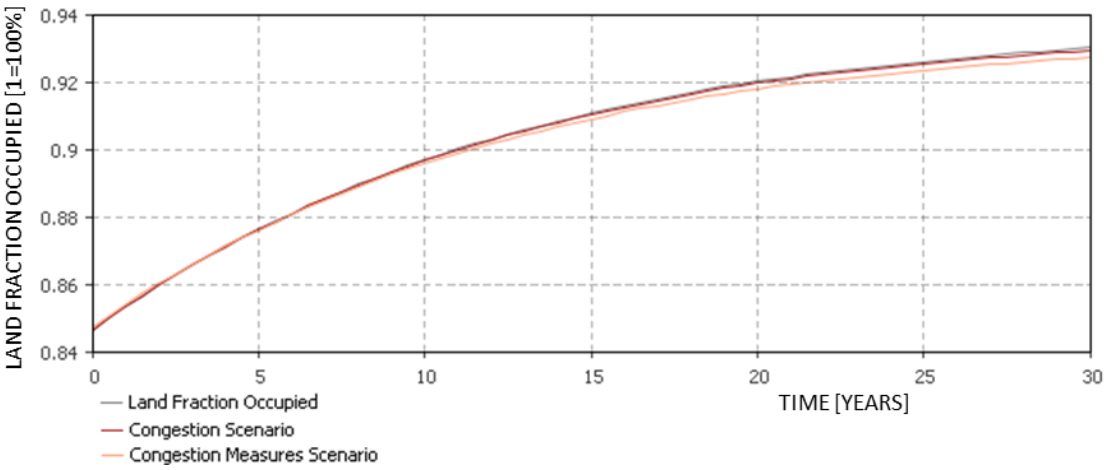


FIGURE 5.3-10: THE DEVELOPMENT OF THE LAND FRACTION OCCUPIED.

GOVERNMENTAL FUNDS

The development of the governmental funds in is shown in Figure 5.3-11. For the congestion scenario, it can be seen that the development of the governmental funds multiplier is approximately equal to the general development.

The congestion measures scenario shows a lower governmental funds multiplier. This is due to the construction and operation and maintenance costs for the congestion measures. Due to the continuous construction and growth of congestion measures to cope with the increasing congestion, the impact of these measures on the governmental funds keeps getting bigger. This leads to a decreasing governmental funds multiplier over time. In total, the governmental funds multiplier for the congestion measures scenario is significantly lower than the general development and the congestion scenario.

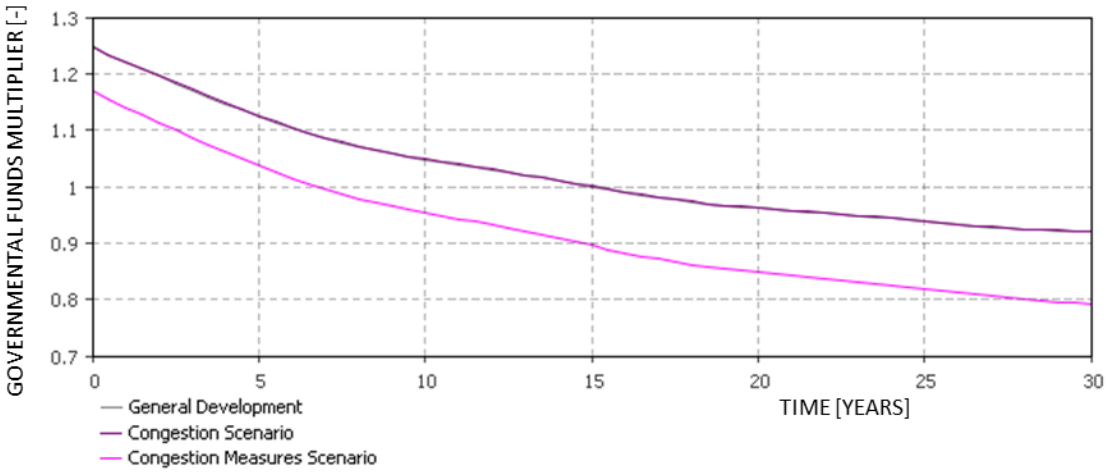


FIGURE 5.3-11: THE DEVELOPMENT OF THE GOVERNMENTAL FUNDS MULTIPLIER.

THE RESULTS OF THE CONGESTION SCENARIOS

The results of the congestion scenarios are given in Table 11. The results are the summation of each output over a period of 30 years. Therefore each value describes the presence of population/employment/structures in years (e.g. the value for the secondary sector business

structures describes the total number of businesses years present). The total time loss in the congestion scenario over the 30-year period is 375 million hours.

TABLE 11: THE CONGESTION SCENARIOS COMPARED TO THE GENERAL DEVELOPMENT RESULTS.

	Absolute			**Percentage**	
	General Model (total)	**Congestion** (difference with general model)	**Congestion Measures** (difference with general model)	**Congestion** (difference with general model)	**Congestion Measures** (difference with general model)
Population [persons]	19.822.873	2.761	-23.335	0,01%	-0,12%
Houses [housing units]	9.531.031	16.877	46.360	0,18%	0,49%
Employment [jobs]	8.612.216	-7.854	-49.173	-0,09%	-0,57%
Secondary sector BS [businesses]	104.546	-716	608	-0,69%	0,58%
Tertiary sector BS [businesses]	586.414	-465	3.176	-0,08%	0,54%
Quaternary sector BS [businesses]	113.292	247	-3.244	0,22%	-2,86%

5.4 COMPARISON OF THE IMPACTS OF FLOODING AND CONGESTION ON ROTTERDAM

The output of all scenarios is compared to the general development. This gives the opportunity to compare each scenario to one basic scenario, thereby comparing the scenarios on the same basis. The output of the models over the 30-year period is incorporated as the total sum of each unit.

Population, Housing and Employment

The changes in population, housing and employment for the four scenarios compared to the general development are given in Table 12.

TABLE 12: THE DIFFERENCES BETWEEN THE GENERAL DEVELOPMENT AND THE FOUR SCENARIOS.

Scenarios	***Flood Event***	***Flood Adaptation***	***Congestion***	***Congestion Measures***
Population [inhabitant years]	**-50.526** (-0,25%)	**-50.811** (-0,26%)	**2.761** (0,01%)	**-23.335** (-0,12%)
Houses [housing units years]	**-5.367** (-0,06%)	**6.784** (0,07%)	**16.877** (0,18%)	**46.360** (0,49%)
Employment [job years]	**-43.093** (-0,50%)	**-52.865** (-0,61%)	**-7.854** (-0,09%)	**-49.173** (-0,57%)

Based on these outcomes, it can be seen that in the scenarios flood event and flood adaptation population declines for both scenarios at a similar rate compared to the general development. The number of houses decreases in the flood event and increases in the flood adaptation scenario. This difference is a consequence of the different land demand in both scenarios. The employment decreases in both scenarios due to a lower average employment density of businesses (flood event scenario) and lower land availability (flood adaptation scenario).

The development of the population for the congestion scenario is similar to the general development. The congestion measures scenario shows a decline, due to lower employment. For both scenarios the number of houses increases compared to the general development. This increase is caused by the lower attractiveness for the construction of (sector specific) business structures and the subsequent higher land availability. The decrease in employment for both scenarios is also caused by the lower attractiveness of one or more of the business sectors.

Business Sectors

The calculation for the comparison is based on the added value to the economy of each business sector. This added value differs per business sector structure and is given in Table 13. The added value per business sector and the total of added value for the scenarios are given in Table 14.

TABLE 13: THE ADDDED VALUE PER ECONOMIC SECTOR BUSINESS PER YEAR (CBS, 2011).

Economic Sector	**Added Value** [million €/year]
Secondary Sector Business Structure	3,0
Tertiary Sector Business Structure	1,2
Quaternary Sector Business Structure	2,7

TABLE 14: THE DIFFERENCES IN THE ADDED VALUE PER SCENARIO PER SECTOR COMPARED TO THE GENERAL DEVELOPMENT.

Scenarios	***Flood Event***	***Flood Adaptation[17]***	***Congestion***	***Congestion Measures[18]***
Secondary Sector BS [million €]	1.045	527	- 2.127	1.805
Tertiary Sector BS [million €]	- 7.372	1.329	- 564	3.856
Quaternary Sector BS [million €]	- 506	- 6.971	678	- 8.918
Total Added Value [million €]	**- 6.833**	**- 5.114**	**- 2.013**	**- 3.257**

For the congestion scenario the time loss costs are combined with the added value losses. The total time loss costs over the 30-year period are 3.606 million euro (VTPI, 2013). The total economic losses are given in Table 15.

TABLE 15: THE TOTAL ECONOMIC LOSSES PER SCENARIO COMPARED TO THE GENERAL DEVELOPMENT.

Scenarios	***Flood Event***	***Flood Adaptation***	***Congestion***	***Congestion Measures***
Total [million €]	**- 6.833**	**- 5.114**	**- 5.619**	**- 3.257**

Scenario Comparison Results

The scenario outputs (population, houses, employment and business structures) cannot be expressed in one distinctive unit (such as a financial unit). Therefore a direct comparison is not possible. The comparison of the results of the scenarios focusses on the economic vitality of cities and therefore based on the added value to the economy. This means that solely the development of the business sectors is used for this comparison.

Based on the total of added value per scenario the ratio between the deviation from the general development and the scenarios is taken. For the flooding scenarios the comparison shows that the *flood adaptation scenario* is the preferable scenario, given the **1 : 1,34** ratio for the flood adaptation scenario versus the flood event scenario. This ratio indicates that implementing flood adaptation measures is more beneficial than a situation of not implementing these measures.

The comparison of the congestion scenarios leads to a ratio of **1 : 1,73** for the congestion measures versus the congestion scenario. This means that the *congestion measures scenario* is the preferable scenario. This result shows that the costs of the implementation of congestion measures is lower than the return it gives via the better accessibility of the city.

A direct comparison between the flooding and congestion scenarios can also be made, but this comparison is based on two independent scenarios and therefore its value is subject to the assumption that the likeliness of both scenarios is equal. For both do-nothing scenarios

[17] The total construction costs of the flood adaptation measures are € 526 million and the operation and maintenance costs of € 974 million over a period of 30 years. These costs are already incorporated in the model via the governmental funds multiplier. In total these construction and O&M costs lead to a saving of € 1.719 million.

[18] The costs of the congestion measures are yearly approximately € 52,2 million for the construction and € 70,0 million for the land use in the urban area. For the 30-year period this leads to a total of € 3.667 million and combined with the total operation and maintenance costs the total costs are € 8.473 million.

(congestion and flood event) the ratio is **1 : 1,22**. This means that the impact of the flood event is 1,22 times higher than the impact of congestion on the economic vitality of a city.

Net Present Value

The output of the added values is not given in the net present value. Implementation of the net present value does not lead to changes in the preferable scenarios, but it does change the extent of the loss in added value per scenario and it influences the ratios between the scenarios. The full outputs in net present value can be found in *Appendix F – Net Present Value.*

Scenario Combination Comparison

Given the impact of each scenario, a combination of the different scenarios is made. Table 16 indicates the changes in population, houses, employment and the losses in added value per scenario combination over the 30-year period. It shows that for the changes in added value the combination of the flood adaptation and the congestion measures is the most beneficial one.

TABLE 16: THE DECLINE IN ADDED VALUE COMPARED TO THE GENERAL DEVELOPMENT GIVEN COMBINATIONS OF FLOODING AND CONGESTION SCENARIOS.

	Flood Event & Congestion	Flood Event & Congestion Measures	Flood Adaptation & Congestion	Flood Adaptation & Congestion Measures
Population [inhabitant years]	-48.443 (-0,24%)	-75.855 (-0,38%)	-49.000 (-0,24%)	-74.649 (-0,37%)
Houses [housing units years]	12.748 (0,13%)	41.818 (0,43%)	23.738 (0,25%)	52.015 (0,54%)
Employment [job years]	-52.152 (-0,60%)	-93.933 (-1,07%)	-61.407 (-0,70%)	-101.162 (-1,16%)
Added Value [million €]	**-12.670**	**-10.285**	**-10.817**	**-8.100**

RANGE OF THE ECONOMIC IMPACT PER SCENARIO

The impact of the global economic development on the four scenarios is checked by implementing three economic scenarios (positive, neutral and negative economic development). This check is done to obtain the sensitivity of each scenario to the economic development. This gives an insight on the economic impact on the different scenarios. Note that these ranges do not represent the full range of the economic impact.

For the *flooding scenarios* the different economic scenarios cause changes in the outputs. These changes are not sufficient to influence the most beneficial flood scenario. The range of the ratio between the flood adaptation and the flood event scenario varies between **1 : 1,26** up to **1 : 1,40** for the economic scenarios.

The impact of the economic scenarios on the congestion scenarios causes the ratio between congestion measures and congestion to vary between **1 : 1,40** up to **1 : 2,17**. The impact of the different economic scenarios therefore does not influence the most preferable congestion strategy, which is the congestion measures scenario. It does underline the fact that countermeasures are beneficial for the economic development of the city.

For a more extended explanation of the economic impacts, see *Appendix C - Economic Impact*.

CONCLUSIONS

CHAPTER 6

The objective of this MSc thesis is to analyse city developments and to quantify the impact of a flood event, flood adaptation, congestion and congestion measures with the help of a quantitative model. The main research question of this thesis is: *What are the impacts of flooding, congestion and adaptation measures on the economic vitality of cities?*

In this research the URBAN2013 model is developed as the quantitative model to analyse city developments. It is used to quantify and analyse the impacts of the flooding and congestion scenarios.

Flood Event and Flood Adaptation

A *flood event* is a one-time event. The consequences of a flood event for a city are the destruction of houses, business structures and infrastructure, deaths, injured and emigration of population, economic losses and a decline in attractiveness of the city. For the pluvial flood scenario implemented for the city of Rotterdam, these consequences lead to a loss in the added value of the business sector of 6.833 million euro over a 30 year period compared to a regular development without flooding. Besides, it leads to a lower population and less employment in the city of Rotterdam.

Flood adaptation measures provide water storage possibilities and thereby lower or even prevent the impact of the flood event. Flood adaptation measures require land area and governmental funding for the construction, operation and maintenance. For the scenario for the city of Rotterdam the implementation of flood adaptation measures leads to a loss in added value of 5.114 million euro compared to a regular development without flooding and flood adaptation measures. It also contributes to a lower population and less employment over the 30 year period because land area is used for adaptation measures instead of for housing and businesses.

A comparison of the flood event and flood adaptation scenarios shows that the flood adaptation scenario has the least negative effect on the added value. The ratio between both scenarios is 1,34 : 1. This leads to the recommendation that (if flooding occurs) flood adaptation measures are the preferable strategy for pluvial flooding in Rotterdam.

Congestion and Congestion Measures

Congestion is a recurrent structural problem. The impact of congestion on cities causes time losses and leads to a decline in attractiveness of the different business sectors. For the scenario as used in this research the consequences of congestion lead to a decline in added value and time loss over a 30 year period of 5.619 million euro. Overall, the effects on population and employment are limited.

The congestion measures scenario provides sufficient transport capacity to limit the impact of congestion. These measures require land area and governmental funding for both a continuous extension and operation and maintenance. The total decline in added value over the 30 year period is 3.257 million euros compared to a regular development without congestion and

congestion measures. It leads to a decrease in employment and an increase in houses, due to decrease in investments which attribute to the attractiveness of the area for businesses (e.g. infrastructure). Due to this lower attractiveness more land area is available for housing.

By comparing the congestion and congestion measures scenarios it follows that the latter has the least negative effect on the added value. The ratio between the scenarios is 1,73 : 1. This indicates that implementing congestion measures is the preferable solution for the city of Rotterdam.

Comparison of the Impacts of a Flood Event and Congestion

Given both the flood event scenario and the congestion scenario, a comparison of the impacts of both scenarios is made. This comparison is subject to the likeliness of occurring of the different scenarios, but it does provide an image of the extent of the impacts of each scenario on Rotterdam. Note that the flooding is a one-time event and the congestion is a recurrent structural problem. The ratio of the impacts between the flood event and the congestion scenario is 1,22 : 1. This means that (given the assumptions made) the consequences of a flood event are bigger than the consequences of congestion in Rotterdam.

A comparison of the combination of the flooding and congestion scenarios shows that the loss in added value is the lowest for the combination of flood adaptation and congestion measures. Therefore this combination of scenarios is the most preferable. This indicates that the influence of a combination of scenarios on the city also leads to the same conclusion as made for the flooding and congestion strategies separately.

Model

The modelling is done using system dynamics. This modelling approach regards the most important interacting aspects of a city and it takes higher order effects into account. Therefore the model can give a complete picture of the direct and indirect effects of different scenarios on the development of the city.

In general, system dynamics has a damping effect on the impact of the scenarios due to the feedbacks in the system. This internal correction is caused by the model structure and its multipliers. In total, it leads to a lower measurable impact of each scenario than it would be with a model approach focused on the direct impacts of a scenario.

The model simulates the main long-term developments of the city, but it is not focused on anticipating policy measures which are aimed at specific variables. The damping effect of the model indicates a self-regulating system in the city. This self-regulating system adapts to off balance situations and thereby adjusts the development. Behaviour towards the original development is in accordance to the real situation. It indicates the adaptive capacity in the city. Given the scenarios for Rotterdam, the adaptive capacity of this city limits the off balance development and thereby it seems to be sufficient to cope with the flood and congestion scenarios.

Recommendations

This research has developed the URBAN2013 model for the quantitative analysis of city development. Based on this research several recommendations can be done to improve this model. These model based recommendations are:

- Combine the city with surrounding municipalities, cities or regions. The URBAN2013 model is based on a stand-alone city. Networks of cities (e.g. the southern part of the Randstad (Zuidvleugel)) are not taken into account, while these combinations share housing and employment markets. These influence the development and the economy of the city.

- Introduce a variable density of land use into the land use. If land becomes scarce the possibility of a more efficient land usage exists (e.g. high-rise buildings). This higher density is subject to higher construction costs. For the model this will lead to a lower impact of the land constraint on the city development.

- Introduce gentrification in the model. The current model describes an average life time of a structure followed by demolition and newly available construction area. In European cities structures and neighbourhoods are also upgraded instead of demolished and rebuilt.

Recommendations for improvements of the research on the impacts of flood and congestion are:

- Perform case studies for different cities. The ratio given in the conclusion of this research solely concerns the city of Rotterdam. By obtaining these ratios for a number of cities a comparison can be made between cities and more general conclusions can be drawn on the ratio between the impact of flood events and congestion. Although a damping effect is present in the model method, it does provide an insight in the ratios of the scale of the threats for the different cities.

- For both flooding and congestion it is recommended to investigate intermediate scenarios, since the scenarios in this research represent two extremes and the most optimal solution can be located between these extremes.

- Extent the number of threats which are researched in the model. Currently one natural disaster (flooding) and one political-economic problem (congestion) are modelled. Further research on different natural disasters (e.g. earthquakes) and political-economic problems (e.g. shift in global economic centres) will give an insight on the impact of a broad variety of threats on the urban area. Other effects which could be researched are for instance the effects of human interventions in urban areas, such as terrorism.

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APPENDICES

Appendix A - Theoretical Model Development
Appendix B - Software Model Development
Appendix C - Economic Impact
Appendix D - Validation
Appendix E - Analysis of the Impacts of Flooding and Congestion
Appendix F - Net Present Value Comparison

THEORETICAL MODEL DEVELOPMENT

APPENDIX A

The theoretical model development is described in the following part. The model will form the basis of the system dynamics model. It shows the theoretical relations and connections between the different building blocks of a city. The model is based on the existing URBAN1 model.

The theoretical model description starts with the business structures and is stepwise expended. Each link is given a number as a reference for clarity.

1.1 BUSINESS SECTOR DEPENDENCIES

A distinction is made between the different business sectors as described in paragraph 3.4 of the main report. From the four economic sectors, the primary, secondary and tertiary sector are free-market sectors. The presence of business structures from these sectors depends on several factors, such as the presence of other free market business structures, the available land area and the available labour force. The primary sector is not incorporated into the model since it is located outside the city boundaries and therefore it is not part of the scope. A schematization for the secondary, tertiary and quaternary sectors is given in Figure 1.

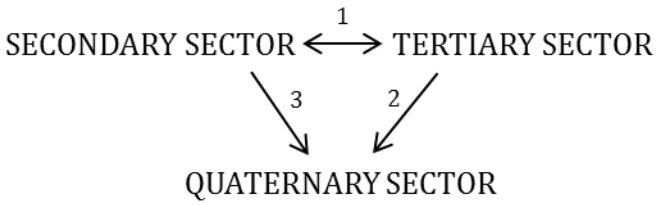


FIGURE 1: THE RELATIONS BETWEEN THE ECONOMIC SECTORS.

For business structures, the positive dependency on other present secondary and tertiary business structures is due to the advantages of scale economies, pecuniary agglomeration economies and technological agglomeration economies. These advantages hold for secondary sector to tertiary sector, tertiary sector to secondary sector and within each sector. This dependency is incorporated in the model by ***link 1***.

The influence of present secondary and tertiary sector structures on quaternary structures is due to the services provided by the quaternary sector. These services are provided for businesses and population[1]. Examples are education for (future) employees, utilities and emergency services. In the figure the relations are indicated by ***links 2 and 3***.

In the development of a city it is important to note that the demand for different business sectors can differ (e.g. the demand for tertiary sector businesses can be much higher than the demand for secondary sector businesses. These demands lead to a willingness to pay for higher land prices and thereby prioritize the sector in high demand.

[1] The relation of the quaternary sector with the population will be discussed further on in the research.

The demand for business structures is subject to inter alia available land, other businesses present, available labour force and global economic developments. The influence of the global economic development differs in impact per business sector. The tertiary sector has a higher dependency on economic developments than the other sectors.

1.1.1 THE RATIO OF ECONOMIC LAND USE BETWEEN ECONOMIC SECTORS

The differences of the economic sectors are of importance in regard to the tax income per area. To clarify the importance of the differences in sectors, the economic sectors in the Netherlands are examined. Table 1 shows the added value per economic sector and Table 2 shows the land usage per economic sector in the Dutch economy.

TABLE 1: THE ADDED VALUE PER ECONOMIC SECTOR IN THE DUTCH ECONOMY.

Economic Sector	**Production as percentage of the total national Added Value**[2]
Primary Sector	1,6%
Secondary Sector	23,8%
Tertiary Sector	49,8%
Quaternary Sector	24,8%

TABLE 2: LAND USAGE PER ECONOMIC SECTOR IN THE DUTCH ECONOMY.

Economic Sector	**Land usage per sector** [km^2][3]
Primary Sector	23.559
Secondary Sector	567
Tertiary Sector	83
Quaternary Sector	258

The land usage can be divided by the production percentage. This result shows the area needed per percentage of the production percentage. This can further on be expressed in a ratio indicating the differences in land usage versus the economic production. Table 3 shows these results. Note that the lower the ratio, the higher the efficiency of the land usage.

TABLE 3: THE LAND USAGE PER PERCENTAGE OF THE PRODUCTION PERCENTAGE AND THE RATIO BETWEEN THE ECONOMIC SECTORS.

Economic Sector	**Land usage per percentage Added Value** [km^2]	**Ratio**
Primary Sector	14724,4	8834,2
Secondary Sector	23,8	14,3
Tertiary Sector	1,7	1,0
Quaternary Sector	10,4	6,2

The outcome indicates the ratio between the output of the land usages. This in turn relates to the tax income per area. By assuming an equal tax rate for each sector, it shows that the tax income per land area is the highest for the tertiary sector, followed by the quaternary sector (at 1/6th) and the secondary sector (at 1/14th). Therefore it is important to divide the present businesses into economic sectors, since the tax income per business structure in comparison to the land usage differs substantially.

[2] Source: (CBS, 2011)
[3] Source: (CBS, 2005)

1.2 MODEL FOUNDATION

The foundation of the model is land, labour (jobs) and capital (governmental funds) as described in Chapter 3 of the main report. These three are direct and indirectly related. Figure 2 shows the three foundation pillars of the model (Land, Labour and Capital) combined with the business structures and the mutual relations.

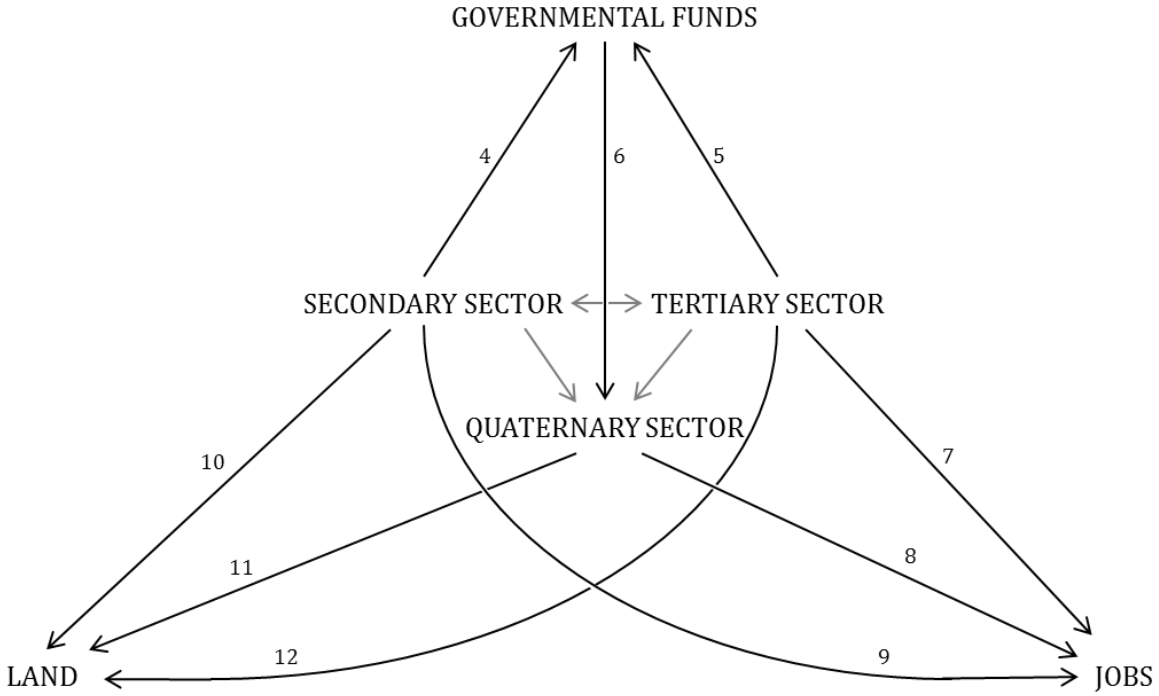


FIGURE 2: THE RELATIONS BETWEEN GOVERNMENTAL FUNDS, JOBS AND LAND WITH BUSINESS STRUCTURES.

1.2.1 GOVERNMENTAL FUNDS (CAPITAL)

Governmental funds describes the financial situation of the local municipality. The municipality has a number of sources for income (Ministerie Binnenlandse Zaken en Koninksrijksrelaties, 2013). These are:

- Payment from the central government (*Gemeentefonds*).
- Payments for specific goals (e.g. public transport or youth care).
- Land value tax (*Onroerendezaakbelasting*).
- Parking charges, tourism tax, dog tax and fees (e.g. building permits, marriages and waste disposal).

It is assumed for the model that the payments from the central government, the payments for specific goals, parking charges, tourism and dog tax and fees are stable and that therefore the only (direct) variable in the model is the land value tax.

The income and expenditure of the governmental funds are divided over different causes (differing in size and priority per municipality). It is assumed that the higher the governmental funds are per capita, the more beneficial this is for the population and business structures (due to more possible investments per capita). Therefore the attractiveness of the area is related to the availability of governmental funds. Obsolescence of infrastructure (and quaternary sector structures) will lead to higher demand for public funding and it will therefore negatively influence this process.

Governmental funds (*Capital*) has a direct input from taxes which result from commercial land value taxes (secondary sector (***link 4***) and tertiary sector (***link 5***)) and housing structures taxes[4].

The governmental funds are used for public goods. Public goods and services are non-excludable and non-rivalrous goods which are available for all individuals. The quaternary sector represents governmental services and is therefore introduced as public goods. The sector receives financial resources from the government and therefore does not contribute to the governmental funds in the form of taxes. The relation with the governmental funds is indicated by ***link 6***.

The responsibility for providing public goods and services depends on the range of the good/service. If it is available on local level, the responsibility in general lies at the local governmental tier (e.g. mass transit, city streets, sewage and emergency services). Public goods and services with a broader range than local urban areas are provided by higher governmental tiers (e.g. national defence, national parks and interstate highways).

The research focusses on urban areas. For the urban model, only part of the local tier public goods are of importance for the research. Therefore a distinction is made between the relevant segments and the general public goods and services (which will be placed in the model as the quaternary sector under business structures).

1.2.2 JOBS (LABOUR)

Jobs (*labour*) are present at business structures. Each business structure sector has a specified number of available jobs per structure. The relation between business structures and jobs are represented in the figure by ***links 7, 8 and 9***. Each link is the total number of jobs available at each business sector. Jobs provide families (households) with income. The size of the present labour force (the part of the population that is in the working age and is employed or seeking employment) depends on the composition of the population and therefore differs per city.

1.2.3 LAND USE (LAND)

Land is a limited resource in the model. Once land is occupied by a building, it cannot be used for any other purpose until it is demolished and the land area is cleared. Land can be used for several purposes, which are in the model business structures, housing and (transport) infrastructure[5]. Each business sector needs a specified land area per structure. The relations in the model are given by ***links 10, 11 and 12*** in the model.

[4] The relation of the governmental with housing units will be discussed further on in the research (see ***link 16***).
[5] Housing and transport infrastructure will be discussed further on in the research.

1.3 POPULATION AND HOUSING

Population represents all inhabitants of the city. Population has several basic needs, the presence and availability of these indicate the attractiveness of the area. The two main needs are housing and jobs. These relations are indicated by the ***links 13 and 14*** in Figure 3.

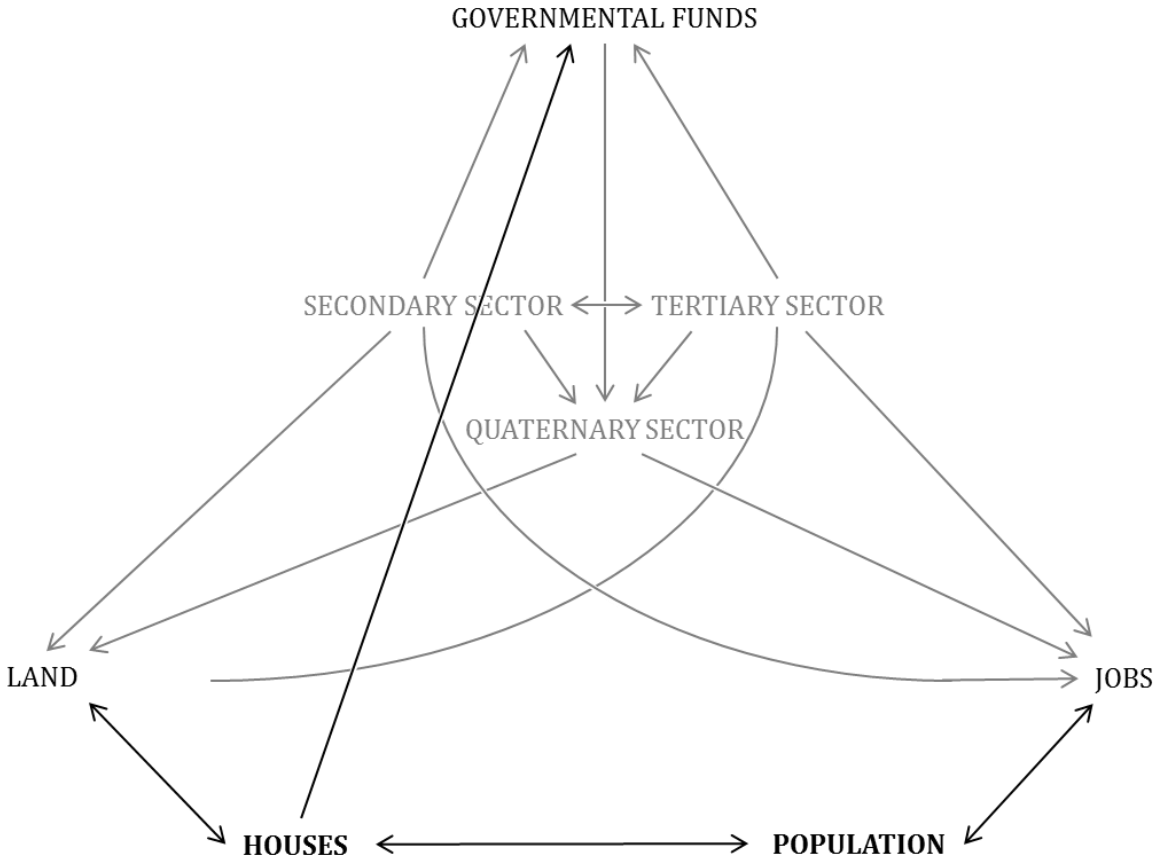


FIGURE 3: THE RELATIONS OF HOUSING AND POPULATION IN THE MODEL.

Link 13 indicates the mutual dependency of population and jobs. This is due to the fact that people need jobs for their livelihood and business structures need people to fulfil their jobs. A lack in jobs will negatively affect the attractiveness of the urban area for immigration and a lack in labour force (people) will negatively affect the attractiveness of the area for businesses. Vice versa holds for both.

The relation between housing and population as indicated by ***link 14*** holds both ways. Housing is a basic need for people and therefore a lack in housing negatively affects the attractiveness of the urban area for people. A lack in population in regard to present houses negatively affects the construction of new housing[6]. Vice versa holds for both.

Each housing unit takes up land area and thereby influences the availability of land. This is indicated by ***link 15***. The land fraction occupied influences housing construction due to the influence this has on land prices. In general, the lower the land availability, the higher the land price will be. The higher this land price will be, the more negatively this will impact the attractiveness for the construction of new housing units. Each housing unit contributes to the governmental funds through the land value tax as described in 1.2.1. This is indicated by ***link 16***.

[6] The relative construction; a positive value for construction minus demolition of houses.

1.4 INFRASTRUCTURE

Infrastructure concerns all present types of infrastructure in the city. Examples are transport infrastructure for people and goods, the electricity network and the sewage system. The presence of well-maintained and sufficient available infrastructure is attractive for the settlement of businesses and people.

In the model, it is assumed that the area used for the basic infrastructure has a multiple usage and that this multiple usage is in combination with transport infrastructure (e.g. a sewage pipe under a road or elevated electricity networks under pavement). The higher the ratio of availability of infrastructure[7], the better the accessibility of the area will be due to the presence of more transport infrastructure per business or housing unit (and thereby a higher capacity). This in turn is positive for the attractiveness of the area for industry and commercial services. Figure 4 shows a schematized representation of infrastructure in the model.

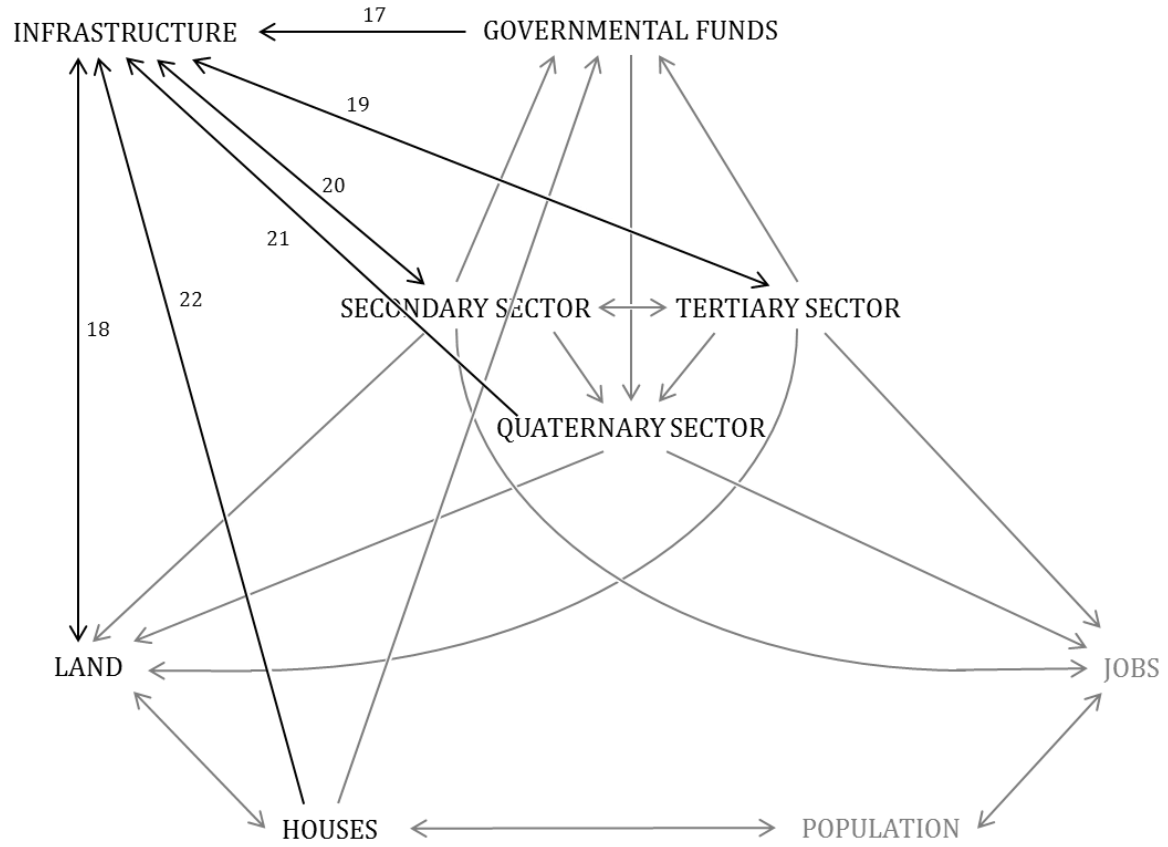


FIGURE 4: THE RELATIONS OF TRANSPORT INFRASTRUCTURE IN THE MODEL.

Infrastructure is a public good. ***Link 17*** indicates the dependency of the infrastructure on funding from the governmental funds. The higher this funding, the more there will be invested in infrastructure and the more beneficial this will be for the attractiveness of the area.

Link 18 indicates the relation between infrastructure and land. Infrastructure takes up land area in the form of transport infrastructure (e.g. roads and railways). A limited percentage of infrastructure is needed per structure (e.g. each business needs to be serviced by a stretch of road, electricity and sewage). Therefore a dependency exists between a minimum necessary infrastructure land area per business and housing structure.

[7] Assuming properly used, maintained and operated infrastructure.

Transport infrastructure has a positive effect on accessibility, which is beneficial for secondary and tertiary business sectors. This is due to economies of scale in transport of resources and goods (which lead to lower costs) and better accessibility of retail for costumers. These influences are indicated by ***links 19 and 20***. The necessary transport infrastructure per business structure or housing unit is indicated by ***links 19, 20, 21 and 22.***

1.5 GLOBAL ECONOMIC IMPACT

Developments in the (global) economy can have an impact on urban areas. This depends on the total exposure of local businesses to the (global) economy, the present sectors and the consequences per sector. This can be the consequence of crises, redistribution of wealth or an effect of globalisation. Figure 5 indicates the influences of external economic developments on the model.

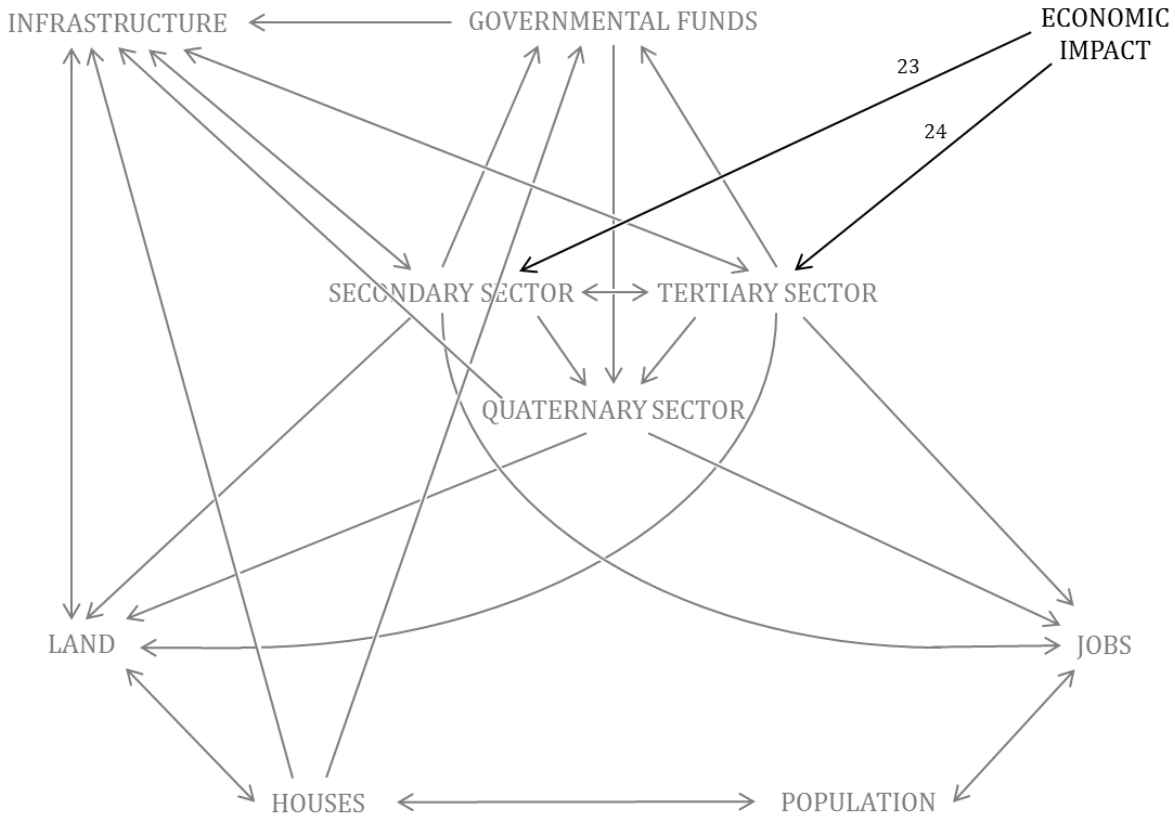


FIGURE 5: THE DIRECT RELATION OF ECONOMIC DEVELOPMENTS.

The impact of economic developments is primarily focused on commercial activities. This is due to the fact these activities are (heavily) reliant on demand and supply. The scale of this reliance depends on the type of business[8] present. ***Links 23 and 24*** indicate this direct relationship[9].

The first tier indirect effect of economic development (positive or negative) reaches all three foundation blocks of the model. This indicates the dependency of the urban area on the (global) economy.

[8] E.g. an international car manufacturer is more sensitive for economic crises than the local bakery.
[9] It is assumed that the impact of the local urban economy on the world economy is of such limited scale that it can be neglected in the model.

1.6 GENERAL CITY MODEL

The foundation of the model; *Land*, *Labour* (jobs) and *Capital* (governmental funds), combined with business, housing, population, infrastructure and the external economic development lead to the model as shown in Figure 6.

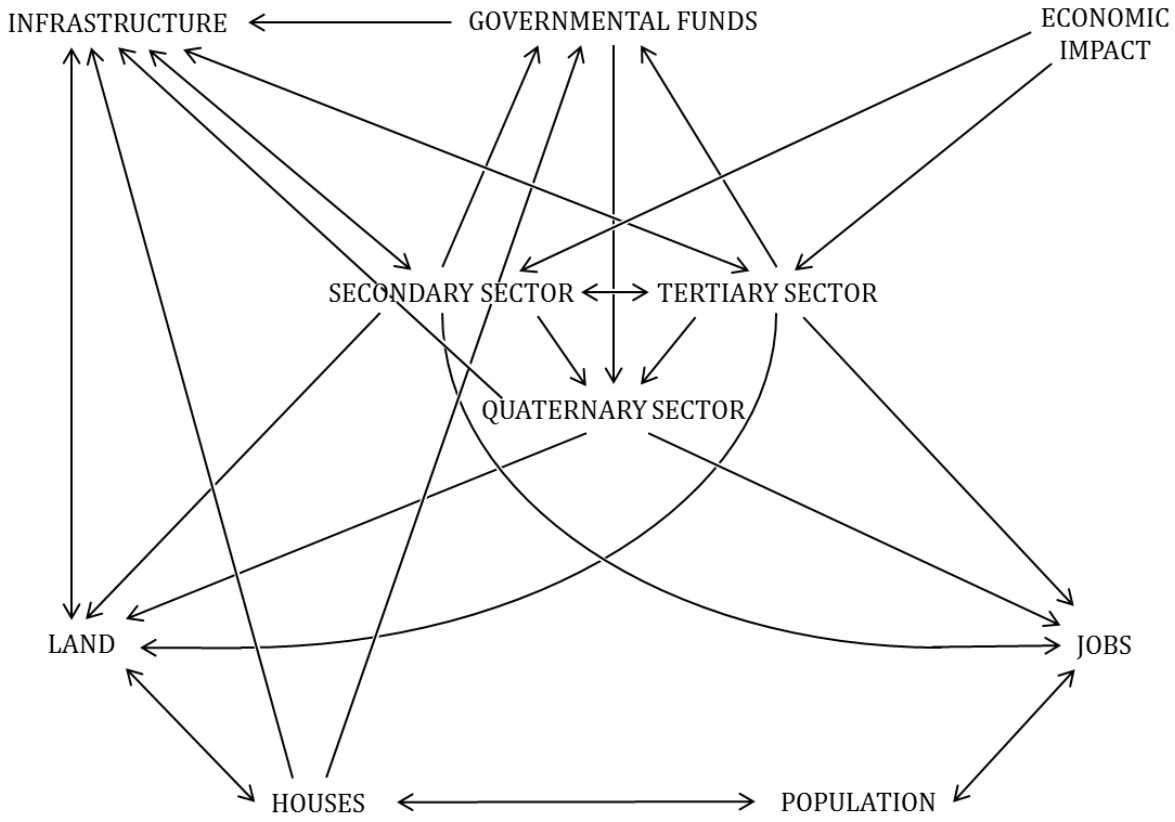


FIGURE 6: THE GENERAL MODEL FOR THE URBAN AREA.

The goal of the general model is to represent the development of an urban area (city) over time. The general model is used as the basic situation. By extending the model with specified segments (flood event, adaptation towards flooding, congestion and adaptation towards congestion) the influences of these events can be observed and quantified. The expenditure for adaptation measures is assumed as an extra investments via the governmental funds.

1.7 FLOODING

The general city model is extended with the influence of a flood event and adaptation towards a flood event.

1.7.1 FLOOD EVENT

The impact of a flood event on an urban area is direct in the form of deaths and damaged structures, infrastructure, goods and . Indirect effects are inter alia emigration, a downturn in the local economy and a decline in faith in local safety. The impact of a flood event is visualised in Figure 7.

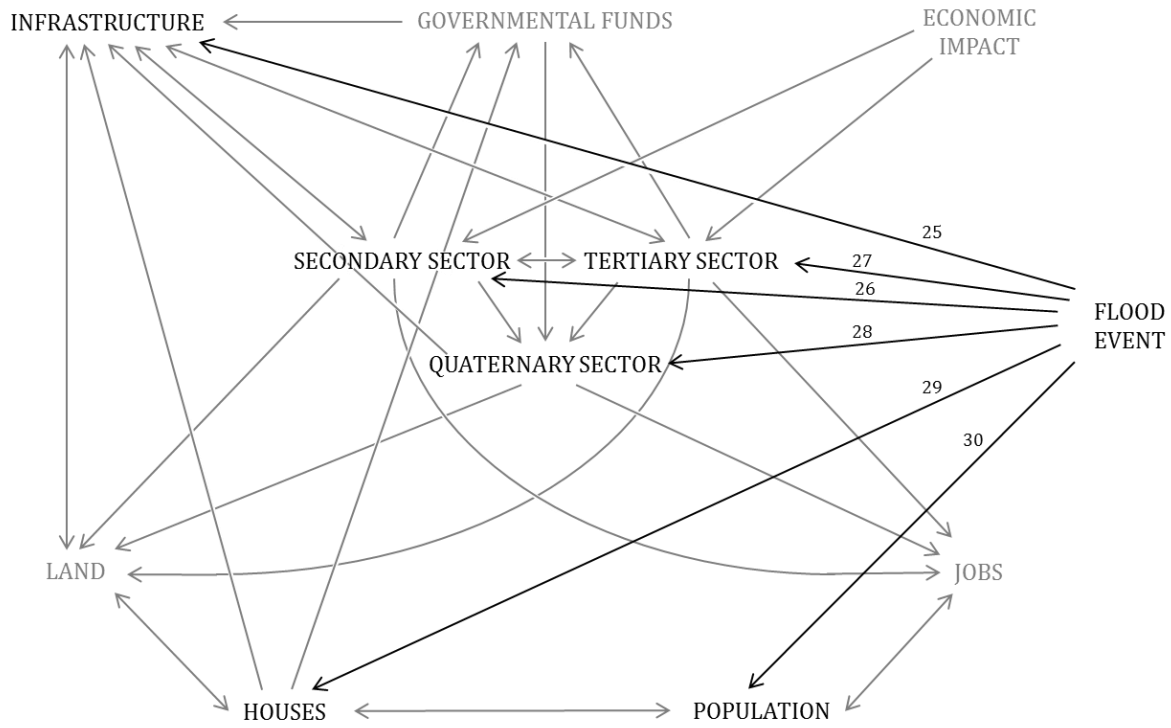


FIGURE 7: THE INFLUENCE OF A FLOOD EVENT ON THE GENERAL MODEL.

Link 25 indicates the damage of a flood event on infrastructure. Examples of damage to infrastructure are washed away roads and water damage to the electricity network. ***Link 26, 27 and 28*** indicate the impact on the secondary, tertiary and quaternary sector. This damage is in the form of damaged or destroyed structures, equipment and stock. ***Link 29*** indicates the damage to housing units in the form of damaged or destroyed structures and contents.

Link 30 indicates the impact of a flood event on the population. This impact can be fatalities, injuries and also a decline in the attractiveness of the area due to a lack in safety from flooding.

Another consequence of a flood event is the necessary relief efforts. These efforts (e.g. evacuation, temporary shelter and basics such as food and water) are costly and therefore will influence governmental funds.

1.7.2 FLOOD PROTECTION

Adaptation towards flooding will help decrease (or even reduce to zero) the consequences of a flood event. The influence of flood protection on the general model is given in Figure 8.

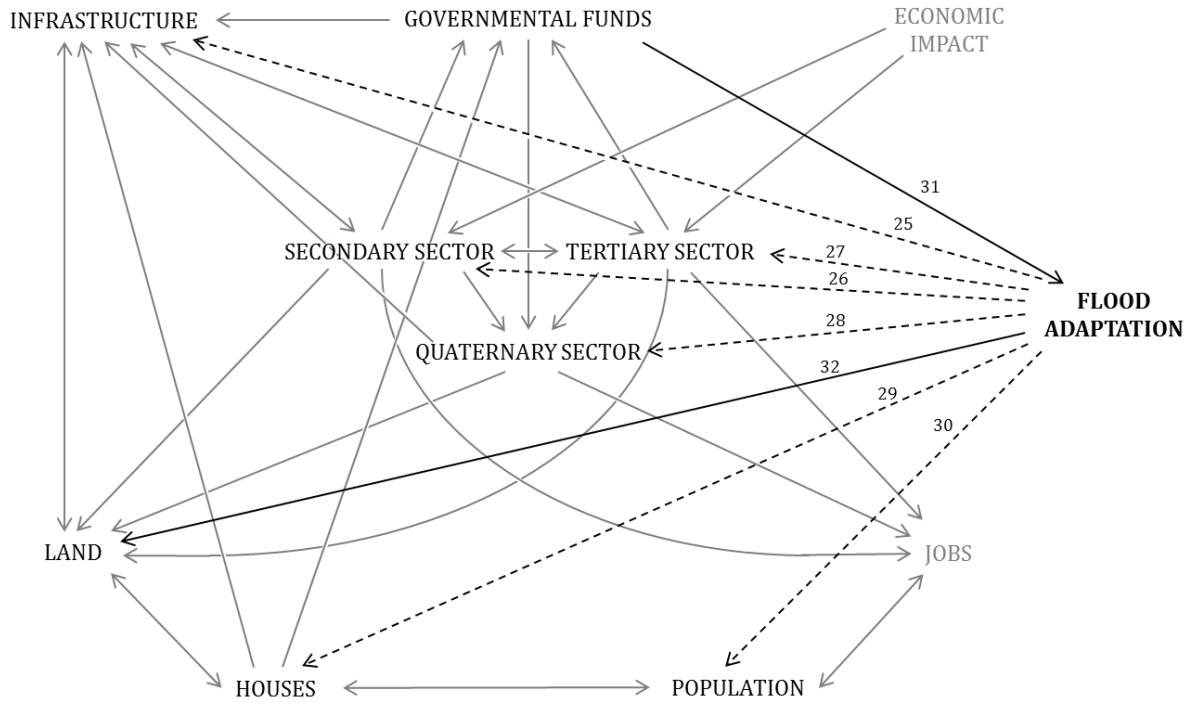


FIGURE 8: THE INFLUENCE OF FLOOD PROTECTION ON THE GENERAL MODEL.

In the case of flood risk reduction, ***link 25 to 30*** indicate the damage to the infrastructure, structures and the impact on the population (as explained in 1.7.1). The relief efforts are also present in the case of a reduction of impact.

If adaptation measures completely reduce the consequences of a flood, ***link 25 to 30*** are not of any influence in regard to damage and deaths or injuries. However, it can (positively) influence the feeling of safety within the population.

Adaptation measures are financed via governmental funds, which is indicated by ***link 31***. The adaptation measures also use land area, which is indicated by ***link 32***.

1.8 ROAD CONGESTION

The general city model is extended with the influence of road congestion and adaptation towards road congestion.

1.8.1 ROAD CONGESTION

The influence of road congestion on the general model can be seen in Figure 9. Road congestion influences the accessibility of the urban area and thereby the attractiveness of the area.

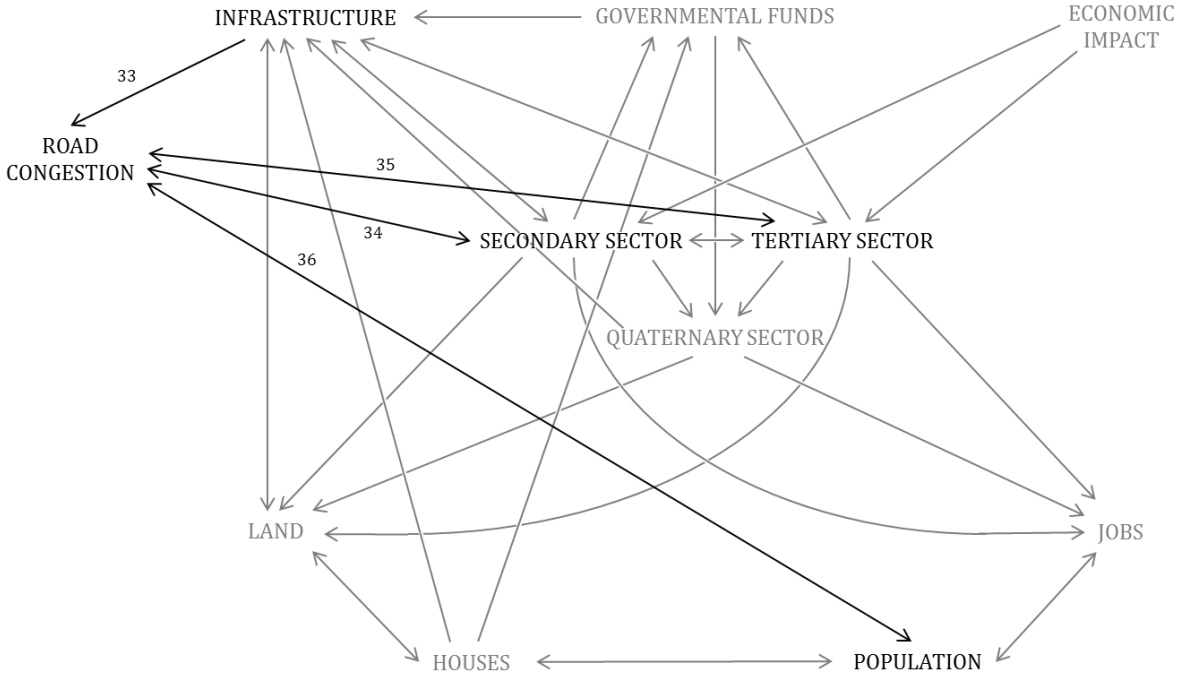


FIGURE 9: THE INFLUENCE OF ROAD CONGESTION ON THE GENERAL MODEL.

Link 33 indicates the influence the infrastructure (which is present) has on road congestion. The higher the total of present infrastructure in relation to the present structures, the more positive the influence is on (the absence of) road congestion.

Link 34 and 35 indicate the influence road congestion has on the secondary and tertiary sector and vice versa. Road congestion influences the attractiveness of both economic sectors. It is assumed that the bigger the road congestion, the lower the accessibility of the area will be, which will negatively influence both sectors due to higher travel times (and thereby higher costs) for goods transport services as costumers. The economic sectors influence the usage of the road infrastructure by goods transport and costumers and thereby influence the road congestion.

Link 36 indicates the influence of the population on road congestion and vice versa. The local population uses road infrastructure for transport (e.g. grocery's by car, cycling to school and visiting the city centre by bus). This usage contributes to road congestion. The modal split per city differs and thereby the usage of the road infrastructure will differ per city. Much road congestion can negatively influence the attractiveness of an urban area for population, due to related pollution and travel time losses.

1.8.2 ADAPTATION TO ROAD CONGESTION

The influence of adaptation to road congestion on the general model can be seen in Figure 10. Road congestion influences the accessibility of the urban area and thereby the attractiveness of the area. By implementing measures which lower the presence of road congestion, the influence of the congestion on the urban area declines.

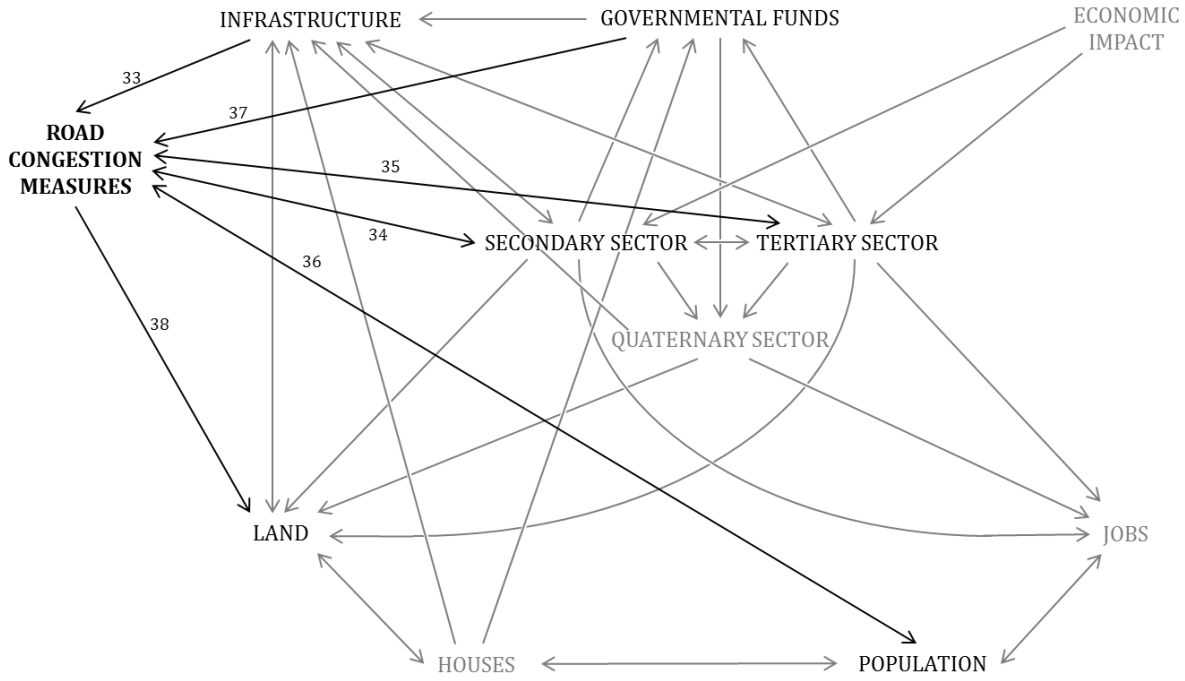


FIGURE 10: THE INFLUENCE OF ADAPTATION TO ROAD CONGESTION ON THE GENERAL MODEL.

Link 33 to 36 represent the same influences as describes in 1.8.1. ***Link 37*** indicates the direct investments made from the governmental funds for the adaptation towards road congestion. These investments bypass other general infrastructure investments. ***Link 38*** indicates the land use by the road congestion measures.

SOFTWARE MODEL DEVELOPMENT

APPENDIX B

The appendix Software Model describes the implementation of the theoretical model (as described in Report 4.2, 4.3 and appendix Theoretical Model) in the software. The appendix first gives an introduction to system dynamics and the software program itself. This is followed by the model listing of the URBAN2013 model and its extensions.

1. INTRODUCTION SYSTEM DYNAMICS & ANYLOGIC SOFTWARE

A city can be described as an area which contains a combination of different dynamic processes. Examples of these dynamic processes are the housing market, the business sector and the land use distribution. These processes are (partly) interlinked and therefore changes in one process can have (major) influences on other processes. Therefore it can be seen as a complex system[1].

System Dynamics is an approach developed for complex systems[2]. The definition of system dynamics is: *System dynamics is a computer-aided approach to policy analysis and design. It applies to dynamic problems arising in complex social, managerial, economic, or ecological systems — literally any dynamic systems characterized by interdependence, mutual interaction, information feedback, and circular causality (System Dynamics Society).*

Using system dynamics an overview of the development of the city over time can be achieved. The results will be in the form of a quantification of stocks, given in graphs over time. Insights in the location of spatial developments are not possible.

HOW DOES SYSTEM DYNAMICS WORK?

The system structure of system dynamics is given in an organizing framework (Forrester, Structure of an Urban Area, 1969):

- Closed boundary
  - Feedback loops
    - Levels (stocks)
    - Rates (flows)
      - Goal
      - Observed condition
      - Discrepancy
      - Desired action

[1] A complex system refers to *a high-order, multiple-loop, nonlinear feedback structure* (Forrester, 1969).
[2] System dynamics was created by Professor Jay W. Forrester of the MIT Sloan School of Management during the 1950s. It was originally developed for corporate and industrial *complex systems*, but this has developed into applications in many other fields, such as urban development, public policy and defence.

CLOSED BOUNDARY

System dynamics is based on a closed-system boundary. This means that outside events are considered as random events. These outside events do not hinder the system itself (and therefore do not give the system its intrinsic growth nor its stability characteristics). The boundary is chosen to include the necessary interacting components to generate the behaviour of interest (Forrester, Structure of an Urban Area, 1969).

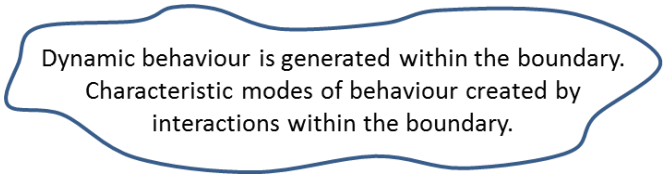


FIGURE 1-1: A DYNAMIC SYSTEM IN A CLOSED BOUNDARY (FORRESTER, URBAN DYNAMICS, 1969).

FEEDBACK LOOPS

The feedback loops generate the dynamic behaviour of the system. An example of a feedback loop can be seen in Figure 1-2. A feedback loop must contain at least one 'rate' and one 'level'. In the feedback loop, the information (which results from one action) travels through the system and eventually arrives (in some form) at its point of origin. This returned information can influence future actions in the system. A loop can either reinforce the initial action (positive feedback loop) or oppose the initial action (negative or balancing feedback loop). A reinforcing loop contributes to growth or accelerating collapse. A balancing loop contributes to stabilizing. The combination of both types of loops can generate all kinds of dynamic patterns (System Dynamics Society, 2012).

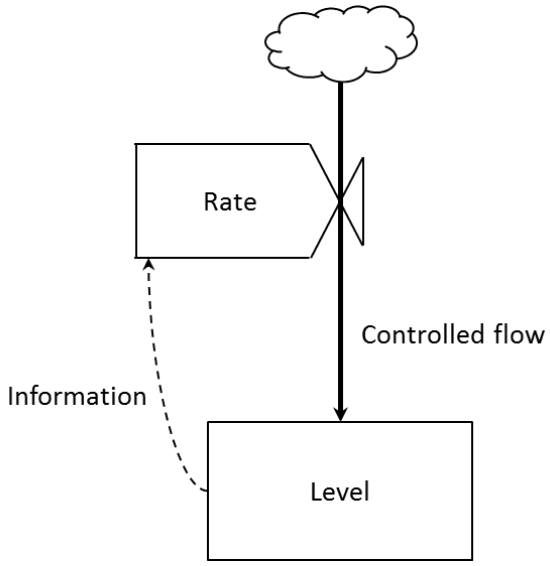


FIGURE 1-2: A FEEDBACK LOOP IN COMBINATION WITH ONE RATE AND ONE LEVEL (FORRESTER, STRUCTURE OF AN URBAN AREA, 1969).

STOCKS

Stocks (levels) are state variables and can be seen as the memory of the dynamic system. They represent the accumulations within the feedback loops (Forrester, Structure of an Urban Area, 1969).

FLOWS

Flows (rates) represent activity within the feedback loops. Goal, observed condition, discrepancy and desired action are all components of rate variables (Forrester, Structure of an Urban Area, 1969):

- Goal: Each rate equation has explicitly or implicitly a goal towards or away from which that decision point in the system is thriving.
- Observed condition: The observed condition (and not the true condition) determines the action.
- Discrepancy: The perceived condition of the system is very often distorted and lags with respect to the true condition.
- Desired action: The desired action will is stated by the rate equation. This results from the discrepancy.

SOFTWARE

The software used for the modelling in system dynamics is *AnyLogic University* by the AnyLogic Company. For more information on this software, see www.anylogic.com. The software package does not contain the *Sensitivity Analysis package* and the *Monte Carlo Experiment package*.

2. GENERAL MODEL CONSTRUCTION

The model listing is the full model as constructed in the AnyLogic software. This appendix gives the setup of the URBAN2013 model. Table 1 gives the description of the type of component.

TABLE 1: THE DESCRIPTION OF EACH COMPONENT TYPE.

Type	Explenation
S	Stock
F	Flow
A	Auxiliary
C	Constant
T	Table
V	Variable
E	Event

MODEL LISTING – URBAN2013

Type	Abbr.	Name	Formula
Business Sectors			
S	SS	Secondary Sector	SS=SS(*T-1*) + DT(SSC-SSD)
			initial value=3132
F	SSC	Secondary Sector Construction	SS=SS*SSCN*MSS*PFSSC
C	SSCN	Secondary Sector Construction Normal	SSCN=0.026
F	SSD	Secondary Sector Demolition	SS=SS*SSDN*PFSSD
C	SSDN	Secondary Sector Demolition Normal	SSDN=0.008
S	TS	Tertiary Sector	TS=TS(*T-1*) + DT(TSC-TSD)
			initial value=17880
F	TSC	Tertiary Sector Construction	TSC=TS*TSCN*MTS*PFTSC
C	TSCN	Tertiary Sector Construction Normal	TSCN=0.026

F	TSD	Tertiary Sector Demolition	TSD=TS*TSDN*PFTSD
C	TSDN	Tertiary Sector Demolition Normal	TSDN=0.008
S	QS	Quaternary Sector	QS=QS(*T-1*) + DT(QSC-QSD)
			initial value=3274
F	QSC	Quaternary Sector Construction	QSC=QS*QSCN*MQS*PFQSC
C	QSCN	Quaternary Sector Construction Normal	QSCN=0.026
F	QSD	Quaternary Sector Demolition	QSD=QS*QSDN*PFQSD
C	QSDN	Quaternary Sector Demolition Normal	QSDN=0.008
Housing			
S	H	Houses	H=H(*T-1*) + DT(HC-HD)
			initial value=297890
F	HC	Houses Construction	HC=H*HCN*PFHC
C	HCN	Houses Construction Normal	HCN=0.018
F	HD	Houses Demolition	HD=H*HDN*PFHD
C	HDN	Houses Demolition Normal	HDN=0.008
Population			
S	P	Population	P=P(*T-1*) + DT(PB-PD+PI-PO)
			initial value=616456
F	PB	Population Births	PB=P*PBN
C	PBN	Population Births Normal	PBN=0.013
F	PD	Population Deaths	PD=P*PDN
C	PDN	Population Deaths Normal	PDN=0.0088
F	PI	Population Inflow	PI=P*PIN
C	PIN	Population Inflow Normal	PIN=0.0556
F	PO	Population Outflow	PO=P*PON
C	PON	Population Outflow Normal	PON=0.0463
Infrastructure			
S	I	Infrastructure	I=I(*T-1*) + DT(IC-ID)
			initial value=1999
F	IC	Infrastructure Construction	IC=GFM*I*IRN + (SSC*LSS+TSC*LTS+QSC*LQS+HC*LH)*LI
F	ID	Infrastructure Demolition	ID=I*IRN + (SSD*LSS+TSD*LTS+QSD*LQS+HD*LH)*LI
C	IRN	Infrastructure Renewing Normal	IRN=0.029
Land use			
A	LFO	Land Fraction Occupied	LFO=(SS*LSS + TS*LTS + QS*LQS + H*LH + I)/AREA
C	LSS	Land Usage per Secondary Sector Structure	LSS=1.071
C	LTS	Land Usage per Tertiary Sector Structure	LTS=0.046
C	LQS	Land Usage per Quaternary Sector Structure	LQS=0.342
C	LH	Land Usage per Housing Structure	LH=0.034
C	LI	Land Usage for Infrastructure	LI=0.153
C	AREA	Area	AREA=20590
Jobs			
A	J	Jobs	J=SS*JSS + TS*JTS + QS*JQS
C	JSS	Jobs per Secondary Sector Structure	JSS=14.9
C	JTS	Jobs per Tertiary Sector Structure	JTS=7.2
C	JQS	Jobs per Quaternary Sector Structure	JQS=25.0

Labour Force			
A	LFO	Labour Force	LF=P*LFPF
C	LFPF	Labour Force Patricipation Fraction	LFPF=0.472
Ratios			
A	LFJR	Labour Force to Job Ratio	LFJR=LF/J
A	HHR	Households to Houses Ratio	HHR=(P/HHRT(*TIME*))/H
T	HHRT	Households to Houses Ratio Table	*See subparagraph Tables*
A	IR	Infrastructure Ratio	IR=I/((SS*LSS + TS*LTS + QS*LQS +H*LH)*LI)
Multipliers			
A	BLFM	Business Labour Force Multiplier	BLFMT(LFJR)
T	BLFMT	Business Labour Force Multiplier Table	*See subparagraph Tables*
A	BLM	Business Land Multiplier	BLMT(LFO)
T	BLMT	Business Land Multiplier Table	*See subparagraph Tables*
A	MSS	Multiplier Secondary Sector	MSS=IM*BLFM*BLM*EISS*TFSS
A	MTS	Multiplier Tertiary Sector	MTS=IM*BLFM*BLM*EITS*TFTS
A	MQS	Multiplier Quaternary Sector	MQS=(((SS*SSQS + TS*TSQS)/QS)*TFQS*BLM*BLFM)*GFM
C	SSQS	Secondary Sector Influence on Quaternary Sector	SSQS=0.156
C	TSQS	Tertiary Sector Influence on Quaternary Sector	TSQS=0.156
A	IM	Infrastructure Multiplier	IM=IMT(IR)
T	IMT	Infrastructure Multiplier Table	*See subparagraph Tables*
A	HLM	Housing Land Multiplier	HLM=HLMT(LFO)
T	HLMT	Housing Land Multiplier Table	*See subparagraph Tables*
A	HAM	Housing Availability Multiplier	HAM=HAMT(HHR)
T	HAMT	Housing Availability Multiplier Table	*See subparagraph Tables*
A	HCM	Housing Construction Multiplier	HCM=HAM*HLM
A	HJAM	Housing and Job Attractiveness Multiplier	HJAM=AHM*AJM
A	AHM	Attractiveness of Housing	AHM=AHMT(HHR)
T	AHMT	Attractiveness of Housing Table	*See subparagraph Tables*
A	AJM	Attractiveness of Jobs	AJM=AJMT(LFJR)
T	AJMT	Attractiveness of Jobs Table	*See subparagraph Tables*
Prioritizing Factor			
A	SUMSES	Summation Sectors	SUMSEC=MSS+MTS+MQS+HCM
A	PFSSC	Prioritizing Factor Secondary Sector Construction	PFSSC=(4*MSS)/SUMSEC
A	PFTSC	Prioritizing Factor Tertiary Sector Construction	PFTSC=(4*MTS)/SUMSEC
A	PFQSC	Prioritizing Factor Quaternary Sector Construction	PFQSC=(4*MQS)/SUMSEC
A	PFHC	Prioritizing Factor Housing Sector Construction	PFHC=(4*HCM)/SUMSEC
A	PFSSD	Prioritizing Factor Secondary Sector Demolition	PFSSD=(1-PFSSC)+1
A	PFTSD	Prioritizing Factor Tertiary Sector Demolition	PFTSD=(1-PFTSC)+1
A	PFQSD	Prioritizing Factor Quaternary Sector Demolition	PFQSD=(1-PFQSD)+1
A	PFHD	Prioritizing Factor Housing Sector Demolition	PFHD=(1-PFHC)+1
Sector Transition			
A	TFSS	Transition Factor Secondary Sector	TFSS=TFSSN**TIME*+1
C	TFSSN	Transition Factor Secondary Sector Normal	TFSSN= +0.003
A	TFTS	Transition Factor Tertiary Sector	TFTS=TFTSN**TIME*+1
C	TFTSN	Transition Factor Tertiary Sector Normal	TFTSN= -0.001125

A	TFQS	Transition Factor Quaternary Sector	TFQS=TFQSN**TIME*+1
C	TFQSN	Transition Factor Quaternary Sector Normal	TFQSN= -0.01875
Economic Waves			
A	EI	Economic Impact	EI=KNOW+KUZW+JUGW+KITW * <*SCENARIO INPUT*>
A	EISS	Economic Impact Secondary Sector	EISS=EI
A	EITS	Economic Impact Tertiary Sector	EITS=EI
A	KONW	Kondratiev Wave	KONW=KONA*sin(((2*PI)/KONP)**TIME*)
C	KONWP	Kondratiev Wave Period	KONWP=54
C	KONWA	Kondratiev Wave Amplitude	KONWA=0.15
A	KUZW	Kuznet Wave	KUZW=KUZA*sin(((2*PI)/KUZP)**TIME*)
C	KUZWP	Kuznet Wave Period	KUZWP=20
C	KUZWA	Kuznet Wave Amplitude	KUZWA=0.033
A	JUGW	Juglar Wave	JUGW=JUGA*sin(((2*PI)/JUGP)**TIME*)
C	JUGWP	Juglar Wave Period	JUGWP=9
C	JUGWA	Juglar Wave Amplitude	JUGWA=0.027
A	KITW	Kitchin Wave	KITW=KITA*sin(((2*PI)/KITP)**TIME*)
C	KITWP	Kitchin Wave Period	KITWP=3.33
C	KITWA	Kitchin Wave Amplitude	KITWA=0.01
Cycle Tertiary Sector			
A	CTS	Cycle Tertiary Sector	CTS=CTSA*sin(((2*PI)/CTSP)**TIME*)
C	CTSP	Cycle Tertiary Sector Period	CTSP=10
C	CTSA	Cycle Tertiary Sector Amplitude	CTSA=0.038
Governmental Funds			
A	GFM	Governmental Funds Multiplier	GFM=(AM-1)+(LVTM-1)+1
A	AM	Aging Multiplier	AM=AI*AB*AH
A	AI	Aging Infrastructure	AI=AIT(IC/I)
T	AIT	Aging Infrastructure Table	*See subparagraph Tables*
A	ABS	Aging Business Structures	ABS=ABST((SSC+TSC+QSC)/(SS+TS+QS))
T	ABST	Aging Business Structures Table	*See subparagraph Tables*
A	AH	Aging Houses	AH=AHT(HC/H)
T	AHT	Aging Houses Table	*See subparagraph Tables*
A	LVTM	Land Value Tax Multiplier	LVTM=LVTB*LVTH
A	LVTB	Land Value Tax Business	LVTB=LVTBT(LFJR)
T	LVTBT	Land Value Tax Business Table	*See subparagraph Tables*
A	LVTH	Land Value Tax Houses	LVTH=LVTHT(HHR)
T	LVTHT	Land Value Tax Houses Table	*See subparagraph Tables*
Transformation Factor			
A	TF	Transformation Factor	TF=TFT(LFO)
T	TFT	Transformation Factor Table	*See subparagraph Tables*

MODEL LISTING – SCENARIO FLOOD EVENT

Flood Event			
E	STARTFE	Start Flood Event	T=3: FLOODEVENT=1
V	FLOODEVENT	Flood Event	*initial value*= 0
E	STOPFE	Stop Flood Event	T:3.99: FLOODEVENT=0
A	ATTFE	Attractiveness Flood Event	ATTFE=ATTFET(*TIME*)
T	ATTFET	Attractiveness Flood Event Table	*See subparagraph Tables*
A	REC	Relief Effort Costs	REF=0.002113*FLOODEVENT
General Model Adjustments			
F	SSD	Secondary Sector Demolition	SSD=SS*SSDN*PFSSD+0.00008*SS*FLOODEVENT
F	TSD	Tertiary Sector Demolition	TSD=TS*TSDN*PFTSD+0.00996*TS*FLOODEVENT
F	QSD	Quanternary Sector Demolition	QSD=QS*QSDN*PFQSDN+0.00131*QS*FLOODEVENT
F	HD	Houses Demolition	HD=H*HDN*PFHD+0.00068*H*FLOODEVENT
F	ID	Infrastructure Demolition	ID=I*IDN+(SSD*LSS+TSD*LTS+QS*LQS+H*LH)*LI+0.0008*I*FLOODEVENT
A	MSS	Multiplier Secondary Sector	MSS=IM*BLFM*BLM*EISS*TFSS*(1-ATTFE)*0.00008
A	MTS	Multiplier Tertiary Sector	MTS=IM*BLFM*BLM*EITS*TFTS*(1-ATTFE)*0.00996
A	MQS	Multiplier Quaternary Sector	MQS=(((SS*SSQS + TS*TSQS)/QS)*TFQS*BLM*BLFM)*GFM*(1-ATTFE)*0.00131
A	HCM	Housing Construction Multiplier	HCM=HAM*HLM*(1-ATTFE)*0.00068
A	HJAM	Housing and Job Attractiveness Multiplier	HJAM=AHM*AJM*(1-ATTFE)*0.0008

MODEL LISTING – SCENARIO FLOOD ADAPTATION

Area			
A	FAA	Flood Adaptation Area	LAUFAT(*TIME*)-R*EFFICIENCY
T	LAUFAT	Land Area Used Table	*See subparagraph Tables*
C	EFFICIENCY	Efficiency	EFFICIENCY=0.05
F	RI	Renewing Inflow	RI=(SSC*LSS+TSC*LTS+QSC*LQS+HC*LH+IC*LI)*F3Y
S	R	Renewing	R=R(*T-1*)+DT(RI)
			initial value=0
V	F3Y	First 3 Years	*initial value*=1
E	F3YS	First 3 Years Stop	T=3: F3Y=0
Construction Costs			
A	CC	Construction Costs (yearly)	CC=1-0.1885*CCLFOT(LFO)
T	CCLFOT	Construction Costs Land Fraction Occupied Table	*See subparagraph Tables*
Operation and Maintenance Costs			
F	CCI	Construction Costs Inflow	CCI=CC*F3Y
S	CCT	Construction Costs Total	CCT=CC(*T-1*)+DT(CCI)
		initial value=0	
A	OMC	Operation and Maintenance Costs	OMC=0.1885*(((*TIME*F3Y)/3)*CCT*OMCP)+(1-F3Y)*OMCP*CCT
F	OMCP	Operation and Maintenance Costs Percentage	OMCP=0.065
General Model Adjustments			
A	LFO	Land Fraction Occupied	LFO=(SS*LSS + TS*LTS + QS*LQS + H*LH + I+LAUFAT)/AREA
A	GFM	Governmental Funds Multiplier	GFM=(AM-1)+(LVTM-1)+(CC-1)*F3Y-OMC+1

MODEL LISTING – CONGESTION

Congestion			
F	CGY	Congestion Growth Yearly	CGY=CGN-1
C	CGN	Congestion Growth Normal	CGN=1.0184
S	C	Congestion	C=C(*T-1)*+DT(CGY)
			initial value=0
A	CCSS	Congestion Consequence Secondary Sector	CCSS=CCT(C/SSI)
C	SSI	Secondary Sector Impact	SSI=1.000
A	CQTS	Congestion Consequence Tertiary Sector	CCTS=CCT(C/TSI)
C	TSI	Tertiary Sector Impact	TSI=1.129
T	CCT	Congestion Consequence Table	*See subparagraph Tables*
General Model Adjustments			
A	MSS	Multiplier Secondary Sector	MSS=IM*BLFM*BLM*EISS*TFSS*SSI
A	MTS	Multiplier Tertiary Sector	MTS=IM*BLFM*BLM*EITS*TFTS*TSI

MODEL LISTING – CONGESTION MEASURES

Congestion Measures			
F	CGY	Congestion Growth Yearly	CGY=CGN-1
C	CGN	Congestion Growth Normal	CGN=1.0184
S	C	Congestion	C=C(*T-1)*+DT(CGY)
			initial value=0
A	CCSS	Congestion Consequence Secondary Sector	CCSS=CCT(C/SSI)
C	SSI	Secondary Sector Impact	SSI=1.000
A	CQTS	Congestion Consequence Tertiary Sector	CCTS=CCT(C/TSI)
C	TSI	Tertiary Sector Impact	TSI=1.129
T	CCT	Congestion Consequence Table	*See subparagraph Tables*
Congestion Measures			
A	CM	Congestion Measures	CM=C-(CMID*CGY)
C	CMID	Congestion Measures Implementation Delay	CMID=5
Congestion Impact on Governmental Funds			
A	TCMIGF	Total Congestion Measures Impact Governmental Funds	TCMIGF=(LUC+YCC+OMC)/TMC
C	TMC	Total Municipalitan Income	TMC=1591531000
Land Use			
A	LUCM	Land Usage Congestion Measures	LUCM=I* CD*LUI
A	LUCMC	Land Usage Congestion Measures Costs	LUCMC=LU*LUC
A	LUC	Land Usage Costs	LUC=LUCM*LUCT(LFO)*250
T	LUCT	Land Usage Costs Table	*See subparagraph Tables*
C	LUI	Land Use Influence	LUI=0.00823778
Construction Costs			
A	YCC	Yearly Construction Costs	YCC=100*CGY*CCP *The 100 multiplication represents the percentage conversion.*
C	CCP	Costs Construction Percentage	CCP=21254487

F	CCG	Construction Costs Growth (over time)	CCG=YCC
S	CCO	Construction Costs Overall	CCO=CCO(*T-1*)+DT(YCC)
			initial value=0
Operation and Maintenance Costs			
A	OMC	Operation and Maintenance Costs	OMC=CCO*OMCP
C	OMCP	Operation and Maintenance Costs Percentage	OMCP=0.065
General Model Adjustments			
A	MSS	Multiplier Secondary Sector	MSS=IM*BLFM*BLM*EISS*TFSS*SSI
A	MTS	Multiplier Tertiary Sector	MTS=IM*BLFM*BLM*EITS*TFTS*TSI
A	GFM	Governmental Funds Multiplier	GFM=(AM-1)+(LVTM-1)-TCMIGF+1

TABLES

General model

Households to Houses Ratio

Time	0	3	6	9	12	15	250
Value	2	1.99	1.98	1.97	1.96	1.95	1.95

Business Labour Force Multiplier

LFJR	0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
Output	0.20	0.20	0.25	0.45	0.70	1.00	1.34	1.59	1.85	2.00	2.10

See also Report 4.4.

Business Land Multiplier

LFO	0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
Output	1.00	1.15	1.30	1.40	1.45	1.40	1.30	1.12	0.825	0.465	0

See also Report 4.4.

Infrastructure Multiplier

IR	0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
Output	0.75	0.7625	0.8	0.85	0.9125	1.0	1.0875	1.15	1.2	1.2375	1.25

Housing Land Multiplier

LFO	0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
Output	0.4	0.7	1.0	1.25	1.45	1.5	1.5	1.4	1	0.5	0

See also Report 4.4.

Housing Availability Multiplier

HHR	0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
Output	0.2	0.25	0.35	0.5	0.7	1.0	1.3	1.525	1.7	1.8	1.85

See also Report 4.4.

Attractiveness of Housing Multiplier

HHR	0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
Output	1.4	1.4	1.35	1.3	1.15	1.0	0.775	0.62	0.5	0.45	0.4

See also Report 4.4.

Attractiveness of Jobs Multiplier

LFJR	0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
Output	2.0	1.9	1.8	1.6	1.35	1.0	0.7	0.5	0.35	0.25	0.2

See also Report 4.4.

Aging of Infrastructure Multiplier

IC/I	0	0.0050	0.01	0.015	0.02	0.025	0.03	0.035	0.04	0.045	0.05	0.055	0.06
Output	0.85	0.86	0.87	0.89	0.92	0.96	1.01	1.05	1.08	1.10	1.12	1.14	1.15

Aging of Business Structures Multiplier

BSC/BS	0	0.0045	0.009	0.0135	0.018	0.0225	0.027	0.0315	0.036
Output	0.85	0.88	0.92	0.96	1.00	1.04	1.08	1.12	1.15

Aging of Houses Multiplier

HC/H	0	0.004	0.006	0.008	0.010	0.012	0.014	0.016	0.020
Output	0.85	0.88	0.92	0.96	1.00	1.04	1.08	1.12	1.15

Land Value Tax Business Multiplier

LFJR	0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
Output	1.05	1.04	1.03	1.02	1.01	1.00	0.99	0.98	0.97	0.96	0.95

Land Value Tax Houses Multiplier

HHR	0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
Output	1.05	1.04	1.03	1.02	1.01	1.00	0.99	0.98	0.97	0.96	0.95

Transformation Factor Multiplier

LFO	0	1
Output	0.02667	1.0

Flood Event

Attractiveness Flood Event Multiplier

Time	0	1	2	2.99	3	4	5	6	7	8	9
Output	1	1	1	1	0.844	0.855	0.866	0.876	0.887	0,898	0.908

Time (cont.)	10	11	12	13	14	15	16	17	18
Output	0.919	0.930	0.940	0.951	0.962	0.972	0.983	0.994	1

Flood Adaptation

Land Area Used Multiplier

Time	0	1	2	3	250
Output	0	40	80	120	120

Construction Costs Land Fraction Occupied Multiplier

LFO	0	1
Output	0.02667	1.0

Congestion

Congestion Consequence Multiplier

C/SSI or C/TSI	1	2	3	4	5	6
Output	1	0.9	0.8	0.7	0.6	0.5

Congestion measures

Land Usage Costs Multiplier

LFO	0	1
Output	0.02667	1.0

REFERENCE LIST

The reference list gives the sources of the values as used in URBAN2013 and its extensions.

General Model	
Component	Source
SS	http://www.rotterdam.nl/werkgelegenheid
SSCN	http://www.cbs.nl/NR/rdonlyres/503E2597-B078-4BFC-9B3B-8135912CE8E5/0/mo007.pdf
SSCD	http://www.cbs.nl/NR/rdonlyres/503E2597-B078-4BFC-9B3B-8135912CE8E5/0/mo007.pdf
TS	http://www.rotterdam.nl/werkgelegenheid
TSCN	http://www.cbs.nl/NR/rdonlyres/503E2597-B078-4BFC-9B3B-8135912CE8E5/0/mo007.pdf
TSDN	http://www.cbs.nl/NR/rdonlyres/503E2597-B078-4BFC-9B3B-8135912CE8E5/0/mo007.pdf
QS	http://www.rotterdam.nl/werkgelegenheid
QSCN	http://www.cbs.nl/NR/rdonlyres/503E2597-B078-4BFC-9B3B-8135912CE8E5/0/mo007.pdf
QSDN	http://www.cbs.nl/NR/rdonlyres/503E2597-B078-4BFC-9B3B-8135912CE8E5/0/mo007.pdf
H	http://www.rotterdam.nl/COS/publicaties/Vanaf%202005/12-3583.Bevolkingsprognose%20Rotterdam%202013-2030.pdf
HC	http://www.cbs.nl/NR/rdonlyres/503E2597-B078-4BFC-9B3B-8135912CE8E5/0/mo007.pdf
HD	http://www.cbs.nl/NR/rdonlyres/503E2597-B078-4BFC-9B3B-8135912CE8E5/0/mo007.pdf
P	http://www.rotterdam.nl/COS/publicaties/Vanaf%202005/12-3583.Bevolkingsprognose%20Rotterdam%202013-2030.pdf
PB	http://www.rotterdam.nl/COS/publicaties/Vanaf%202005/12-3583.Bevolkingsprognose%20Rotterdam%202013-2030.pdf
PD	http://www.rotterdam.nl/COS/publicaties/Vanaf%202005/12-3583.Bevolkingsprognose%20Rotterdam%202013-2030.pdf
PIN	http://www.rotterdam.nl/COS/publicaties/Vanaf%202005/12-3583.Bevolkingsprognose%20Rotterdam%202013-2030.pdf

PON	http://www.rotterdam.nl/COS/publicaties/Vanaf%202005/12-3583.Bevolkingsprognose%20Rotterdam%202013-2030.pdf
I	Kerncijfers Wijken en Buurten Rotterdam
IRN	http://www.cbs.nl/NR/rdonlyres/503E2597-B078-4BFC-9B3B-8135912CE8E5/0/mo007.pdf
LSS	http://statline.cbs.nl/StatWeb/publication/?VW=T&DM=SLNL&PA=7041bbod&D1=a&D2=0&D3=a&HD=130211-1624&HDR=G2&STB=T
LTS	http://statline.cbs.nl/StatWeb/publication/?VW=T&DM=SLNL&PA=7041bbod&D1=a&D2=0&D3=a&HD=130211-1624&HDR=G2&STB=T
LQS	http://statline.cbs.nl/StatWeb/publication/?VW=T&DM=SLNL&PA=7041bbod&D1=a&D2=0&D3=a&HD=130211-1624&HDR=G2&STB=T
LH	http://statline.cbs.nl/StatWeb/publication/?VW=T&DM=SLNL&PA=7041bbod&D1=a&D2=0&D3=a&HD=130211-1624&HDR=G2&STB=T
LI	http://statline.cbs.nl/StatWeb/publication/?VW=T&DM=SLNL&PA=7041bbod&D1=a&D2=0&D3=a&HD=130211-1624&HDR=G2&STB=T
AREA	http://www.cbs.nl/NR/rdonlyres/DC3AC221-BCEB-4554-BB26-AB7B9FDC9237/0/Rotterdam.pdf
JSS	http://statline.cbs.nl/StatWeb/publication/?VW=T&DM=SLNL&PA=7041bbod&D1=a&D2=0&D3=a&HD=130211-1624&HDR=G2&STB=T
	http://statline.cbs.nl/StatWeb/publication/?VW=T&DM=SLnl&PA=80802NED&LA=nl
JTS	http://statline.cbs.nl/StatWeb/publication/?VW=T&DM=SLNL&PA=7041bbod&D1=a&D2=0&D3=a&HD=130211-1624&HDR=G2&STB=T
	http://statline.cbs.nl/StatWeb/publication/?VW=T&DM=SLnl&PA=80802NED&LA=nl
JQS	http://statline.cbs.nl/StatWeb/publication/?VW=T&DM=SLNL&PA=7041bbod&D1=a&D2=0&D3=a&HD=130211-1624&HDR=G2&STB=T
	http://statline.cbs.nl/StatWeb/publication/?VW=T&DM=SLnl&PA=80802NED&LA=nl
LFPF	http://statline.cbs.nl/StatWeb/publication/?VW=T&DM=SLNL&PA=71958ned&LA=NL
SSQS	http://www.rotterdam.nl/werkgelegenheid
TSQS	http://www.rotterdam.nl/werkgelegenheid
TFSSN	Prediction (see report 4.2)
TFTSN	Prediction (see report 4.2)
TFQSN	Prediction (see report 4.2)
KONWP	http://www.sciencedirect.com/science/article/pii/0016328776901063
KONWA	http://www.sciencedirect.com/science/article/pii/0016328776901063
KUZWP	http://www.sciencedirect.com/science/article/pii/0016328776901063
KUZWA	http://www.sciencedirect.com/science/article/pii/0016328776901063
JUGWP	http://www.sciencedirect.com/science/article/pii/0016328776901063
JUGWA	http://www.sciencedirect.com/science/article/pii/0016328776901063
KITWP	http://www.sciencedirect.com/science/article/pii/0016328776901063
KITWA	http://www.sciencedirect.com/science/article/pii/0016328776901063
CTSP	http://www.pdx.edu/sites/www.pdx.edu.realestate/files/02%20Lee%20Quarterly%20201105.pdf
CTSA	http://statline.cbs.nl/StatWeb/publication/default.aspx?DM=SLNL&PA=81589NED&D1=0%2c9-
Flood Event	
ATTFET	http://www.emeraldinsight.com/journals.htm?articleid=845537&show=abstract
FEC	(Kok, 2006)
DAMAGE	Based on the Rotterdam maps (provided by Gemeente Rotterdam)
Flood Adaptation	
EFFICIENCY	Assumption. Based on expert consultation with Frans van de Ven (TU Delft).
OMCP	http://www2.emersonprocess.com/siteadmincenter/PM%20Central%20Web%20Documents/plantweb-ops-maint.pdf
Congestion	
C	Scenario (http://www.welvaartenleefomgeving.nl)
SSI	http://www.rug.nl/staff/p.h.pellenbarg/voordrachten/10._dynamiek_in_vestigingsgedrag.pdf
TSI	http://www.rug.nl/staff/p.h.pellenbarg/voordrachten/10._dynamiek_in_vestigingsgedrag.pdf

Congestion Measures	
C	Scenario (http://www.welvaartenleefomgeving.nl)
SSI	http://www.rug.nl/staff/p.h.pellenbarg/voordrachten/10._dynamiek_in_vestigingsgedrag.pdf
TSI	http://www.rug.nl/staff/p.h.pellenbarg/voordrachten/10._dynamiek_in_vestigingsgedrag.pdf
CMID	http://www.pbl.nl/sites/default/files/cms/publicaties/CPB-PBL%20Notitie%20Prijsbeleid%20voor%20wegverkeer%20-%20kosten%20en%20invoeringstermijnen.pdf
TMC	(Gemeente Rotterdam, 2012)
LUC	The 250 multiplication is based on expert consultation (Ger Sterks, ARCADIS). This multiplication represents the maximum land costs.
LUI	Assumption. Based on the implementation of several different types of measures (VTPI, 2013).
CCP	(CE Delft, 2008)
OMCP	http://www2.emersonprocess.com/siteadmincenter/PM%20Central%20Web%20Documents/plantweb-ops-maint.pdf
Tables	
HHRT	http://www.rotterdam.nl/COS/publicaties/Vanaf%202005/08-2926.Bevolkingsprognose%20Rotterdam%202010-2025.pdf
BLFMT	(Alfeld & Graham, 1976), adjustments made in Report 4.4.
BLMT	(Alfeld & Graham, 1976), adjustments made in Report 4.4.
IMT	Assumption; based on influence of present infrastructure on attractiveness of area for businesses.
HLMT	(Alfeld & Graham, 1976), adjustments made in Report 4.4.
HAMT	(Alfeld & Graham, 1976), adjustments made in Report 4.4.
AHMT	(Alfeld & Graham, 1976), adjustments made in Report 4.4.
AJMT	(Alfeld & Graham, 1976), adjustments made in Report 4.4.
AIT	http://www.cbs.nl/NR/rdonlyres/503E2597-B078-4BFC-9B3B-8135912CE8E5/0/mo007.pdf
ABST	http://www.cbs.nl/NR/rdonlyres/503E2597-B078-4BFC-9B3B-8135912CE8E5/0/mo007.pdf http://www.utrecht.nl/smartsite.dws?id=212996
AHT	http://www.cbs.nl/NR/rdonlyres/503E2597-B078-4BFC-9B3B-8135912CE8E5/0/mo007.pdf http://www.utrecht.nl/smartsite.dws?id=212996
LVTBT	(Gemeente Rotterdam, 2012), derived from document.
LVTHT	(Gemeente Rotterdam, 2012), derived from document.
TFT	Expert consultation (Ger Sterks, ARCADIS).
ATTFET	http://www.emeraldinsight.com/journals.htm?articleid=845537&show=abstract
LAUFAT	Assumption (see report 5.2).
CCT	http://reason.org/files/ps371_growth_gridlock_cities_full_study.pdf
LUCT	Expert consultation (Ger Sterks, ARCADIS).

APPENDIX ECONOMIC IMPACT

APPENDIX C

The economic impact in URBAN2013 describes the impact of the global economic development on a city. This impact has direct influence on the secondary and tertiary business structures. No valid forecast for the future economic development exists. Therefore the implementation of a standard economic forecast in the model is not possible. By using economic waves (as described in the report in 4.3), the range of the economic impact can be approximated.

Since the Monte Carlo experiment is not available in the software package, the bandwidth of the influence of the economic impact on the model cannot be determined. This would otherwise be combined with a randomizer coupled with the different economic waves to create the bandwidth (range) of the model output. Due to this unavailability, the economic impact component in the model is taken into account by implementing three economic scenarios:

- **Positive economic development**: The positive economic development scenario starts with an economic growth for the next period, as can be seen in Figure 1.

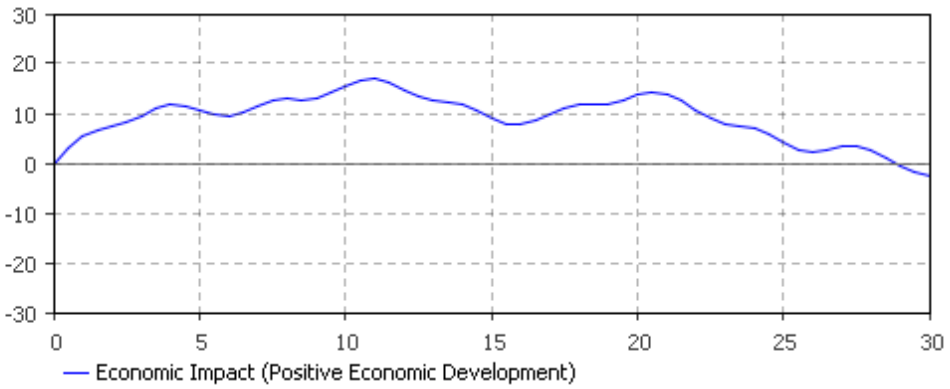


FIGURE 1: THE POSITIVE ECONOMIC DEVELOPMENT SCENARIO.

- **Neutral economic development**: The neutral economic development scenario assumes no economic growth or decline. It basically describes the model without any economic input as can be seen in Figure 2.

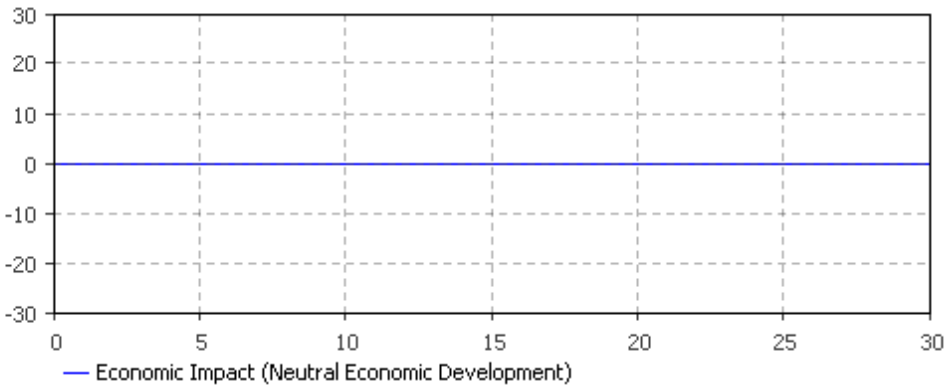


FIGURE 2: THE NEUTRAL ECONOMIC DEVELOPMENT SCENARIO.

- **Negative economic development**: The negative economic development scenario starts with an economic decline for the next period, as can be seen in Figure 3.

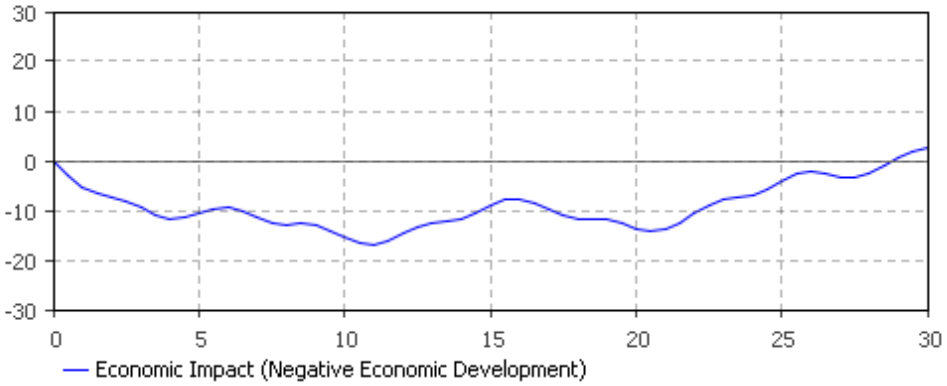


FIGURE 3: THE NEGATIVE ECONOMIC DEVELOPMENT SCENARIO.

It is important to note that these three scenarios are not veracious, but they give an insight on the influence of the economic development on the development of the city. For the analysis the model runs are based on the neutral economic scenario. However, both other scenarios are run as well to provide with an insight of the development of the scenario with different economic impacts.

For the model the main influence of the economic impact is on the secondary and tertiary sector. This direct influence means that the attractiveness of these sectors increases with economic growth and declines with economic decline. This in turn influences the pressure on the land use. As a consequence, in time of economic growth business structures grows at the expense of housing units and in time of economic decline the attractiveness of business sectors declines, which positively influences housing construction.

FLOODING SCENARIOS

The three economic scenarios are implemented in the flooding scenarios. The different outcomes of the flooding scenarios are compared to see the range of the impact of the economic development. By determining this range it can be seen whether the impact of the economic development on the scenarios can lead to a difference in the most beneficial (or least costly) strategy.

Positive Economic Development

TABLE 1: THE IMPACT OF THE POSITIVE ECONOMIC SCENARIO ON THE FLOODING SCENARIOS.

	Absolute			**Percentage**	
	General Model (total)	**Flood Event** (difference)	**Flood Adaptation** (difference)	**Flood Event** (difference)	**Flood Adaptation** (difference)
Population [people]	19.888.366	- 50.883	- 47.506	- 0,26%	- 0,24%
Houses [housing units]	9.430.012	- 5.925	7.011	- 0,06%	0,07%
Employment [jobs]	8.751.459	- 44.766	- 51.868	- 0,51%	- 0,59%
Secondary sector BS [businesses]	107.725	402	167	0,37%	0,16%
Tertiary sector BS [businesses]	603.210	- 6.377	1.048	- 1,06%	0,17%
Quaternary sector BS [businesses]	112.130	- 193	- 2.476	- 0,17%	- 2,21%

Neutral Economic Development

TABLE 2: THE IMPACT OF THE NEUTRAL ECONOMIC SCENARIO ON THE FLOODING SCENARIOS.

	Absolute			**Percentage**	
	General Model (total)	**Flood Event** (difference)	**Flood Adaptation** (difference)	**Flood Event** (difference)	**Flood Adaptation** (difference)
Population [people]	19.822.873	- 50.526	- 50.811	- 0,25%	- 0,26%
Houses [housing units]	9.531.031	- 5.367	6.784	- 0,06%	0,07%
Employment [jobs]	8.612.216	- 43.093	- 52.865	- 0,50%	- 0,61%
Secondary sector BS [businesses]	104.546	352	178	0,34%	0,17%
Tertiary sector BS [businesses]	586.414	- 6.075	1.095	- 1,04%	0,19%
Quaternary sector BS [businesses]	113.292	- 184	- 2.536	- 0,16%	- 2,24%

Negative Economic Development

TABLE 3: THE IMPACT OF THE NEGATIVE ECONOMIC SCENARIO ON THE FLOODING SCENARIOS.

	Absolute			Percentage	
	General Model (total)	**Flood Event** (difference)	**Flood Adaptation** (difference)	**Flood Event** (difference)	**Flood Adaptation** (difference)
Population [people]	19.753.311	- 50.877	- 47.506	- 0,26%	- 0,28%
Houses [housing units]	9.641.443	- 4.994	7.011	- 0,05%	0,07%
Employment [jobs]	8.472.050	- 41.836	- 51.868	- 0,49%	- 0,64%
Secondary sector BS [businesses]	101.311	298	167	0,29%	0,18%
Tertiary sector BS [businesses]	569.324	- 5.799	1.048	- 1,02%	0,20%
Quaternary sector BS [businesses]	114.535	- 181	- 2.476	- 0,16%	- 2,28%

Impact calculation

The impact calculation is equal to the calculations as performed in the main report (5.4). The calculations use the added value per economic sector structure.

TABLE 4: THE ADDED VALUE PER ECONOMIC SCENARIO FOR THE FLOODING SCENARIOS.

Economic Scenario	**Positive**		**Neutral**		**Negative**	
Flooding Scenario	*Flood Event*	*Flood Adaptation*	*Flood Event*	*Flood Adaptation*	*Flood Event*	*Flood Adaptation*
Secondary Sector [million €]	1.192	497	1.045	528	885	547
Tertiary Sector [million €]	- 7.740	1.272	- 7.372	1.329	- 7.038	1.357
Quaternary Sector [million €]	- 532	- 6.807	- 506	- 6.971	- 498	- 7.167
Total [million €]	**- 7.079**	**- 5.262**	**- 6.833**	**- 5.115**	**- 6.650**	**- 5.262**

The range of the economic impact for the economic scenarios describes the difference between both scenarios and is indicated in Table 5. The range is based on the difference between the general model outcome on one side and the outcomes of the flood event and flood adaptation scenarios.

TABLE 5: THE RANGE OF THE ECONOMIC IMPACT ON THE FLOODING SCENARIOS.

	Flood Event Scenario	**Flood Adaptation Scenario**
Positive Economic Development	**1,40**	**1,00**
Neutral Economic Development	**1,34**	**1,00**
Negative Economic Development	**1,26**	**1,00**

Conclusion Flood Scenarios

The different economic scenarios cause changes in the outputs of the flooding scenarios. Although these changes influence the outputs, the changes are not significant to influence the preferable flood scenario. The range of the ratio between the flood event and the flood adaptation scenario varies between 1,26 up to 1,40 to 1,00. The economic impact does not influence the most preferable flooding strategy, which is the flood adaptation strategy.

CONGESTION SCENARIOS

The three economic scenarios are implemented in the congestion scenarios. The different outcomes of the congestion scenarios are compared to see the range of the impact of the economic development. This range can indicate whether the impact of the economic development on the scenarios can lead to a difference in the most beneficial (or least costly) strategy.

Positive Economic Development

TABLE 6: THE IMPACT OF THE POSITIVE ECONOMIC SCENARIO ON THE CONGESTION SCENARIOS.

	Absolute			Percentage	
	General Model (total)	**Congestion** (difference)	**Congestion Measures** (difference)	**Congestion** (difference)	**Congestion Measures** (difference)
Population [people]	19.888.366	3.721	- 16.515	0,02%	- 0,08%
Houses [housing units]	9.430.012	17.462	45.148	0,19%	0,48%
Employment [jobs]	8.751.459	- 8.065	- 44.709	- 0,09%	- 0,51%
Secondary sector BS [businesses]	107.725	-792	648	- 0,73%	0,60%
Tertiary sector BS [businesses]	603.210	-392	3.382	- 0,06%	0,56%
Quaternary sector BS [businesses]	112.130	262	- 3.148	0,23%	- 2,81%

Neutral Economic Development

TABLE 7: THE IMPACT OF THE NEUTRAL ECONOMIC SCENARIO ON THE CONGESTION SCENARIOS.

	Absolute			Percentage	
	General Model (total)	**Congestion** (difference)	**Congestion Measures** (difference)	**Congestion** (difference)	**Congestion Measures** (difference)
Population [people]	19.822.873	2.761	- 23.335	0,01%	- 0,12%
Houses [housing units]	9.531.031	16.877	46.360	0,18%	0,49%
Employment [jobs]	8.612.216	- 7.854	- 49.173	- 0,09%	- 0,57%
Secondary sector BS [businesses]	104.546	- 716	608	- 0,69%	0,58%
Tertiary sector BS [businesses]	586.414	- 465	3.176	- 0,08%	0,54%
Quaternary sector BS [businesses]	113.292	247	- 3.244	0,22%	- 2,86%

Negative Economic Development

TABLE 8: THE IMPACT OF THE NEGATIVE ECONOMIC SCENARIO ON THE CONGESTION SCENARIOS.

	Absolute			Percentage	
	General Model (total)	**Congestion** (difference)	**Congestion Measures** (difference)	**Congestion** (difference)	**Congestion Measures** (difference)
Population [people]	19.753.311	1.996	- 30.945	0,01%	- 0,16%
Houses [housing units]	9.641.443	16.178	47.702	0,17%	0,49%

Employment [jobs]	8.472.050	- 7.388	- 53.827	- 0,09%	- 0,64%
Secondary sector BS [businesses]	101.311	- 635	568	- 0,63%	0,56%
Tertiary sector BS [businesses]	569.324	- 508	2.974	- 0,09%	0,52%
Quaternary sector BS [businesses]	114.535	229	- 3.348	0,20%	- 2,92%

Impact Calculation

The impact calculation is equal to the calculations as performed in the main report (5.4). The calculations use the added value per economic sector structure. The output describe the deviation in added value to the general model output.

TABLE 9: THE ADDED VALUE PER CONGESTION SCENARIO FOR EACH ECONOMIC SCENARIO.

Economic Scen.	**Positive**		**Neutral**		**Negative**	
Flooding Scenario	*Congestion*	*Congestion Measures*	*Congestion*	*Congestion Measures*	*Congestion*	*Congestion Measures*
Secondary Sector [million €]	- 2.351	1.923,4	- 2.127	1.805	- 1.886	1.688
Tertiary Sector [million €]	- 475	4.104,8	- 564	3.856	-617	3.609
Quaternary Sector [million €]	720	- 8.655,0	678	- 8.918	630	- 9.204
Total [million €]	**- 2.106**	**- 2.627**	**- 2.013**	**- 3.257**	**- 1.872**	**- 3.907**
Total including congestion time loss costs [million €]	**- 5.712**	**- 2.627**	**- 5.619**	**- 3.257**	**- 5.478**	**- 3.907**

The range of the economic impact for the economic scenarios describes the difference between both scenarios and is indicated in Table 5. The range is based on the difference between the general model outcome on one side and the outcomes of the flood event and flood adaptation scenarios.

TABLE 10: THE RANGE OF THE ECONOMIC IMPACT ON THE FLOODING SCENARIOS.

	Congestion Scenario	**Congestion Measures Scenario**
Positive Economic Development	**2,17**	**1,00**
Neutral Economic Development	**1,73**	**1,00**
Negative Economic Development	**1,40**	**1,00**

Conclusion Congestion Scenarios

The different economic scenarios cause changes in the outputs of the congestion scenarios. Although these economic scenarios influence the outputs, the changes are not significant to influence the preferable congestion scenario. The range of the ratio between the congestion measures and the congestion scenario varies between 1,40 : 1 to 2,17 : 1. The economic impact does not influence the most preferable congestion strategy.

VALIDATION

APPENDIX D

The validation of the model is the check whether the model behaves as it is supposed to. The check is performed by using different inputs in the model and observe its subsequent behaviour. By comparing the expected behaviour and the real behaviour of the model, a conclusion can be drawn on the functioning of the model. If the expected and real behaviour match, the model behaves is considered valid. The behaviour is checked using seven parameters:

- Population
- Housing
- Secondary Sector Business Structures
- Tertiary Sector Business Structures
- Quaternary Sector Business Structures
- Infrastructure
- Land Fraction Occupied

The model validation is divided into four groups. This is done to check the behaviour of the model on different types of changes. These groups are:

- The influence of changes in the input
- The behaviour of the model extensions
- The impact of incidents on each sector
- The behaviour of the full scenarios

The results of this validation check are given below.

RESULTS OF THE VALIDATION CHECK

The results of the validation check are given in Table 1. The table describes the behaviour of the event as described on the seven parameters.

+	Indicates an increasing parameter given the event.
0	Indicates no (significant) change given the event.
-	Indicates a decreasing parameter given the event.

Table 2 explains noteworthy outputs, given the context of the model and the subsequent behaviour. The validation check proves that the behaviour of the model is equal to the expectations. Therefore the conclusion can be made that the model is valid.

Note that for the comparison of the expectations and the model output that the available land area is a constraint. The impact of this influence is taken into account in the expectation.

TABLE 1: THE RESULTS OF THE VALIDATION CHECK.

	Population	Houses	Secondary Sector BS	Tertiary Sector BS	Quaternary Sector BS	Infrastructure	Land Fraction Occupied
Input							
Population		+	+	+	+	+	+
Houses	+		- (A)	- (A)	- (A)	- (A)	+
Business Structures	+	0				- (A)	+
Secondary BS	- (B)	- (A)		- (A)	- (A)	- (A)	+
Tertiary BS	+	+(A)	- (A)		+	- (A)	0 (B)
Quaternary BS	+	+(A)	- (A)	- (A)		- (A)	+
Infrastructure	0	- (C)	+	+	+		+
Extension							
Governmental Funds	+	- (A)	+	+	+	+	+
Economic Waves	0 (D)	- (D)	+	+	+	0 (D)	0 (D)
+ Sec. Sector	- (E)	- (A)	+	-	-	0	0
+ Ter. Sector	- (E)	- (A)	+ (A)	- (F)	-	0	0
+ Quat. Sector	- (E)	- (A)	+ (A)	- (A)	- (F)	0	0
Incidents							
Population increase	+	- (H)	+	+	+	+	+
Housing decrease	-	-	+ (G)	+ (G)	+ (G)	+ (G)	-
Sec. Sector decrease	+ (G)	+ (G)	-	+ (G)	- (G)	-	-
Ter. Sector decrease	-	-	+ (G)	-	- (G)	+	-
Quat. Sector decrease	-	+	+	+	-	-	-
Infrastructure decrease	0	+ (G)	-	-	0 (I)	-	-
Area increase	+	+	+	+	+	+	-
Scenario's							
Flood event	-	-	-	-	-	-	-
Flood Adaptation	0	0	-	-	-	0	+
Congestion	0	0	-	-	-	0	-
Congestion Measures	0	0	+	+	-	-(J)	+

TABLE 2: THE EXPLENATION OF NOTABLE RESULTS.

(A)	Due to land constraints in the model. This land constraint causes an increasing multiplier in one sector to lead to a relative decrease of the other sectors.
(B)	Due to the high business activity per ha. A tertiary business structure takes less space than a secondary structure for example and therefore the influence on the LFO is limited.
(C)	Due to the increase in infrastructure, the attractiveness of the secondary and tertiary sector increases and this leads to a shift in prioritizing. It follows with less space for the housing sector.
(D)	Due to the difference in positive impact of the economic waves
(E)	Due to the ratio between employment per business structure and the ratio of employment per area.
(F)	Due to the already negative multiplier of the tertiary and quaternary sector the increase of this multiplier leads to a steeper descent. This is not taken into account in the expectation.
(G)	Due to the high pressure on the available land area. If area comes available, all sectors will 'expand' and thereby it can lead to a different composition after an incident/event.
(H)	An increase in population leads to a higher available percentage of employees, which positively benefits companies and therefore increase the 'competition' for available land area.
(I)	There is no direct dependency between the quaternary sector and the presence of sufficient infrastructure.
(J)	The congestion measures are taken as a independent from the total present infrastructure. Therefore the overall infrastructure present declines with the implementation of congestion measures.

ANALYSIS OF THE IMPACTS OF FLOODING AND CONGESTION

APPENDIX E

This appendix is an extension of chapter 5 of the main report. This extension shows additional information per scenario. This appendix is divided into two parts; the flooding scenarios (E1) and the congestion scenarios (E2).

APPENDIX E1: FLOODING SCENARIOS

Property Impact of a Flood Event

The property impact of the flood event scenario is based on damage factors. These factors describe the damage to a construction in a percentage based on the water level of the flood. The damage factors used are given in Table 1.

TABLE 1: THE DAMAGE FACTORS (1=100%) FOR BUSINESS STRUCTURES, HOUSING AND INFRASTRUCTURE (GENOVESE, 2006).

Water level [m]	Business Structures	Houses	Infrastructure
0	0	0	0
0.5	0,2	0.06	0,1
1	0,4	0.08	0,2
1.5	0,6	0.10	0,3
2	0,8	0.44	0,4
3	0,9	0.62	0,6
4	1	0.78	0,8
5	1	0.80	1
6	1	1	1

The quantity of flood water is known (1.200.000 m^3) and can be combined with the height map of Rotterdam to determine the percentage of land area hit by the flooding and the water level in these affected areas.

The height map of Rotterdam is combined with a map which indicates the land uses in Rotterdam. This combination provides information on the percentage of affected structures per sector. This sector division contains the housing area, the secondary sector areas and the tertiary sector areas.

The quaternary sector is assumed as evenly divided over the housing and tertiary sector areas due to the unbound character of this sector (e.g. the location of schools and hospitals). Infrastructure is assumed as evenly divided over the entire area. The impact of the 1.200.000 m3 flood event on property is indicated in Table 2. These values are used in the 2015 flood event scenario.

TABLE 2: THE NUMBER OF STRUCTURES AND AREA DEMOLISHED BY THE FLOOD EVENT.

Sector	**Demolished structures** [# structures]
Secondary sector	0,3
Tertiary sector	183,1
Quaternary sector	4,6
Housing sector	205,7
Infrastructure	1,7 ha

Land use

As indicated in paragraph 5.2 of the main report, the land fraction occupied is similar for the general development and the two scenarios. Differences exist in the land usage, as indicated in Figure 1, Figure 2 and Figure 3.

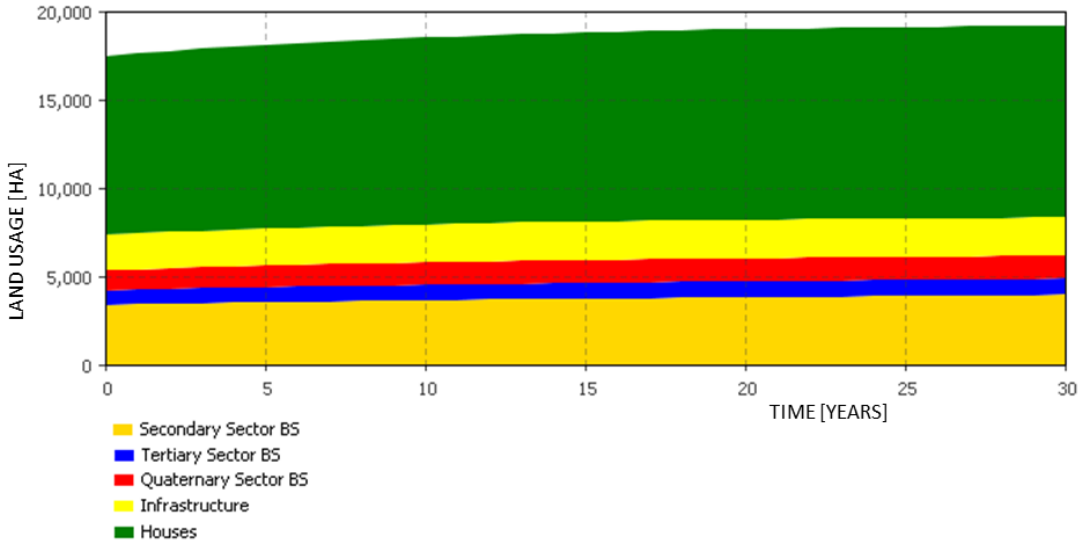


FIGURE 1: THE LAND USAGE IN THE GENERAL DEVELOPMENT.

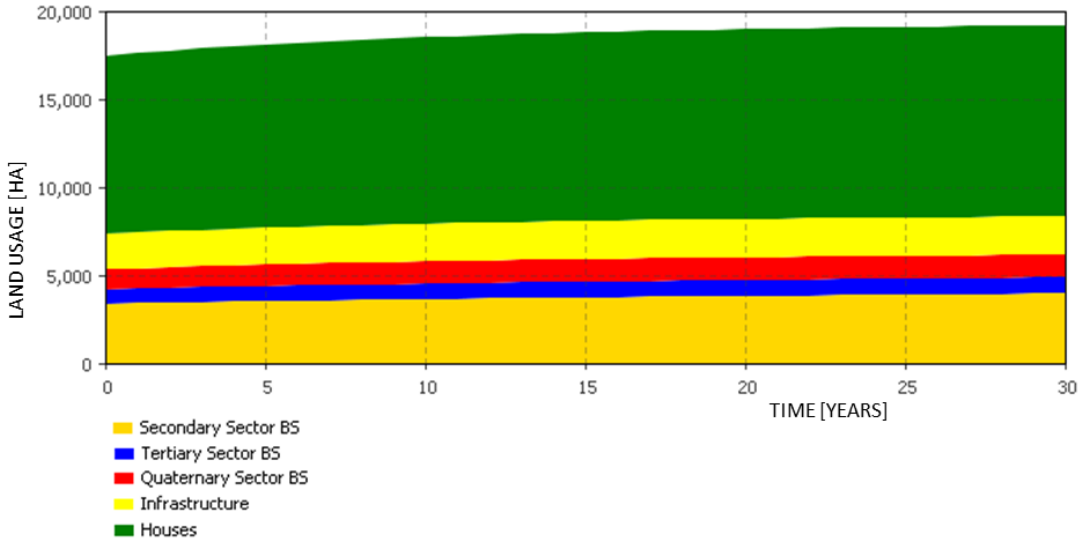


FIGURE 2: THE LAND USAGE IN THE FLOOD EVENT SCENARIO.

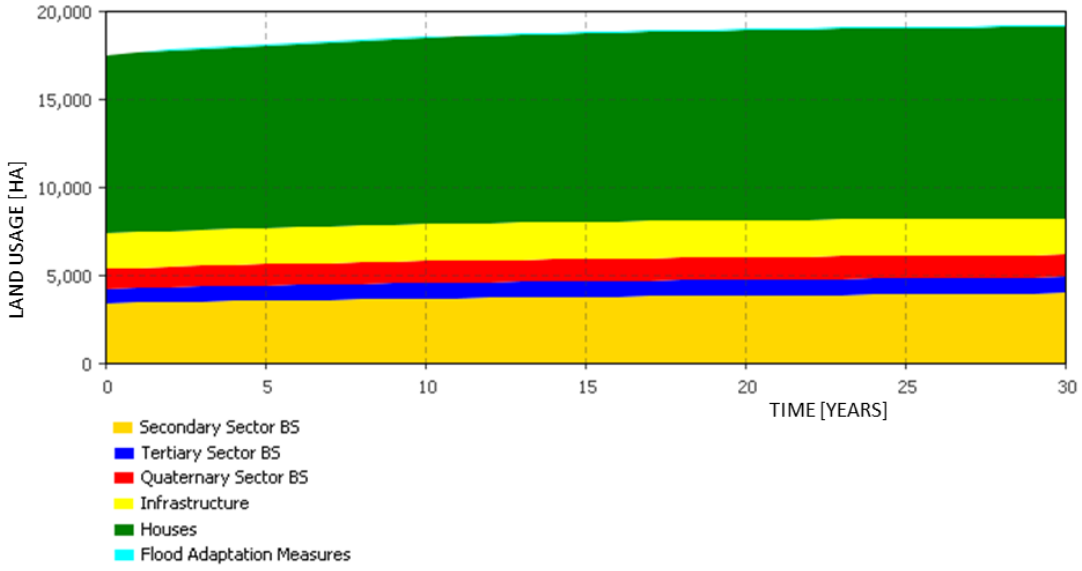


FIGURE 3: THE LAND USAGE OF THE FLOOD ADAPTATION SCENARIO.

APPENDIX E2: CONGESTION SCENARIOS

Scenario

The scenario for congestion is derived from the '*Welvaart en Leefomgeving*' study (CPB, 2006). This study is undertaken by the *Centraal Planbureau*, the *Milieu- en Natuurplanbureau* and the *Ruimtelijke Planbureau*. Goal of the study is to map a variety of possible changes (e.g. aging, individualisation, economic development and migration) and their impact on the physical living environment.

The study describes four scenarios and from these the *Global Economy* scenario is taken as input for the research. This scenario is chosen because of the impact it has on congestion. The scenario predicts population growth, a further European economic and monetary integration, global free trade and economic growth. For congestion it describes an increase in congestion hours of 70% by 2040 (using 2002 as a base year).

Land Use

As indicated in paragraph 5.3 of the main report, the land fraction occupied is similar for all general development and the two scenarios. Differences exist in the land usage as indicated in Figure , Figure and Figure .

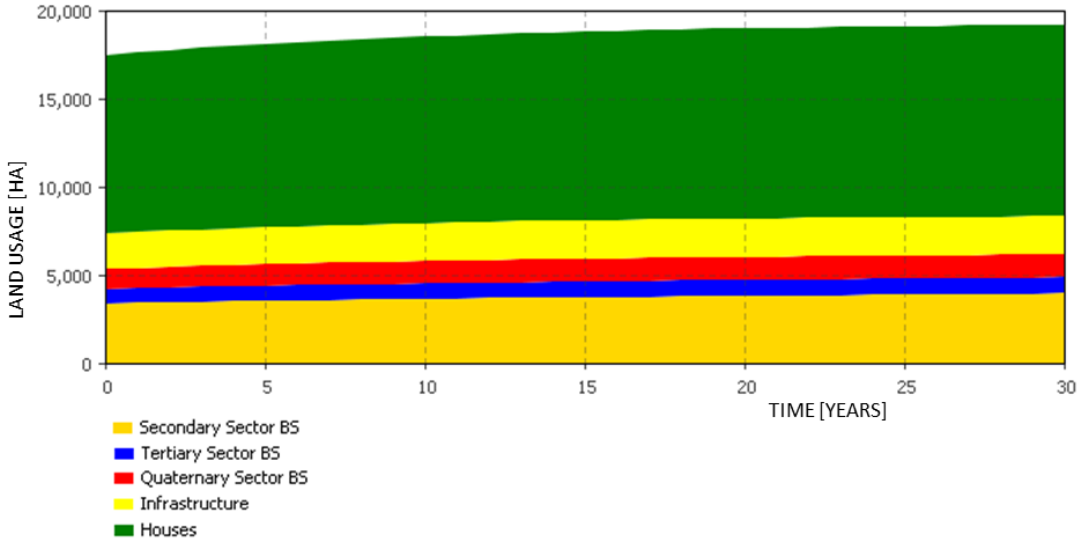


FIGURE 4: THE LAND USAGE IN THE GENERAL DEVELOPMENT.

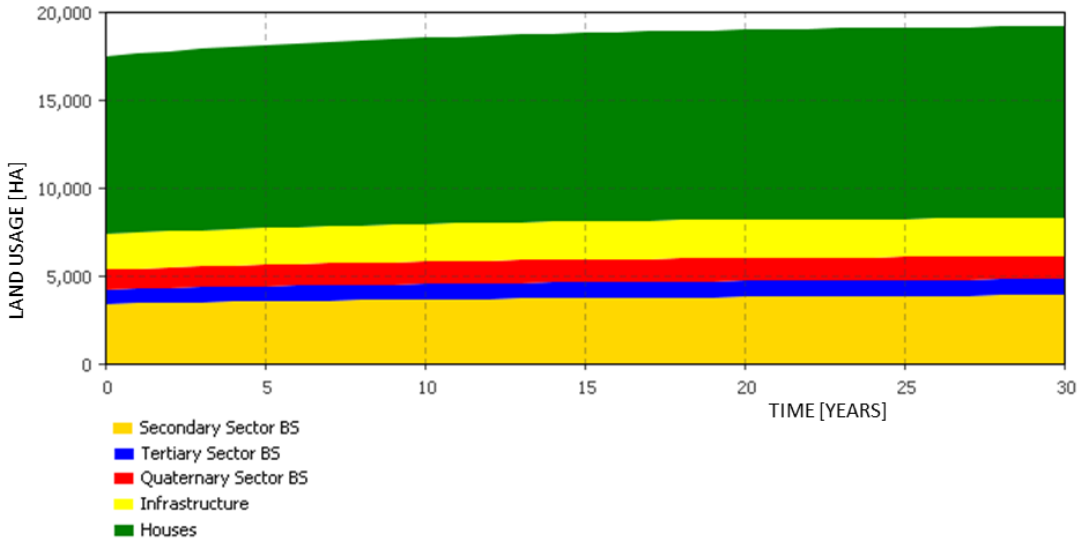


FIGURE 5: THE LAND USAGE IN THE CONGESTION SCENARIO.

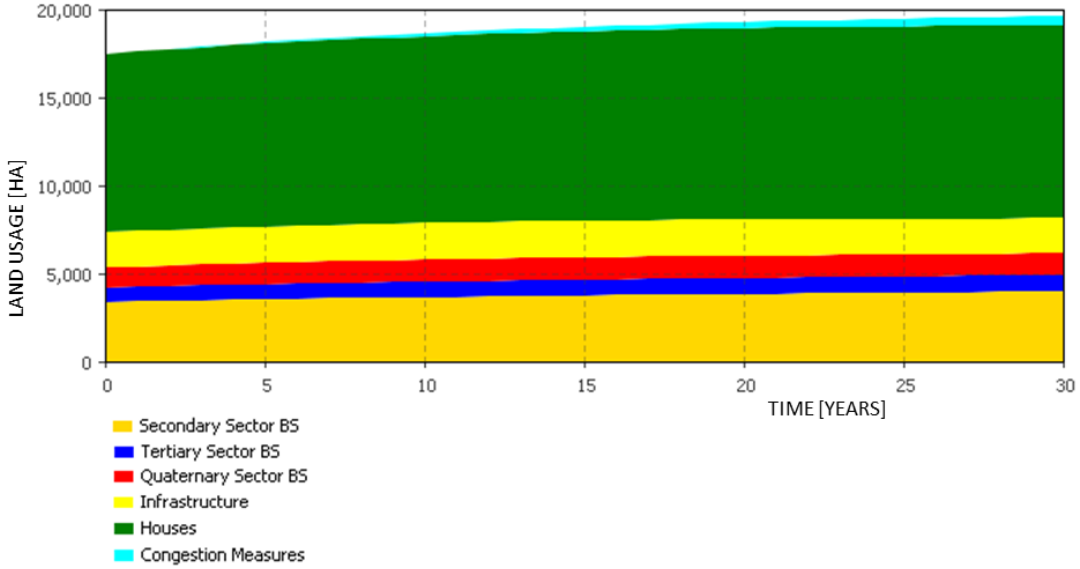


FIGURE 6: THE LAND USAGE OF THE CONGESTION MEASURES SCENARIO.

NET PRESENT VALUE COMPARISON

APPENDIX F

The comparison in the main report is based on the total sum over the 30-year period. The net present value is not taken into account in this calculation, since not all outputs can be converted using the net present value. For the added value of each business sector, the output can be converted in the net present value. This appendix gives the output of this conversion.

The net present value calculation is based on an interest rate of 4,0%. The results for the scenarios are given in Table 1. The time loss costs are added to the congestion scenario.

TABLE 1: THE TOTAL ECONOMIC LOSSES PER SCENARIO COMPARED TO THE GENERAL DEVELOPMENT.

Scenarios	***Flood Event***	***Flood Adaptation***	***Congestion***	***Congestion Measures***
Total (Net Present Value) [million €]	**- 3.701**	**- 2.791**	**- 2.514**	**- 1.752**
Total (No Net Present Value) [million €]	- 6.833	- 5.114	- 5.619	- 3.257

For the ratios this leads to the results as described in Table 2. It can be seen that the extent of the ratios changes, but the preferable scenarios stay the same for each comparison.

TABLE 2: THE RATIOS GIVEN THE NET PRESENT VALUE AND THE COMPARISON WITH THE NO NET PRESENT VALUE SITUATION.

Scenarios	**Net Present Value**	**No Net Present Value** *(main report version)*
Flood event vs. Flood Adaptation	1,33 : 1	1,34 : 1
Congestion vs. Congestion Measures	1,44 : 1	1,73 : 1
Flood Event vs. Flood Adaptation	1,47 : 1	1,22 : 1