Lotte Lourens

Resilient and Equitable Accessibility

Taking into account societal vulnerability in decision making on the placement of flood adaptation policies in an urban setting

TU Delft

Deltares

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TAKING INTO ACCOUNT SOCIETAL VULNERABILITY IN DECISION MAKING ON THE PLACEMENT OF FLOOD ADAPTATION POLICIES IN AN URBAN SETTING

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LOTTE LOURENS

4565371

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CHAIRMAN / SECOND SUPERVISOR	PROF.DR. G.P. (BERT) VAN WEE	TU DELFT
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EXTERNAL SUPERVISOR	DR. M.J.E. (MARGREET) VAN MARLE	DELTARES

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To every era comes an end. After almost 20 years of study, I can now say that I have (almost) finished every step I needed to take to get to the degree of Master of Science. I feel very emotional writing this, something I did not expect to feel so soon already. I am starting to realize that the time of writing my thesis is ending. I'd like to thank the people that have joined me on this journey.

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Lotte Lourens
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Executive Summary

Transportation systems are being put under increasing pressure due to economic developments and increased demand of transportation. When taking into account other factors like climate change, the pressure increases even more as a disruption in the system causes even more congestion in other places. One of the main factors causing this increase in pressure is extreme rainfall events.

Globally, the frequency of extreme rainfall events is expected to increase due to climate change. The past 20 years have been marked at a global scale by a significant increase in pluvial flooding. This increased pressure on transportation systems due to this flooding can be best seen in urban areas where the systems are dense and, therefore, vulnerable to weather-related hazards. Improving the resilience to these hazards has become a vital aspect of managing an urban area that is economically viable as well as livable.

Resilience interventions are being done more often but is not clear yet who will benefit from these efforts. Multiple studies have shown that hazards disproportionally impact low-income and minority communities, as they receive less resources to recover. Furthermore, this disruption often increases inequalities as these socially vulnerable groups are in need of more accessibility compared to other groups. In this research different interventions based on equity principles are therefore compared to understand the impact on the accessibility of different societal groups. The research question has become:

What is the role of different equity principles in addressing inequalities to guide resilient accessibility policy in the context of a rainfall-induced disruption?

To answer the main research question, a methodology has been developed which calculates the accessibility for different societal groups to different destinations. It uses the capacity to resist a disruption as a definition for resilience and models this capacity to resist by showing the accessibility during a business-as-usual scenario, the accessibility after a disruption scenario and accessibility after interventions scenario. A case study of an extreme precipitation event of 70 mm in one hour in The Hague, The Netherlands, will be used to demonstrate the methodology developed.

The accessibility during a business-as-usual scenario is determined by taking the neighborhoods in The Hague and calculating the travel time to the socio-economic opportunities. When a rainfall-induced disruption happens, certain road segments are blocked and therefore the travel time increases as inhabitants of the neighborhood have to take a detour. The interventions taken are location-based and are determined by comparing the routing of the different groups during this business-as-usual case and after a disruption. Then, the different

equity principles, Utilitarianism, Rawls' Theory of Justice & Equal Sharing, are quantified which will show a list of road segments where interventions will need to be placed. After identification of the location of these interventions, the accessibility after the interventions can be calculated after which all the accessibility values can be compared.

The results show that equity principles-based interventions have a clear impact on the accessibility of different societal groups. The effect can be noted both in the travel time after a disaster-induced disruption and in the number of people blocked from their destinations.

During a business-as-usual case, all societal groups show a sufficient travel time based on the concept of a 15-minute city. It is shown that the societal groups living on the outskirts of The Hague have a longer travel time than the groups living in the center of The Hague. The group in the center can be classified as most vulnerable group.

After a disruption scenario, travel time increases significantly for all groups and in some cases, is over 15 minutes of travel. It is shown that travel time for the most socially vulnerable group increases most compared to other groups in the urban area. Besides the increase in travel time, this societal group also has the most people unable to reach a location because the roads surrounding them are blocked. Therefore, they are blocked from their needs.

Different locations of interventions are shown when basing these interventions on different measurements which different policymakers can find important, such as the destinations one wishes to reach or the difference in equity principle. There are road segments that overlap between the different scenarios showing that decisionmakers do not always disagree on the placement of the interventions.

Utilitarianism based interventions decrease the travel time of the general population, but do not specifically intervene on the travel time for specific societal groups. Utilitarian based interventions thus perform well for the general population but do not perform well for the specific groups. The same effect can be seen for the blocked population.

Rawls' Theory of Justice based interventions decrease the travel time for the general population, although, less than the Utilitarian principle would do. Rawlsian based interventions do have a significant impact on the most socially vulnerable group. This principle specifically targets this group. The blocked population also decreases for the most socially vulnerable group.

Equal Sharing based interventions show less impact on the general population than the Utilitarian or Rawlsian based interventions since these interventions are split evenly for all groups and therefore also impact groups that need the interventions less as they have a minor delay due to the disruption. One group shows significance but this group is the smallest group which therefore relatively has the highest amount of interventions per inhabitant.

The results show that simply changing the underlying assumptions of why a certain intervention is placed at a certain location can have an impact on the groups living in the urban area. Decisionmakers should therefore be aware of the impact they want to have on the urban area and pick an intervention that fits the goals they want to achieve. To reduce the inequity in accessibility during disruption, the Rawlsian principle focused on the socially most vulnerable group would be the best fit.

The methodology developed in this research can be used in future studies dealing with accessibility during disruptions. Future studies should use this analysis as a basis to conduct more research on different transportation networks, more equity principles and the usage of a continues time during disruption instead of taking only the scenario right after a rainfall-induced disruption has happened.

Table of Contents

List of Figures

List of Tables

1 Introduction

1.1 Problem context

1.1.1 Accessibility

Having access to socio-economic opportunities, such as employment, education, healthcare services and social interaction is essential for all individuals regardless of their societal background (*Abley, 2010*; *Geurs & Van Wee, 2004*; *Harris, 2002*). Providing inadequate access to these opportunities will constrain specific societal groups' right to basic needs. Communities who disproportionately lack access to the destinations and activities that provide individuals their basic needs are excluded from full and equal participation in society (*Kenyon, Lyons, & Rafferty, 2002*; *Murie & Musterd, 2004*).

Accessibility is a term more often used in literature and can be defined in different ways such as "the potential of opportunities for interaction" (*Hansen, 1959, p. 73*), "the ease with which any land-use activity can be reached from a location using a particular transport system" (*Dalvi & Martin, 1976, p. 18*) and "the freedom of individuals to decide whether or not to participate in different activities" (*Burns, 1979, p. 185*). As groups with a lower societal[1] status suffer from the lack of private and public transport services, they are more dependent on walking and cycling or are compelled to purchase private motorized vehicles (*Barter, 1999*; *Titheridge, Mackett, Christie, Oviedo Hernandez, & Ye, 2014*). This tends to make groups with a lower societal status less mobile (*Lucas, Mattioli, Verlinghieri, & Guzman, 2016*). This lack of mobility can, in turn, limit lower societal status groups' accessibility to socio-economic opportunities such as employment, education, healthcare services, food and social interaction.

In urban areas, accessibility can be used as a way to understand the urban environment (*Handy, 2020*). Neighborhoods in urban areas are often segregated based on societal status

[1] This includes the social, demographic and economic (societal) background

(*McFarlane & Rutherford, 2008*). These neighborhoods vary in the levels of accessibility they offer residents, which adds to the growing inequity between societal groups that have access to socio-economic opportunities and groups that struggle to access these opportunities (*Bocarejo & Oviedo, 2012*). If socio-economic opportunities remain inaccessible to certain social groups, these groups become prone to succumbing to poorer education, unequal employment opportunities, poor physical and mental health and social exclusion (*Glaeser, Resseger, & Tobio, 2009*; *Massey, Condran, & Denton, 1987*).

1.1.2 Transport policies assessment

Transport infrastructure plays a pivotal role in the accessibility of socio-economic opportunities (*Carp, 1988*; *Kwan, Murray, O'Kelly, & Tiefelsdorf, 2003*). Historically, the definition of an infrastructural project's usefulness was mostly measured on its ability to cost-effectively provide access to socio-economic opportunities (*Lyons, 2004*). This definition, however, is due for change as transportation services, despite being designed to be more cost-effective than before, have not improved the accessibility to socio-economic opportunities for everyone (*Lyons, 2004*). Which communities benefit from new transport infrastructure development is inevitably related to the decisions made during government transport planning (*K. Martens, Golub, & Robinson, 2012*). As urbanization has increased an individual's dependency on mobility to access socio-economic opportunities, policymakers in charge of transport planning should, in addition to focusing on cost-effectiveness, think about how the benefits of new transport infrastructure development are distributed (*Lyons, 2004*; *Spinney, Scott, & Newbold, 2009*).

Although policies in the past have aimed to reduce the inequalities related to accessibility in urban areas (*Handy, 2020*; *K. Martens et al., 2012*; *Spinney et al., 2009*), studies show that the groups with the lowest societal status in society do not equally benefit from new or improved transport infrastructures and services (*Booth, Hanmer, & Lovell, 2000*; *Gachassin, Najman, & Raballand, 2010*; *Hettige, 2006*; *Khandker & Koolwal, 2011*; *Van de Walle & Mu, 2011*). This has been assessed by considering the concepts of horizontal inequity and vertical inequity. The horizontal equity can be defined as equity among equals, all getting a fair share (*Rubensson, Susilo, & Cats, 2020*). Vertical equity is equity among unequal's, where equity is assessed between groups formed with different societal backgrounds (*Rubensson et al., 2020*). In these studies, it is shown that people living on the outskirts of an urban area or in rural areas often have less access to socio-economic opportunities while these groups often have a lower societal status as well.

Policies can follow ideas that resemble equity principles. *Behbahani, Nazari, Jafari Kang, and Litman (2019)* state that different ethical principles of equity could be added to the assessment of a policy. These include Utilitarianism, Rawls's theory of Justice, Egalitarianism, Equal Sharing, Narrowing the gap in final benefits, limiting the variance in Added benefits, Sadr's theory of Justice (*Behbahani et al., 2019*). All of these principles are based on a different school of thought and therefore have their own definition of what could be considered equitable. The Gini or Suits coefficient could also be used to assess the equity of accessibility, as has been done by *Rubensson et al. (2020)*. These are not based on a school of thought, but on indices created to assess equality.

Currently, as mentioned, transport policies that are meant to reduce inequalities are often based on cost-benefit analyses, which follow a concept reminiscent of the Utilitarian principle. Utilitarianism aims to optimize the utility for the collective of society. Currently, Utilitarianism is, for instance, evident in cost-benefit analyses (CBAs) (*Pereira, Schwanen, & Banister, 2017*; *Van Wee & Roeser, 2013*), which aim to give an overview of all the pros (benefits) and cons (costs) of a project or policy option, often expressed in monetary terms. CBAs allow evaluation of policies based on their utility to society, however, this is often done without distinguishing the distribution of costs and benefits to different societal groups.

1.1.3 Issues with the current assessment method

An issue with using Utilitarianism is that it often leads to focusing on maximizing aggregate utility for all involved rather than making sure that all groups are equitably considered (*K. Martens & Hurvitz, 2011*). This focus on maximizing utility aggregated over an entire society can lead to both horizontal and vertical inequity. For instance, designing an intervention that reflects the Utilitarian principle may possibly lead to the exclusion of a certain neighborhood with less accessibility, but the outcome of this intervention might still provide the maximum number of benefit to the entirety of society. For example, in recent years, the public transport connections to the outskirts and industry districts of an urban area have decreased to create more connections within the city center of an urban area (*Jeekel, 2011*; *C. J. C. M. Martens, 2000*; *Ong & Miller, 2005*). However, lower societal groups often work in these outskirt areas and are therefore disproportionately affected (*Buunk & Bastiaanssen, 2016*). If policy design keeps correlating with this Utilitarian principle, the inequalities in accessibility and socio-economic opportunities could be maintained or even increased (*Konow, 2003*; *Leroux & Ponthiere, 2013*; *Pazner & Schmeidler, 1978*) as the Utilitarian principle does not consider how the utility is distributed among citizens of societal groups.

Although the Utilitarian principle is the equity principles that is most reminiscent of current decision making,, other ethical principles of equity can also be used to measure the impact (costs and benefits) of a policy (*Van Wee & Roeser, 2013*). Using these different principles requires a different approach for determining the policies which requires more effort for policymakers (*Behbahani et al., 2019*; *Rubensson et al., 2020*). The societal groups would have to be located and used for other equity principles while this is not required when using the current approach. Creating a framework of these principles and assessing the difference in effect will benefit policymakers by allowing them to understand how to incorporate ethical principles into their policy analysis and potentially create more equitable accessibility.

While there have been some studies focusing on the impact of equity principles in normal circumstances (*Nahmias Biran, Martens, & Shiftan, 2017*), only a few studies actually focus on the impact on different societal groups in an urban area during natural or man-made disruptions. These normal circumstances refer to scenarios where a new policy has to be tested for its impact on society and disruptions refer to scenarios where a hazard disrupts the accessibility of an area. There has been little research done on cases focusing on the impact of these equity principles on transport policy in context of climate resilience. These cases become interesting as transportation networks are likely to be disrupted more often due to climate change which impacts different groups in an urban area. The impact of equity principles on resilient transport planning interventions is not well-known. A case study that explores the impact of equity principles on resilient transport planning interventions can offer insights on how policymaking can be shaped to both account for equity and climate resiliency. This can ultimately allow transport infrastructure investments to be made that target objectives from both policy domains.

1.2 Knowledge gap: equity and transport resilience

Transportation systems are being put under increasing pressure by population and economic growth, urbanization, increasing interdependency of infrastructures and natural hazards worsening due to climate change (*Chen & Wang, 2019*; *Schreider, Smith, & Jakeman, 2000*). With regard to the latter, the frequency of extreme rainfall events at a global scale is expected to increase as a result of climate change (*Kasmalkar et al., 2020b*; *Kendon, Roberts, Senior, & Roberts, 2012*; *Pachauri et al., 2014*). Globally, the past 20 years have been marked by a significant increase in the frequency of flood events (*He, Thies, Avner, & Rentschler, 2021*).

The increase in pressure on transportation systems is most pronounced in urban areas where the transport networks are dense and have a high demand. A disruption in the system will cause congestion at many other places. Therefore, they are more vulnerable to weather-related hazards (*Pregnolato, Ford, Glenis, Wilkinson, & Dawson, 2017*; *Singh, Sinha, Vijhani, & Pahuja, 2018*; *Yin, Yu, Yin, Liu, & He, 2016*). Improving the resilience to these natural hazards has become a vital aspect of managing a city that is both economically viable and livable (*Pregnolato, Ford, Wilkinson, & Dawson, 2017*).

Current resilient assessments focus on different costs concerned with disruptions (*Meyer et al., 2013*). They can be split up into two different categories: risk mitigation costs and damage costs. Risk mitigation costs are the costs associated with mitigation measures taken before a disruption. Damage costs consist of direct costs, business interruption costs and indirect costs. Direct costs cover the losses and damage to physical assets. Business interruption costs account for the costs of the economy not being operational, for example, due to working places being flooded or inaccessible. Indirect costs are losses induced by the direct costs and the business interruption costs. Often enough, there is no consideration of the immediate socio-economic losses that are induced by disruption (*Meyer et al., 2013*). Hence, part of the costs assessment should also include an analysis of the distribution of socio-economic losses over different societal groups. The indirect costs could include the different groups but often does not currently (*Meyer et al., 2013*).

Cities have increased their focus on resilience assessments but investments are being made based on losses. Therefore, these cities have stopped short of accounting for the impact of socio-economic losses on different societal groups (*Meerow, Pajouhesh, & Miller, 2019*). Multiple studies show that hazards disproportionally impact low-income and minority communities, that they receive less resources to recover and that this disruption often increases inequalities (*Bolin & Kurtz, 2018*).

A knowledge gap exists on the understanding of the effect of using different ethical principles to decide on the placement of interventions in the transportation network to avoid the blocking of this network (Figure 1.1). A framework that allows policymakers to incorporate ethical principles in their resilience assessments has not yet been produced.

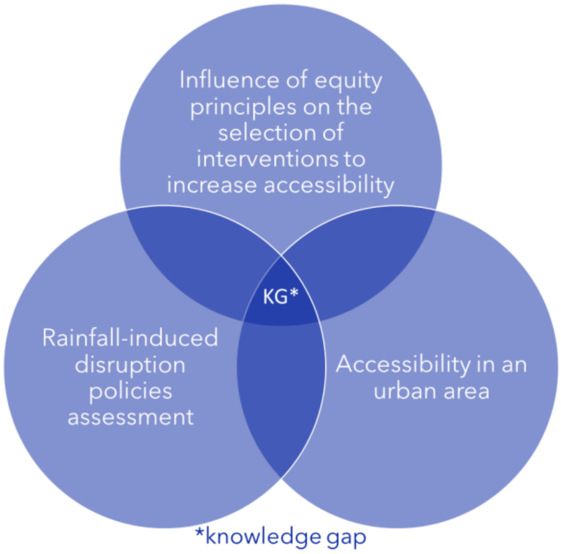

Figure 1.1 Knowledge gap

1.3 Research objective

This study assesses the role of specific equity principles on the outcome of mitigation decisions concerned with improving climate resilience of transport infrastructure. It focusses on one urban area and one precipitation event in three different scenarios: a business-as-usual scenario, an after-disruption scenario and an after interventions scenario. It considers the change in accessibility for different societal groups in the urban area. This helps policymakers to understand how to incorporate different equity principles in their resilient accessibility policies to potentially create more equitable accessibility in the context of a weather-related disruption. The methodology developed in this research can be used in context of different disruption topics and for different transportation networks. It also shows a way to compare the different principles for decision makers.

1.4 Research questions

This will be done by answering the following research question:

What is the role of different equity principles in addressing inequalities to guide resilient accessibility policy in the context of a rainfall-induced disruption?

To answer this research question, multiple sub-questions will be considered.

- What is the accessibility to socio-economic opportunities for different societal groups under normal conditions (business-as-usual)?
- What is the impact of a rainfall-induced disruption on the accessibility to these socio-economic opportunities for the different societal groups?
- How does the decision regarding the placement of interventions change when different equity principles are considered?
- What is the accessibility after a rainfall-induced disruption mitigated by interventions based on equity principles for different societal groups?

1.5 Case study: resilience in The Hague

To execute the research a case study of a 70 mm/h precipitation event in the urban area of the Hague, the Netherlands, is used. This is a 1 in 100-year event which means that this precipitation intensity is expected to occur once every 100 years based on model output, but this does not mean that it cannot happen more frequent. Best is to explain this by stating that the probability of occurrence for this event is 1% per year. Often return periods between 1 in 2-year and 1 in 1000-year events are used for research. The lower the return period is, the more extreme an event will be.

The municipality of The Hague is an urban area in the Netherlands, a developed country with groups of varying societal characteristics (*GGD Haaglanden, n.d.*). The existence of these groups in the urban area fit this research as a clear division between societal status is needed to understand the impact of a disruption on different groups. These groups are needed for the quantification and implementation of interventions based on equity principles as well.

The municipality of The Hague has developed a resilience strategy (*Resilient The Hague team, 2019*). The municipality is strengthening their infrastructure to be prepared for climate related disruptions (*Resilient The Hague team, 2019*), therefore, reflecting on the policies related to resilient accessibility. As the municipality is engaged in resilient policies against weather-related disruption, maps of flooding are available for this case as well (*Klimaataltas, n.d.*).

1.6 Thesis outline

The thesis outline is shown in Figure 1.2. Chapter 2 of this thesis will go into depth on the literature on accessibility, accessibility after disruptions and equity in context of accessibility and define some of the key concepts used in this research. Chapter 3 will discuss the methodology that eventually leads to the answers of this research. Chapter 4 presents the results following the methodology. Chapter 5 will provide some verification for the model. Chapter 6 will discuss the implications of this research. The final chapter will conclude with answering the research questions.

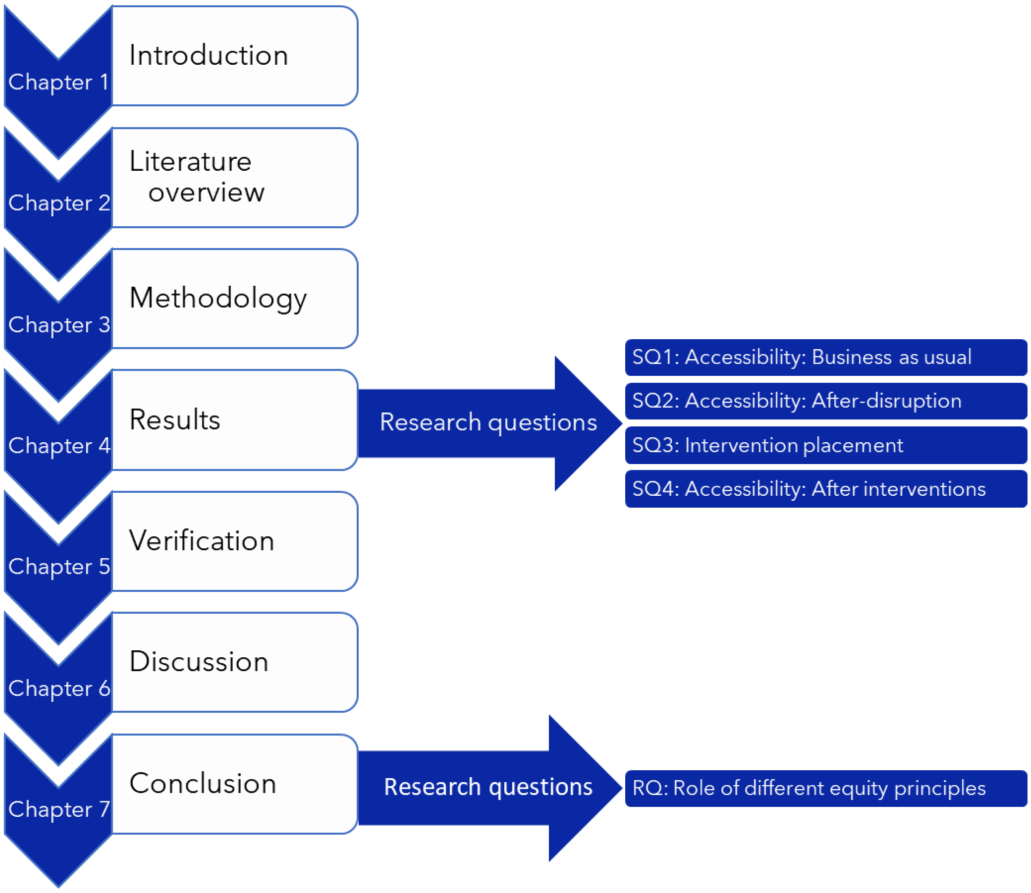

Figure 1.2 Thesis outline

2 Literature overview

To understand what is important for resilient and equitable accessibility policies, some key concepts in literature need to be established. These policies revolve around the concept of accessibility. It is therefore important to understand what the concept of accessibility entails. Accessibility during a disruption is another aspect that needs to be analyzed to understand what exactly is different between the accessibility in a business-as-usual (BAU) case and accessibility after a disruption has happened. Finally, the equity aspect of accessibility needs to be understood. Equity needs to be put in the context of accessibility during disruptions and different ethical principles, that each have their own conception of equity, need to be analyzed. To use these principles the difference between certain societal groups needs to be understood. The literature selected is used for the context of the case study area The Hague which is a city in a developed country.

Literature was selected by using different keywords either separately or in combination with each other. Both Google Scholar and Scopus are used to find literature on the different topics. Snowballing has been used for finding more papers related to a certain topic of a paper as well. The information taken from the literature review is split up into their own topic areas once again. The following paragraphs summarize the relevant information taken from different papers. Table 2.1 shows the selected keywords and their synonyms in the literature review.

The information taken from the literature review is split up into their own topic areas once again. The following paragraphs summarize the relevant information taken from different papers.

Table 2.1 Selected keywords for literature review

Accessibility	Urban	Transport	Equity	Disruption	Resilience	Policy assessment
Accessibility	Urban	Transport	Equity	Disruption	Resilience	Risk assessment
Access	City	Road	Inequality	Weather	Robustness	Cost-benefit analysis
	Cities	Network criticality	Equality	Hazard		Transport policy assessment
			Inequity	Network criticality		
			Social vulnerability	Flood*		

2.1 Accessibility

Accessibility has been used and developed over a long time in urban planning. Most often the definition "a potential of opportunities for interaction" by *Hansen (1959)* is used in accessibility studies. This definition is still very broad. The opportunities can relate to fundamental destinations such as schools, supermarkets (*Farber, Morang, & Widener, 2014*), doctors (*Joseph & Bantock, 1982*), jobs (*Bucci & Russo, 2011*; *Shen, 1998*). The subject for the interaction is not defined and the potential is also not clear. Furthermore, this definition can be used for all different types of transport: bike (*MIRT, 2017*), public transport (*Fransen et al., 2015*), individual car (*Dalvi & Martin, 1976*), etc. Therefore, the definition by *Hansen (1959)* often serves as an initial definition and researchers adapt this definition based on the context of their research.

Since the research of *Hansen (1959)* more studies have been performed on accessibility, broadening the definition and concept even further. Therefore the need for a clear framework was accentuated (*Geurs, 2018*). *Halden (2011)* has broken down accessibility to a framework at the conceptual level in three parts. This framework is used for its simplicity to understand and quantify:

1. What is the subject that is being considered? Accessibility is a property of people or places. Where are the opportunities located? These are the points of interest that allow people or places to satisfy their needs. How is the subject separated from the points interest? These are deterrents or barriers to access such as distance, time, or information.
2. What is measured with the accessibility? The ability to access a place or the ease with which something can be accessed? What is an acceptable threshold for the measurement?
3. What perspective does the study have? The study can use the needs of the subject, perceived accessibility or compare different groups.

2.1.1 Subject, opportunities and separation

The subject being considered in this thesis are the inhabitants of The Hague as this is the case chosen as explained in chapter 1.5.

The location of the opportunities are the places in The Hague that the inhabitants need or the wish to use in an urban area. The opportunities are based on the need or the wish to access certain places in an urban area as well as literature related to spatial equity issues (*Abley, 2010*; *Dempsey, Bramley, Power, & Brown, 2011*; *Geurs & Van Wee, 2004*; *Harris, 2002*; *Lotfi & Koohsari, 2009*; *Taleai, Sliuzas, & Flacke, 2014*; *Tsou, Hung, & Chang, 2005*). This leads to a list of 19 places that are considered a location of a socio-economic opportunity in an urban area (Table 2.2). Cemeteries are not used as this research focusses on the destinations inhabitants might want to reach daily. Places of employment are left out as these places are harder to locate and most of the times, people will not go to the nearest place of employment, but they are willing to travel to work. This makes including employment in this analysis more difficult. All other destinations based on the literature mentioned above are used in this research as a destination. This is done to get a very inclusive idea of the accessibility to different destinations on a day-to-day basis.

The destinations and the origin (subject) are separated by travel time. The travel time is used as it is easily interpretable, can be understood at a global scale and has already been used in previous research with regards to accessibility (*Bhatt et al., 2015*; *Frelat et al., 2016*; *Gilbert et al., 2014*; *Nelson & Chomitz, 2011*; *Schmitz et al., 2012*). The travel time also captures opportunity costs of travel better than network distance and reflects information decision makers use well (*Weiss et al., 2018*).

Table 2.2 Destinations used in different literature that has or has not been used in this research. Employment has been left out of this research as it is difficult to find the exact location of employment of someone as this data is usually private. Cemeteries have been left out as it is not a location most people would visit on a day-to-day basis.

	Destination	*Abley (2010)*	*Dempsey et al. (2011)*	*Geurs and Van Wee (2004)*	*Lotfi and Koohsari (2009)*	*Taleai et al. (2014)*	*Tsou et al. (2005)*
Used	Pharmacy		x	x			
	Doctor	x	x	x			
	Hospital	x		x			
	Supermarket	x	x	x	x		x
	School (primary/ secondary)	x	x		x	x	x
	Kindergarten		x			x	
	Childcare		x			x	
	Bank		x				
	Post office		x				
	Sport		x	x			
	Fitness		x	x			
	Park		x	x	x	x	x
	Pub		x	x			
	Community space		x	x			x
	Library		x	x			x
	Restaurant		x	x			
	Café		x	x			
	Bar		x	x			
	Fast food		x	x			
Not used	Employment	x		x			
	Cemetery						x

2.1.2 Measurement and threshold

Accessibility can be determined in both the ability of access or the ease of access. The ability of access considers the number of opportunities that can be reached within a time limit. The ease of access can also include the concept of proximity of *Halden (2011)*, the number of choices people have in different opportunities of the same category. Both have benefits and drawbacks. The ability of access does not consider proximity but is easier to understand and compare between groups. The ease of access does consider this proximity, but it is harder to interpret. Since the ease of access includes also other harder to model aspects such as comfort and reliability of the transportation mode (*van Wee, Rietveld, & Meurs, 2006*), this research just focusses on the ability to access opportunities. This framework will be used in this research to further quantify the concept of accessibility used.

The research will use the concept of a 15-minute city (*15 minute city, n.d.*) to understand if an opportunity is accessible for the inhabitants of The Hague. When a destination is within 15 minutes of travel, the accessibility is sufficient.

2.1.3 Perspective of study

This study aims to analyze the different accessibility levels between different groups. Therefore, the perspective of this study is to first identify different social vulnerable groups and then compare these. The different needs of these groups (e.g., education, food, etc.) are included, therefore, multiple destinations are considered in this analysis.

2.2 Accessibility after a disruption

Transport is particularly vulnerable to extreme weather and climate change (*Hooper, Chapman, & Quinn, 2014*). Based on previous research of *Koetse and Rietveld (2009)* the transportation network in an urban area is mostly affected by the change of precipitation. Coastal areas will have an increased impact of flooding events due to sea level rise as well.

Precipitation events causing pluvial flooding cause the most lost travel trips for travelers for the public transportation system compared to other transportation networks. The trips will decrease by 73% according to *Han, Zegras, Rocco, Dowd, and Murga (2017)* which used a case study in Boston, United States. Road transportation and walking would have a decrease of respectively 9.9% and 7.8%. This shows that these networks are very dense in an urban area as there are other options to travel towards a destination. Most travelers will shift towards walking when a precipitation event occurs.

In western countries road surfaces take up a large portion of the urban area with 8,5% in London (*O'Hare, 2005*) and 30% in North American cities (*Rodrigue, 2013*). Roads are often constructed from impermeable materials and are therefore vulnerable for flooding, making this portion of the urban area important. Intense rainfall can therefore lead to a rapid surface water flooding. This can lead to a road having a decreased capacity or being entirely unusable (*Pregnolato, Ford, Glenis, et al., 2017*) and therefore people experiencing increased travel times (*Mao, Zhu, & Duan, 2012*). In developing countries, transport disruptions are often aggravated by lack of adequate flood control infrastructure, financial resources, or technical capacity (*Hallegatte, Rentschler, & Rozenberg, 2019*). *Pachauri et al. (2014)*, from the IPCC report, concluded it to be "very likely" that the frequency of heavy precipitation events will increase over most areas of the world through this century. This shows the challenge of guaranteeing reliable transport services.

Flooding is the main cause of weather-related disruption in the transport sector (*Brown, Curley, & Smith, 2014*). Many studies have investigated the increase in travel times for weather-related phenomena by considering the impact of flooding (*Pregnolato, Ford, Glenis, et al., 2017*). Some run models to see the impact on the travel time for all commuters (*Pregnolato, Ford, Glenis, et al., 2017*) which shows an increase in travel times in certain road segments. *He et al. (2021)* shows the impact of flooding on the accessibility of different areas in Kinshasa and translates this into economic costs. The impact on the outskirts is larger as there is a less redundant network in place while more vulnerable groups are living on these outskirts making them even more vulnerable.

2.3 Transport policies assessment

When it comes to resilient transport policies, a few definitions have to be explained to understand the focus of this study. The definition of resilience is needed to understand what effect the interventions in this study need to achieve. Secondly, the focus of the interventions in the network needs to be understood so that it is known what interventions will be used. Next, it needs to be understood how the transportation network will be analyzed to understand the impact of a disruption on the network compared to a BAU scenario. Lastly, the current practice of selecting the intervention will be presented and the selection of interventions based on equity principles will be discussed.

2.3.1 Resilience

A risk can be interpreted as the total reduction in the critical functionality of a transport system (*Linkov et al., 2014*). The risk can be different in different situations due to the threat, vulnerability or consequences for the system (*Linkov et al., 2014*). The risk can be induces by both shocks and stresses. A shock is what is used in this research as it causes an immediate drop in functionality of the system, stresses can slowly but surely weaken a system. A shock can happen due to a disruption in the transportation network due to extreme rainfall. Policies mitigating the risk are often focused on the resilience of the system (*Madni, Erwin, & Sievers, 2020*). Resilience is often explained with the curve in Figure 2.1. The curve shows the events that define resilience. First, the system performance is at a BAU level. A disruption happens that lowers the system performance. The system than recovers to a new performance level.

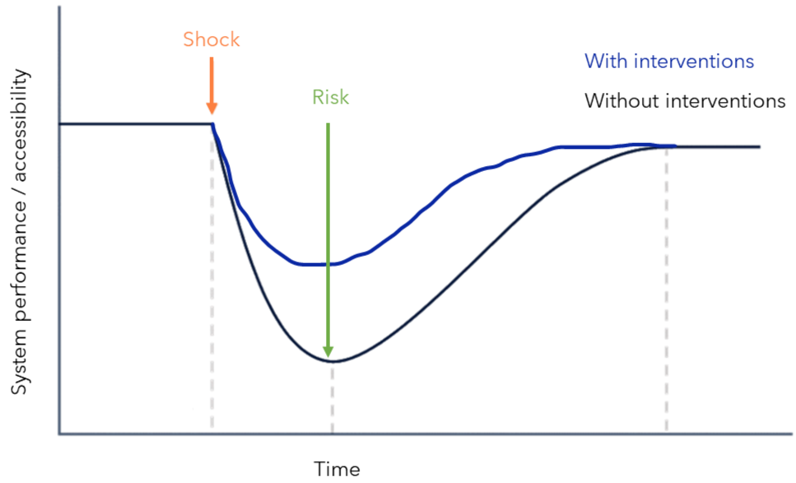

*Figure 2.1 Resilience curve showing the system performance over time (*Robinson, 2020*).*

The definition of resilience used depends on the research. This definition can be categorized into four different groups (*Madni et al., 2020*):

1. Capacity to rebound
   - To what level can the system rebound to the state before a disruption? This can be fully or partially.
2. Capacity to resist
   - How well can a system resist a disruption and keep its performance level high? This could also be called the robustness of the system.
3. Capacity to adapt
   - How well can a system offer a dynamic change to bring back the system performance quicker?
4. Capacity to continually adapt
   - How well can a system continually adapt without getting trapped in unsafe scenarios over time? This is very difficult in practice.

As this study considers three different moments in time, BAU, after disruption and after interventions, the second definition of resilience is used in this research. The travel time mentioned in paragraph 2.1 is the system performance. The interventions will be tested on their ability to resist a shock by keeping the travel time low (Figure 2.1).

2.3.2 Focus of interventions

Once the goal of the intervention is clear, the type of intervention needs to be determined. To improve the accessibility in a city, *Geurs and Van Wee (2004)* state there can be a different focus on the different components of accessibility. This focus identifies four different measures that can be used to improve this accessibility:

- Infrastructure-based measures address the performance of the transport infrastructure which is used in transport planning.
- Location-based measures address the accessibility at locations including competition effects.
- Person-based measures address the accessibility at an individual level such as the opportunities in which someone can participate at a given time.
- Utility-based measures address the economic benefit that people get by accessing activities.

The location-based measure is used to analyze accessibility at locations, mainly on a macro-level. This measure is used to describe the level of accessibility to spatially distributed activities. These measures are most often used in urban planning and geographical studies.

This study focusses on this location-based measure as it uses the location of road segments between the locations as places where interventions can be placed. By using the location-based measures, the research method tries to reduce the risk and keep the performance of the network higher after interventions than after the disruption scenario.

2.3.3 Network criticality

Network criticality can be used to understand what road segments are most important within the network (*García-Palomares, Gutiérrez, Martín, & Moya-Gómez, 2018*). This is done by disrupting a road segment one at a time. The effect of closing this road segment on the rest of the network can be shown. This is called the redundancy of the network. This helps policymakers understand what road segments can make a network vulnerable by, for instance, creating traffic bottlenecks once they are closed off.

This network criticality is currently being used to understand the effect of a disruption due to a hazard happening. Instead of closing down road segment by road segment, a map of a hazard can be used, as has been done by *Espinet and Rozenberg (2018)* and *Nelson et al. (2019)*. Multiple segments based on the hazard are blocked and the impact of this hazard on the network can be analyzed.

2.3.4 Selection of interventions

2.3.4.1 Current practice

Resilient assessments can focus on damage costs or risk mitigation costs (Table 2.3). In current practice, the assessments done often focus on the direct costs of damage and risk mitigation (*Meyer et al., 2013*). Especially the indirect, intangible costs are currently hard to measure and to model (*Meyer et al., 2013*). The focus of this research is to provide more insights into one of these costs: the indirect intangible costs by the effect on different societal groups.

Intervening before disruptions, provides less costs due to damages but more costs upfront. However, these costs will provide benefits in savings. In current practice, these costs are compared with one another to understand if the intervention would be a suitable investment. These comparisons are often done using cost-benefit analyses.

Cost-benefit analyses are an often used as an ex-ante evaluation method in many countries (*Bristow & Nellthorp, 2000*; *Grant-Muller, MacKie, Nellthorp, & Pearman, 2001*; *Hayashi & Morisugi, 2000*). A CBA gives an overview of all the pros (benefits) and cons (costs) of a policy option (*Buunk & Bastiaanssen, 2016*; *van Wee, 2012*). This is quantified in monetary terms as much as possible. Costs and benefits that occur in future years are discounted and presented as a net present value. Oftentimes these are dependent on different scenarios that take into account factors such as the economic and population growth (*Buunk & Bastiaanssen, 2016*). The results based on these CBAs are generally presented with summarizing indicators, for instance the difference between the costs and benefits, a return of investment or the benefit-cost ratio.

Table 2.3 Cost categorization used in resilient assessments according to *Meyer et al. (2013)*.
This research provides more insights into the intangible, indirect damage costs as these are hard to measure and model.

		Tangible costs	Intangible (non-market) costs
Damage costs	Direct	• Physical damage to assets – Buildings – Contents – Infrastructure	• Loss of life • Health effects • Loss of environmental goods
	Business interruption	• Production interruption because of destroyed machinery	• Ecosystem services interrupted
	Indirect	• Induced production losses of suppliers and customers of companies directly affected by the hazard	• Inconvenience of post-flood recovery • Increased vulnerability of survivors
Risk mitigation costs	Direct	• Set-up of infrastructure • Operation and maintenance costs	• Environmental damage – Due to the development of mitigative infrastructure – Due to a change in agricultural practices
	Indirect	• Induced costs in other sectors	

2.3.4.2 Equity principles

In recent years, equitable accessibility studies in transport have emerged to reflect on the consequences in the distribution of transport policies (*Beyazit, 2011*; *K. Martens, Bastiaanssen, & Lucas, 2019*). This field mainly focuses on the question who benefits and who has the burdens of certain transport policies for certain groups within the population. The concepts discussed in this field therefore mainly get their inspiration from distributive justice theories (*Konow, 2001*; *Törnblom & Vermunt, 1999*).

Behbahani et al. (2019) suggests ways of incorporating social equity measures in transport planning using more classical equity principles. This general framework for including equity in infrastructure studies has three steps:

1. Determine the distributable benefit/cost
    - What benefits and/or costs should be considered? The impacts can be classified into two groups:
        i. Added benefits: The way the new benefits are assigned to each person or group by adopting the policy. For example, the extra subsidy that is paid extra to someone is an added benefit.
        ii. The final benefits: The cumulative sum of all the benefits that are already in place and the benefits that are added because of the policy. This is, for example, the subsidy that one had before the new policies combined with the subsidy one would get because of the new policy.
2. Definition and classification of target groups
    - Here proper classification of the society into different target groups that correspond to the nature of the problem of the study is necessary. This grouping can be done based on various factors such as the age, race or income or any other demographic. Another way of classifying is based on travel mode, vehicle type or trip purpose.
3. Selecting the equity approach
    - How will the distribution of impacts be evaluated and prioritized? An equity theory has to be chosen to answer this question. The theory chosen should reflect social values of decision-makers and the communities represented with this policy.

2.3.4.2.1 Determine the distributable benefit/cost

As discussed in paragraph 2.1 this research considers the benefit having a low traffic time to destinations. This study considers travel time as the main way of measurement. The benefit one has is the lowest travel time or the lowest decrease in travel time because of a disruption happening. Since it is both interesting for this study to consider the BAU travel time as well as the travel time after a disruption, both the Added benefits and the Final benefits will be used as a measurement for this study. The Added benefits will be the decrease in extra travel time because of a disruption that one has. The final benefits will be total travel time of the normal travel time with the extra travel time.

2.3.4.2.2 Definition and classification of target groups

In the existing literature, societal characteristics have been defined as determinants of social vulnerability during a disruption (*Koks, Jongman, Husby, & Botzen, 2015*). According to *Blaikie, Cannon, Davis, and Wisner (2005)* and *Cutter, Mitchell, and Scott (2000)* a household's socioeconomic status is a main determinant of this social vulnerability. More wealth increases the chances to prepare for a disruption and to recover from a disruption by having insurance and safety nets. This study will use the income of a household as a proxy for the wealth of a household similar to *Koks et al. (2015)*.

Age is another main determinant for the vulnerability and can affect the vulnerability in two different ways (*Cutter et al., 2000*; *Hewitt, 2014*). Households with younger children have more problems as they can lose time and money caring for children when daycare facilities or schools are affected. Households with elderly have more mobility constraints and may increase the burden of care to others. Families with children below 12 years old and households with a higher percentage of 65 years old people compared to other groups are both considered more vulnerable.

Ethnicity is a factor that can influence social vulnerability because of possible language and cultural barriers which can cause issues after a disruption (*Fothergill, Maestas, & Darlington, 1999*). This study will consider groups with a different ethnic background to be more vulnerable than groups with less percentage ethnic background.

The final factor which is important for finding the target groups is the percentage of single-parent households, as these households have fewer financial means to outsource the care for their children. This can cause a decreased resilience to a disruption (*Blaikie et al., 2005*; *Koks et al., 2015*).

2.3.4.2.3 Selecting the equity approach

Rubensson et al. (2020) use an equity method in which a target accessibility is created. Different groups are plotted against this target accessibility using the Gini-coefficient and the Suits-index. The groups should be as close as possible to this target accessibility and interventions should be placed in such a way that the difference of all groups to this target accessibility is decreased. The accessibility is based on the actual situation in a network deeming some inequality necessary as some places might attract more people than others. Accessibility should then be higher. This is what this method does consider. However, the quantification of this method is rather complex and a lot of data is needed to execute their framework. Therefore, this study focuses on easier to understand for policymakers equity principles that are based on literature.

Behbahani et al. (2019) noted seven equity principles each with their school of thought behind the approach and definition of how to incorporate these principles using the framework created in the paper.

This research has selected three different equity principles for analysis that all have a different school of thought to what is equitable for a society. This limits the selection to Utilitarianism, Rawls' Theory of Justice, Sadr's Theory of Justice as these all have a different school of thought (Table 2.4) and one principle that is based on Socialism which are Egalitarianism, Equal Sharing, Narrowing the Gap in Final Benefits, Limiting the Variance in Added benefits as these are all based on Socialism. As Equal Sharing has a different school of thought than Utilitarianism, Rawls' Theory of Justice and Sadr's Theory of Justice and as this principle focusses on the interventions placed instead of on the final distribution of benefits, which is different from the other principles mentioned, Equal Sharing is chosen as a principle. Sadr's Theory of Justice is left-out as it is a combination of different principles added together and harder to quantify and understand for policymakers. The three chosen principles are elaborated on more below. Utilitarianism is important to include as this principle is reflected in most decisions made.

Table 2.4 Equity principles and their definition as has been used by *Behbahani et al. (2019)*.

Equity principle	School of thought	Motivation
Utilitarianism	Utilitarian, Liberalism, Scholastic Philosophy	To maximize benefits (Utilities) of the society as a whole
Rawls' Theory of Justice	John Rawls	To maximize the benefits of the poorest group of the society
Egalitarianism	Socialism	To maximally achieve equality in the benefits
Equal Sharing	Socialism	To maximally achieving equality in the distribution of benefits in the community
Narrowing the Gap in Final Benefits	Socialism, Deontological, Liberalism, Sadr	To maximize the total final benefits, with the consideration of narrowing the gap in final benefits of the groups in the community
Limiting the Variance in Added benefits	Socialism, Deontological, Liberalism, John Rawls, Sadr	To maximize the total final benefits, with the consideration of limiting the variance in added benefits for all groups in the community (to protect the poor)
Sadr's Theory of Justice	Sadr	To maximize the total final benefits of the society, while ensuring a minimum final benefit for the poorest group, and narrowing the gap in total final benefits

Utilitarianism

Maximize the total utility (benefits) over society.

Utilitarianism has its basis in increasing the aggregated happiness for all people, therefore ensuring maximum happiness for the largest number of individuals. The approach is to increase the maximum efficiency for the entire society with no constraints in the distribution of the happiness.

Rawls' Theory of Justice

Maximize the total final benefits of the poorest group of the society.

According to John Rawls' theory, all basic social advantages should be equally distributed across society unless unequal distribution is in favor of the poorest groups (*Behbahani et al., 2019*). A simpler interpretation is that the benefits should be maximized over the poorest groups of society. What is considered poor, depends on the study being conducted. In this study, groups with a lower societal background are considered 'poor'.

Equal Sharing

The benefits should be divided equally among all groups.

This can be considered as the simplest way to divide the benefits over society. Equal Sharing assumes the equal distribution of benefits among the groups. This method is not meant to establish a uniform society but can be used to reach an approximation of an equal level of welfare when other means of measurement are not reliable.

Table 2.5 Chosen equity principles with definition used in this research. The principles are chosen since they have different ideas on what is the best approach and the fact if these principles are not based of one another.

Chosen equity principle	Definition
Utilitarianism	Maximize the total utility (benefits) over society.
Rawls' Theory of Justice	Maximize the total final benefits of the poorest group of the society.
Equal Sharing	The benefits should be divided equally among all groups.

3 | Methodology

Based on previous research and literature that has been found on accessibility, accessibility after disruptions and transportation policies assessment, a methodology has been developed which combines all different topics in decision making. This includes the usage of network criticality to understand the impact of a disruption and the location-based intervention meant to resist the impact of the disruption. This is done to understand the impact of a disruption on the travel time of the different societal groups. Especially on the most socially vulnerable group. This methodology aims to understand the impact of equity principles on the accessibility to socio-economic opportunities of different societal groups.

A research methodology of four steps has been developed to combine the different aspects. The first step is to understand and calculate the accessibility in a BAU situation in the urban area. This includes identifying the neighborhood origin points and identifying and categorizing destination points. Based on the road network available the accessibility between the origins and destinations, in travel time, is calculated. The second step is to identify what the accessibility is after a disruption. In this step a hazard map (rainfall event of 70mm/hour) is introduced, and its disruptive effect on the network is analyzed. In step three, the locations of the interventions are selected. Different scenarios in which interventions are located, are established based on destinations groups, the location of different societal groups and different travel time types. The destinations categories are created by using Maslow's Hierarchy of Needs. The different societal groups are located by using societal characteristics and clustering the groups. In step four, the accessibility in travel time is calculated again with interventions in place. The travel time after interventions is compared to the travel time after a disruption scenario to understand the impact on both the general population and on the different societal groups. Figure 3.1 Research Flow Diagram shows the research process. These steps will be taken using a case study. This case study is introduced first and the method will be explained using the case study.

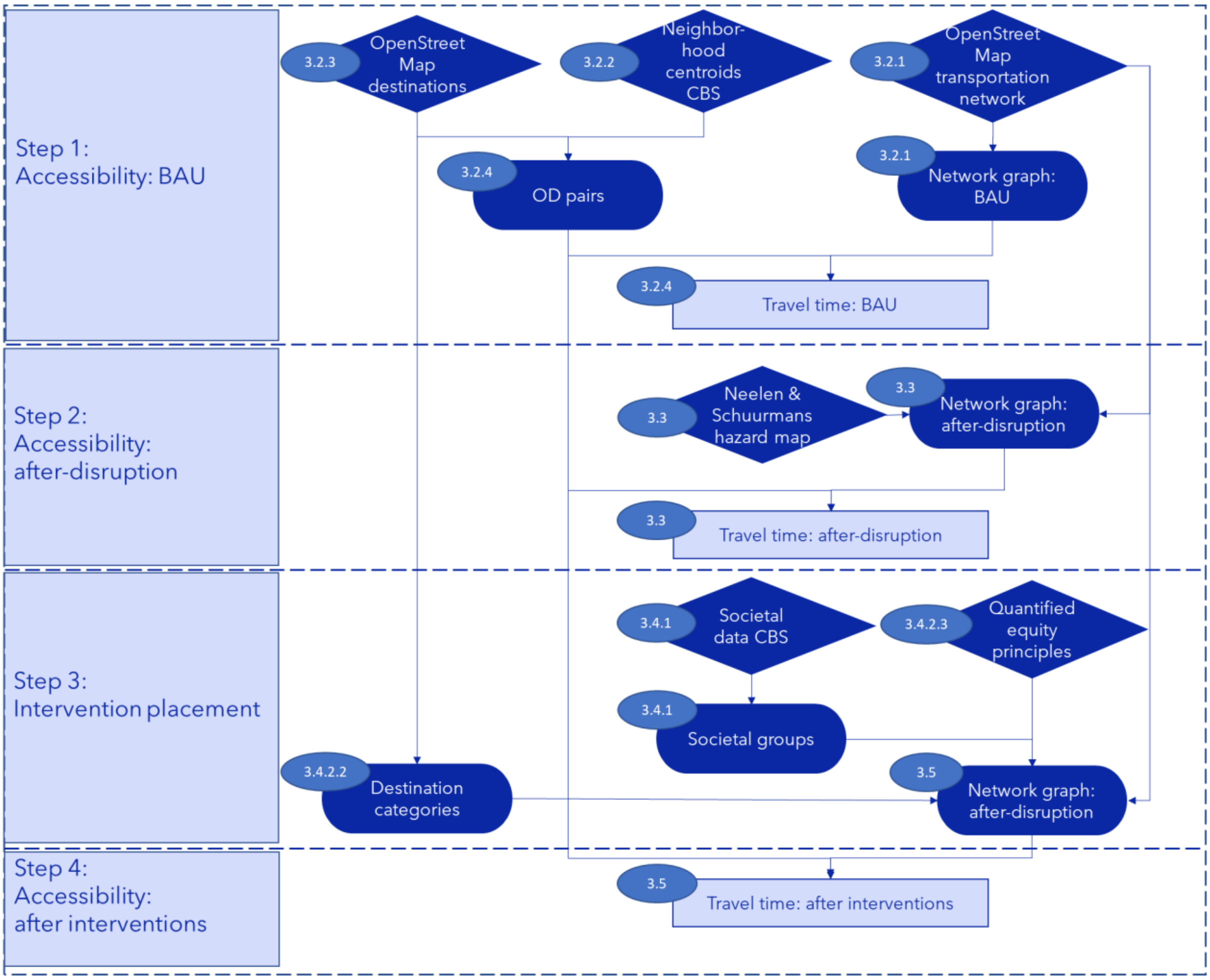

Figure 3.1 Research Flow Diagram.
The diamond shows the input data needed for the analysis, the darker ovals show the different data created in the analysis, the boxes show the different travel times calculated in the model. The lighter ovals show the paragraph in which the topic is discussed.

3.1 Case study: resilience in The Hague

As has been mentioned in chapter 1.5, a case study of The Hague is studied for this research. The Hague is a coastal city with roughly 550,000 inhabitants (*Gemeente Den Haag, 2021*). The total area of The Hague is 98 km^2 (*Gemeente Den Haag, 2021*). The Hague has ten rainy days per month on average with an average precipitation total of 71 mm per month (*Climate-data, n.d.*).

The motivation for the city of The Hague is based on three aspects. Firstly, given all the different components of the methodological framework, it was important that sufficient data is available to execute all the different steps. The Hague has both data on a rainfall-induced disruption and a clear division of societal groups. The second reason is that the municipality of the Hague is working on resilience strategies. This means that results and insights from this study could be of direct use. The last point of motivation for this case study is that as a researcher living in the Netherlands, The Hague is also close to home making it easier to understand what exactly is happening in this area and easier for the researcher to interpret the results of this research.

To understand the redundancy of the network without a disruption, a redundancy analysis is performed. The redundancy analysis in The Hague shows what the extra travel time would be to get from point A to B, when blocking a specific road segment. Figure 3.2 shows that the main roads that connect neighborhoods in the modelled road network area of The Hague are the most critical as they are shown to cause the highest increase to travel time. Road segments within neighborhoods are, therefore, less critical. The network seems to be characterized by a high level of redundancy as there are only a few segments that cause a large increase to travel time. A higher degree of the road network would have to be blocked to notably increase the travel time.

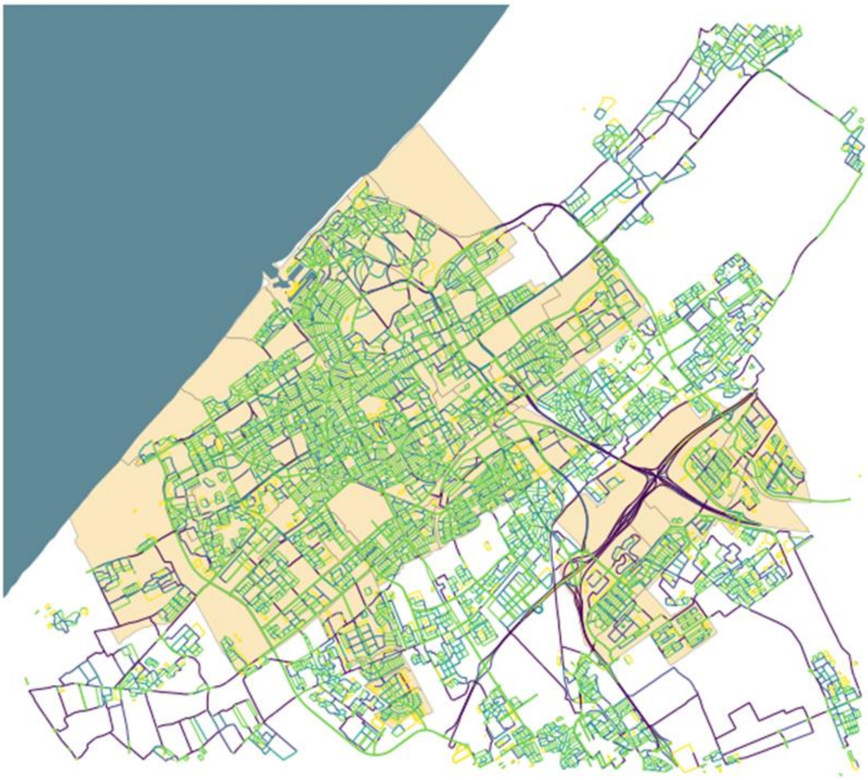

Figure 3.2 Network criticality of The Hague.
The most delay in travel time is caused by the main roads in the urban area of The Hague. The darker the color, the more delay it causes when the road segment is blocked.

3.2 Accessibility: business as usual

The literature review on accessibility showed that three factors are necessary to calculate the accessibility. These three factors are the network, the origin and the destination.

3.2.1 Network

3.2.1.1 Network selection

A scope of which modes of transport and which transport networks are studied as part of this research still must be made. The inhabitants of The Hague are separated from the destinations they wish to reach and transportation methods can allow inhabitants to reach these places. As the public transportation network is heavily impacted by rainfall-induced disruptions as has been argued in chapter 2.2, the public transportation network is not focused on in this study. Additionally, as transport by car is the main way of transportation within the area of The Hague with 42% of trips in 2019 being made by car (*Kennisinstituut voor Mobiliteitsbeleid, 2019*), this study focuses on car transport. Besides that, it can be noted that there is not much of a difference between car ownership in different neighborhoods in the center of The Hague (Figure 3.3) and that these do not one to one correlate with the disadvantage scores shown in Figure 3.4. The municipality of The Hague has created a disadvantage score of their neighborhoods. This score is based on the percentage of inhabitants with a non-western migration background, percentage of inhabitants with social benefits, average income, property valuation (WOZ) and percentage of inhabitants that moved in the last 3 years (*Den Haag, n.d.*). Higher values show a higher level of disadvantage. The values are grouped between below -12, -12 until -6, -6 until 0, 0 until 6 and higher than 6. Figure 3.4 shows the disadvantage scores of the different neighborhoods in The Hague. This classification shows a clear distinction between the different societal groups in the urban area. Especially in the city center the disadvantage scores are higher meaning there are more disadvantage people living here.

The correlation between these disadvantage scores and the number of cars per household does not seem to correlate one to one. A correlation between the city center and outskirts seems more present. Some disadvantaged groups still have cars, while others do not have cars.

Another argument for choosing the road network for cars is that for this type of network it is easiest to determine when the road is blocked or not. Cars cannot easily go off-road when the road is blocked and there is a clear definition of when a road can be considered blocked. Pedestrians can use other networks to walk over (such as greenspaces, sidewalks, etc.) and go off the road network if necessary to go somewhere. It is also not clear where the cutoff point would be of when a road would be blocked or not.

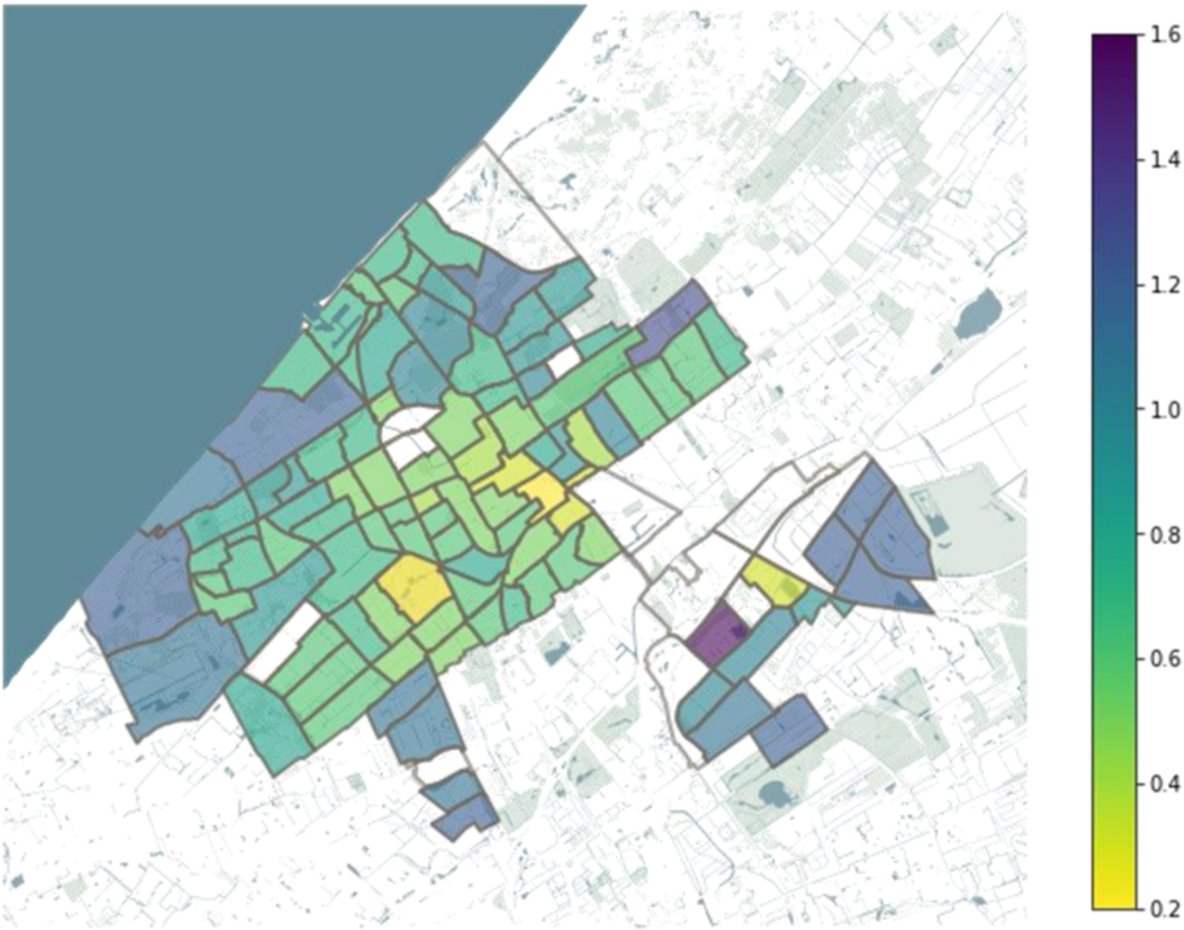

Figure 3.3 Number of cars per household.
Data from CBS showing the average number of cars per household on a neighborhood level.

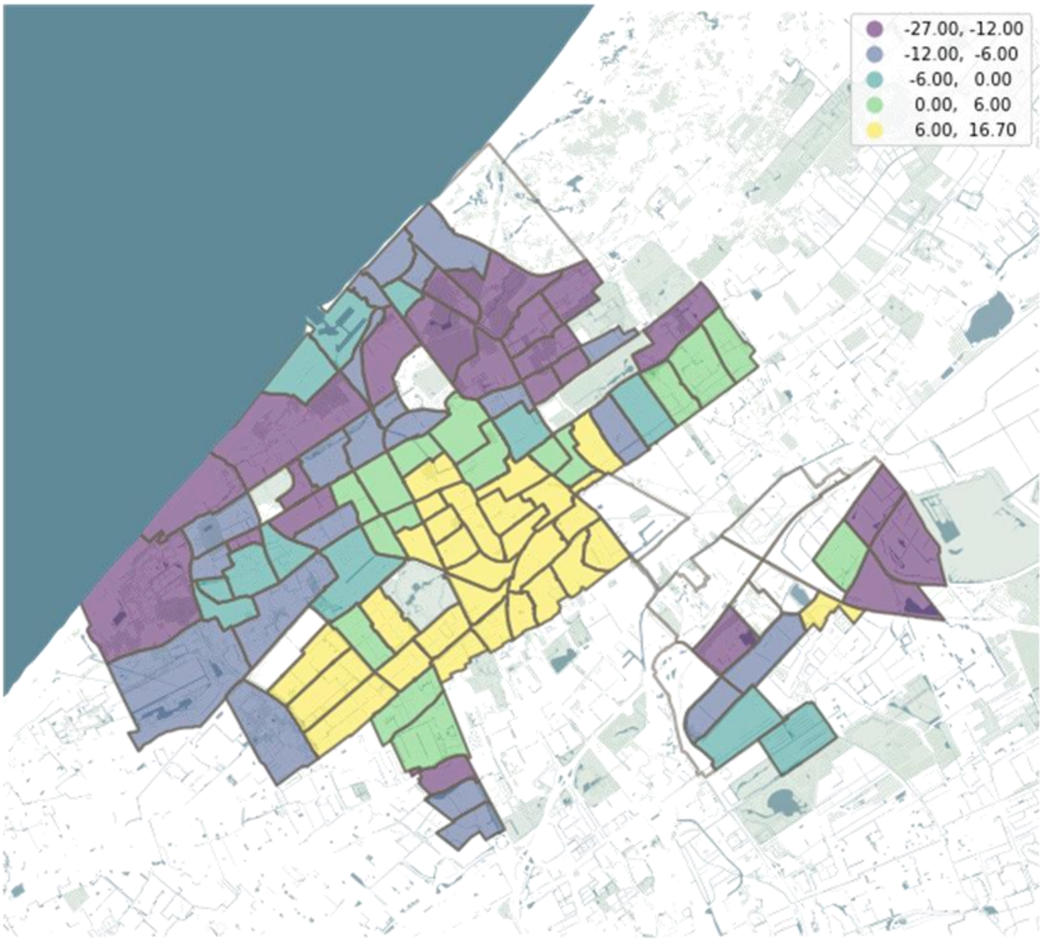

Figure 3.4 Groups based on disadvantage scores.
*The scores are based on percentage of inhabitants with a non-western migration background, percentage of inhabitants with social benefits, average income, property valuation (WOZ) and percentage of inhabitants that moved in the last 3 years (*Den Haag, n.d.*). Higher values show a higher level of disadvantage.*

3.2.1.2 Network modelling

The most well-known method for computing travel times in a network is Dijkstra's Algorithm (*Dijkstra, 1959*) which is used in the network criticality method mentioned in chapter 2.3.3. This algorithm calculates the shortest path between nodes in a graph (i.e., network). Dijkstra's Algorithm is simple to implement and is very well-established in graph-theory. This algorithm uses a graph which has nodes and edges. The main computational limitation for this algorithm is that the graph depends on the origin-destination pairs (OD pairs) that are considered. It recalculates the travel time for every pair which increases the computation time. It is therefore important to keep the number of origins and destinations to a minimum. However, as it is easily implementable and the most widely known algorithm, this is the algorithm that will be used in this research. This algorithm is used in the Risk Assessment and Adaptation for Critical InfrastructurE (RA2CE) platform developed by Deltares. The network criticality module within RA2CE will be used as the basis for the accessibility analysis as it also has the option to use a disruption map which can alter the travel time in the further research.

Dijkstra's Algorithm can be implemented in Python by using the NetworkX package (*NetworkX, n.d.*). This function needs a graph, an origin, a destination and a weight as input and will return the shortest path for this set. The weight used is the performance measure used in this research: travel time.

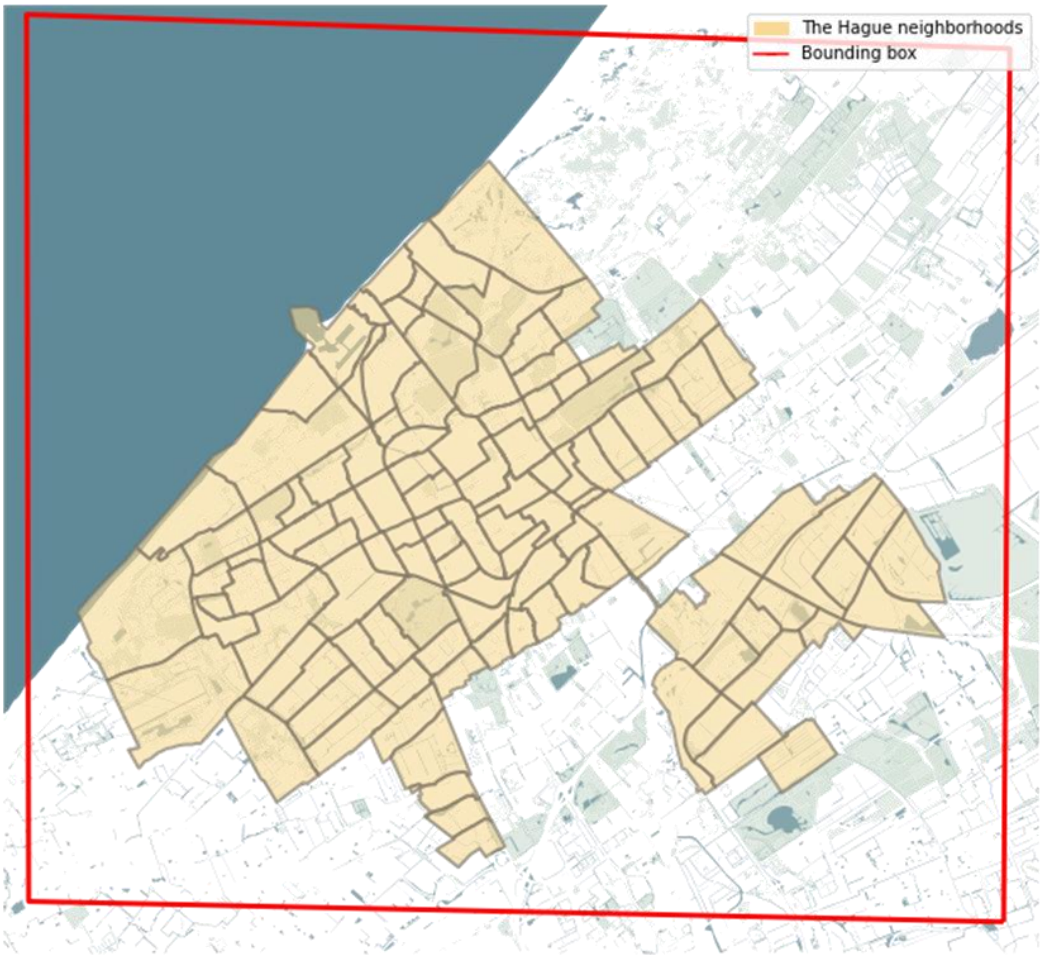

Figure 3.5 The neighborhoods of The Hague and the Bounding box used for the road network.
This bounding box is used for generating the road network for the analysis. If this bounding box would not be used, the eastern part of The Hague would only be connected with one road making it vulnerable for disruptions.

The graph can be created once and can be used for all future OD pairs in the analysis. This graph is created by loading in the network via the OSMnx package in Python (*OSMNX, n.d.*). OSMnx offers different options to create a graph directly from the most up-to-date open-source data from OpenStreetMap (OSM) of the area of The Hague. This package will load in a graph in which the edges of the graph are the roads and the nodes in this graph are the cross-sections of these roads. For this study a graph from a bounding box will be used. Figure 3.5 shows the neighborhoods of The Hague with the bounding box. Figure 3.6 shows the network within the bounding box with all road types: motorway, trunk, primary, secondary, tertiary, unclassified and residential. The Hague has an area at the eastside of the municipal boundaries that are connected to the westside of the city with only one road segment. As this road segment would be vulnerable to disruptions and it can be assumed that people on the eastside will not only travel through municipal boundaries but will use the shortest travel time towards their destination, a bounding box that has edges near the most outer points of the municipal boundaries is taken as a boundary for the network. This is also done to make sure people will use the fastest route available to them to get to their destinations (e.g., highways instead of tertiary roads).

From OpenStreetMap, the speed that can be driven on the roads is given as an attribute to the edge that represents that road segment. This speed limit will be used to calculate the travel time for this road segment by multiplying the distance of this segment with the speed limit.

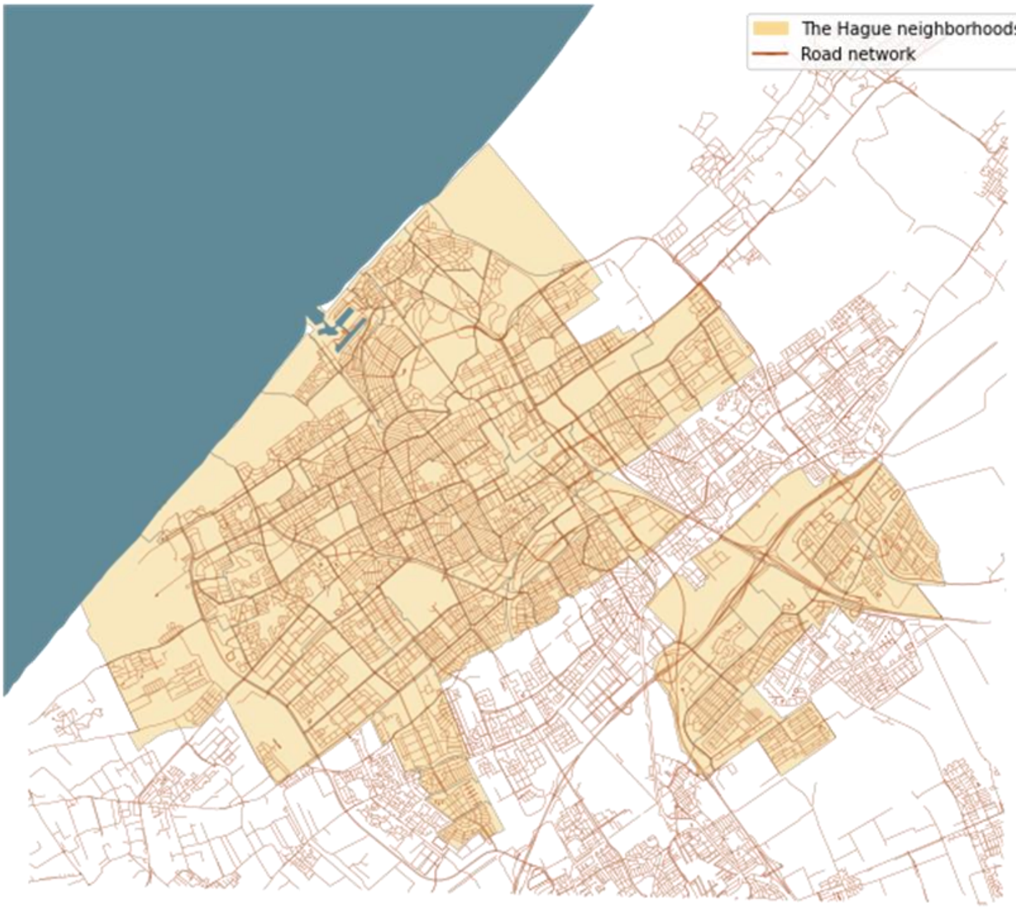

Figure 3.6 The road network in and around The Hague.
This road network will be used for the travel time calculations in the model. All road types in OpenStreetMap are included: motorway, trunk, primary, secondary, tertiary, unclassified and residential.

3.2.2 Origin

The inhabitants of The Hague are the subjects of interest in this research. These people live in the different neighborhoods in The Hague. Since it is computationally demanding to calculate the travel time for every household of The Hague, the neighborhoods will be used as a proxy for all people living in this area as the largest neighborhood is 3,4 km^2 and the smallest neighborhood only 0,1 km^2.

The location of the neighborhoods in The Hague is retrieved from Statistics Netherlands (CBS). The dataset has the name and code of every neighborhood together with the geographical data about the extent of the neighborhood (polygon) which shows the location of this neighborhood. As the travel time calculation demands a specific point, the centroid of every neighborhood will be taken. This can be done in Python by using the Shapely package and using the centroid function. This centroid is not the precise location of every household but will be used as a proxy for the travel time calculations. All the inhabitants of this neighborhood will be assigned to this centroid. So, if a centroid would have 2000 inhabitants with a travel time of 4 minutes to a certain destination, 2000 people would be assigned a travel time of 4 minutes to this destination.

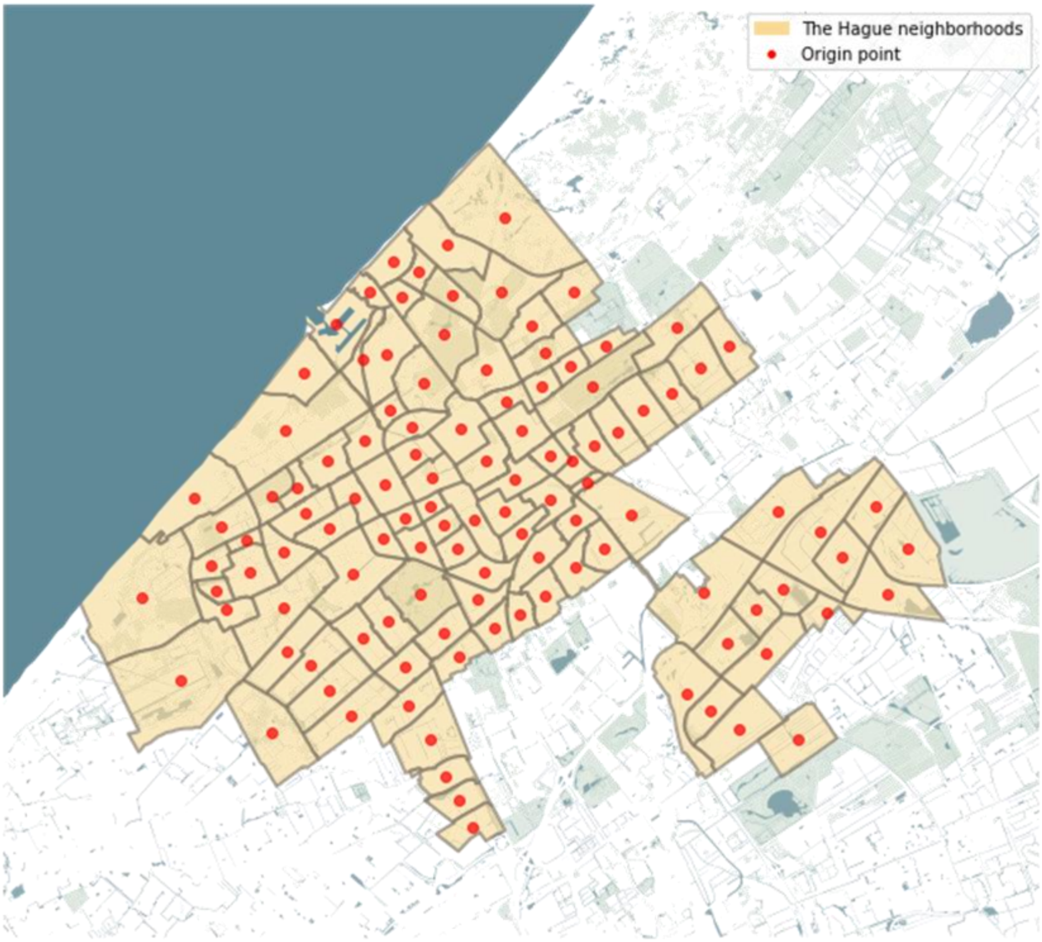

Figure 3.7 The centroids of the neighborhoods in The Hague.
These centroids will be used as the origin points in the travel time calculations.

3.2.3 Destinations

The destinations are the opportunities for the people living in the municipality of the Hague. These opportunities have been determined in subchapter 2.1.1. These location of these datapoints can be retrieved from OSM. OSM has datapoints for certain amenities. Every amenity has a tag. This tag says something about the location of the amenity. The amenities for a place with certain tags can be retrieved with the OSMnx package in Python (Appendix A Destinations).

The OSMnx package offers the function *geometries_from_place* in which the location name and the tags can be used as input. As The Hague is the area of interest, this will be used as the input place. Appendix A Destinations shows the location of all destinations. These destinations are all used for calculating the travel time from the origin to the destination.

3.2.4 Travel time calculation

The redundancy introduced in subchapter 2.3.3 is calculated to get an initial feeling for how vulnerable the network is to disruptions. After this analysis, the travel time for the general population in The Hague can be found and used for the further analysis.

The travel time for each neighborhood will be calculated towards each destination by using the graph of the road network in The Hague as input, the centroids of the neighborhoods and all different destinations by amenity type.

The model will go through all origins for a destination of a specific category and will save only the five closest by destinations (with travel time) of every amenity type. This is done as it can be assumed that not all people go to, for instance, the same supermarket, but they will split themselves across the 5 closest supermarkets. For example, the model uses as input the graph of the road network of The Hague, the centroids as origin points and all different supermarkets as destination points. For an origin point, the shortest travel time to all supermarkets will be calculated by Dijkstra's Algorithm. Once the shortest travel time to these destinations has been found, only the five destinations with the shortest travel time for this origin point will be saved. Five will give a neighborhood the option to choose from different supermarkets as they might prefer one supermarket over another, but it will decrease computational power in the further analysis. Once this has been done for one origin point, the next origin point will go through the same cycle. This will be done for all destinations.

3.3 Accessibility: after disruption

For the calculation of travel time after a disruption, data on the impact of a disruption is needed to combine this with the graph of the road network. Figure 3.8 shows the data on the weather-related disruption that will be used for this research. The data on the disruption is retrieved by downloading open source data with water depth after a 70 mm/h precipitation event at a 0.25 m^2 from Neelen & Schuurmans (*Klimaataltas, n.d.*). For the municipality of The Hague, Neelen & Schuurmans has run a flood model in which they take a 2D terrain model to understand where water will accumulate. This terrain model uses information on land use, ground composition and takes the drainage via sewage and open water into account. This model can show what the flood depth would be after a precipitation event of 70 mm in one hour. This is the same amount of rain in one hour as would normally happen in one month in The Hague. Such a precipitation event is expected to occur once every hundred years and is likely to result in pluvial floods that potentially disrupt an urban road network. However, due to climate change, these events are more likely to happen. The data is available at a spatial resolution of 0.25 m^2. Figure 3.8 shows the flood depth after the precipitation at a 0.25 m^2 resolution. The minimum is 0 meters and the maximum flood depth is 1 meter.

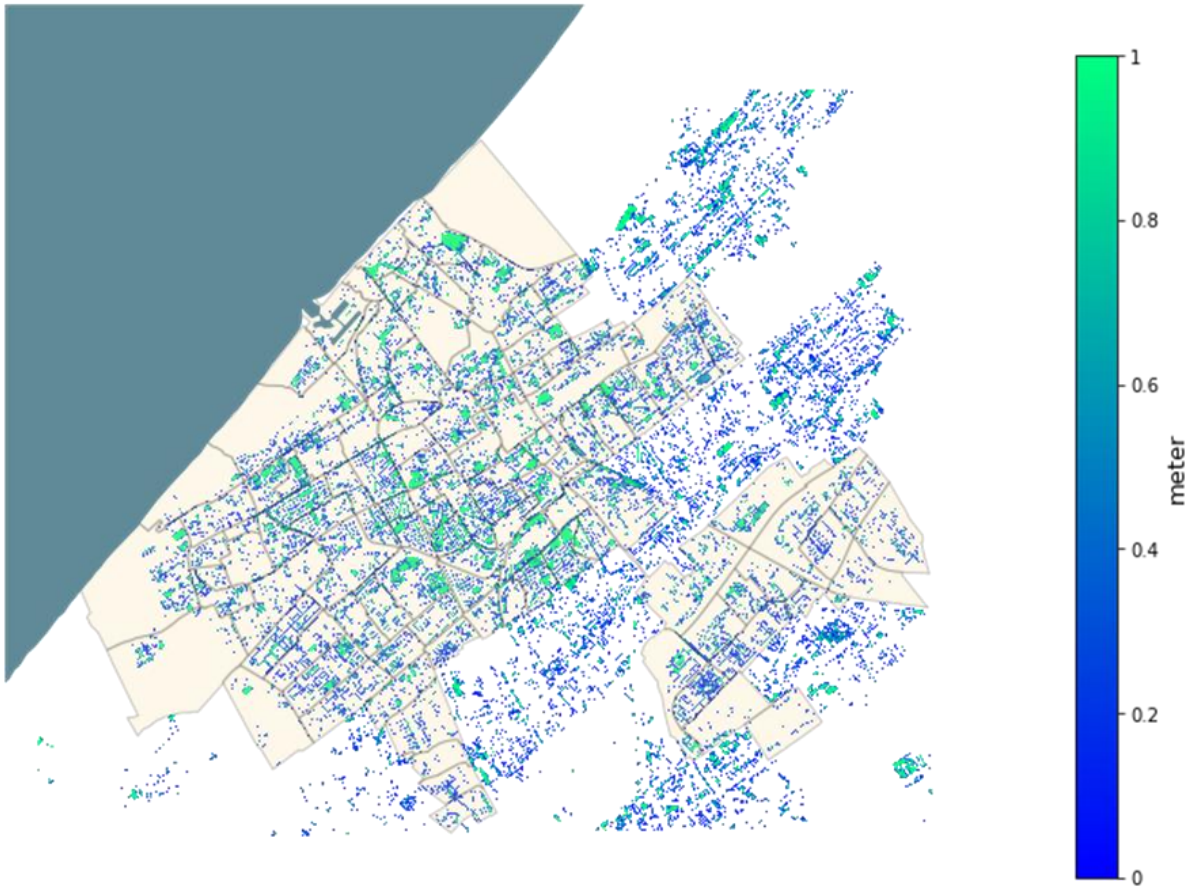

Figure 3.8 Water level after 70 mm/h precipitation in The Hague. This precipitation is measured at 0,25 m^2 resolution. The data of this event will be used as the disruption data for the accessibility model.

The data on flood depth needs to be combined with the graph of the road network of The Hague to calculate the travel time after a disruption. According to *Kasmalkar et al. (2020a)*, the road network will not be accessible for most type of road transportation vehicles if the level of water is over 0.3 meter (12 inches) as calculated by their model. Therefore, the assumption is made that once the water level is over 0.3 meters somewhere on the edge in the graph, this edge should no longer be accessible and the edge is removed from the graph for the travel time calculations (Figure 3.9). If the edge has a lower water level, no impact is made on the travel time across this edge. This is the same assumption that Neelen & Schuurmans (*Klimaataltas, n.d.*) made in their model.

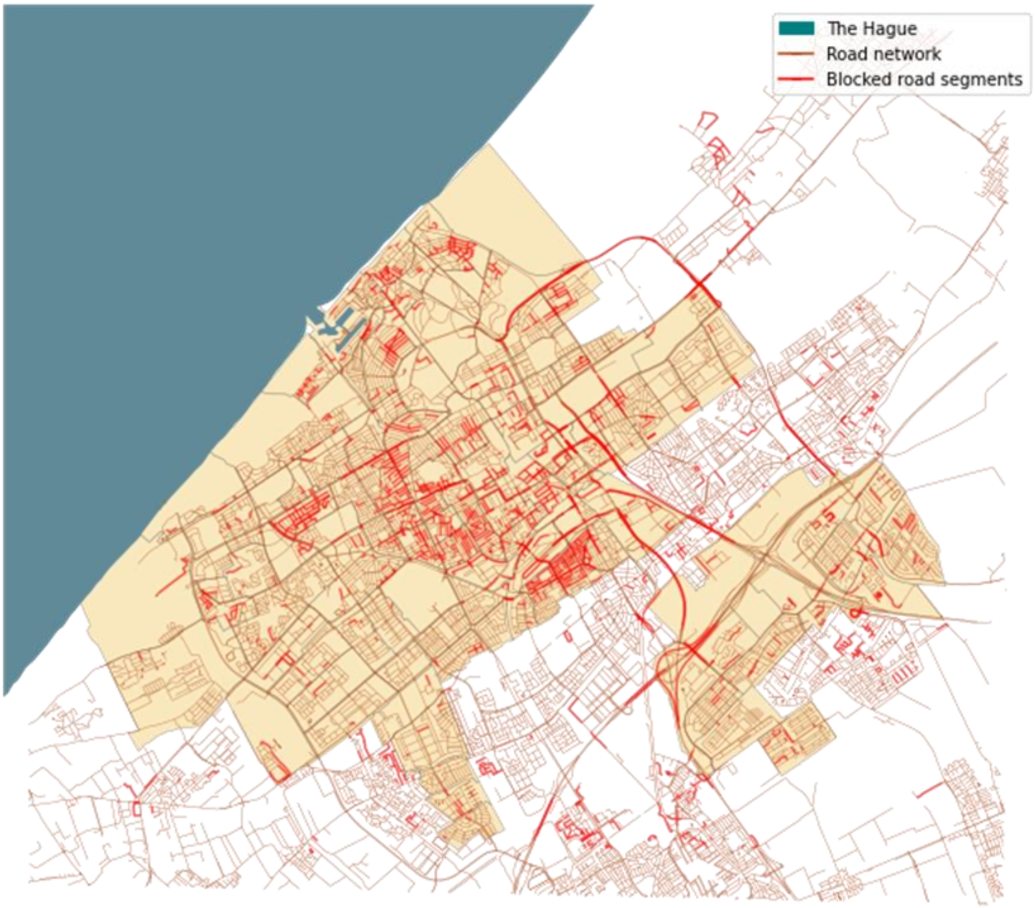

Figure 3.9 Road network and blocked roads after disruption in The Hague. The blocked roads are no longer used in the travel time calculations after the disruption. The orange roads are left for this analysis.

The travel time after a disruption is calculated the same way as in paragraph 3.2.4, however the new graph with the removed edges after the disruption is used. To save computational time, only the five destinations with the shortest travel time selected in the BAU accessibility calculations will be used as the available destinations for an origin point. For instance, for the Rietbuurt neighborhood in The Hague, five supermarkets were found with the shortest travel time. After a disruption, instead of finding five new supermarkets, only the travel time to these supermarkets will be calculated. The routing might change as some edges (roads) have a water level of over 0.3 meter. Once the routing from the Rietbuurt to these supermarkets has been calculated, the next neighborhood will go through the same process.

It is possible that a neighborhood is completely blocked off from destinations as there is no road for them to travel to a different neighborhood anymore. In this instance, an hour will be added to the travel time of a destination as it is assumed that it might take an hour for the roads to be cleared again and the people to move again from their destination. An hour also shows the significance of being blocked from your destination.

3.4 Placement of interventions

3.4.1 Socially vulnerable groups

To apply equity principles, different societal groups have to be located in The Hague to know which ones could be considered more vulnerable than other groups. These groups are based on societal data from CBS. CBS has societal data on the neighborhood level for The Hague.

The grouping of disadvantage scores (subchapter 3.2.1.1) is not used in this research as the scores are based on percentage of inhabitants with a non-western migration background, percentage of inhabitants with social benefits, average income, property valuation (WOZ) and percentage of inhabitants that moved in the last 3 years (*Den Haag, n.d.*). Literature shows that other factors as the average age, the average number of children, the wealth level or a foreign ethnic background should be considered as this can make groups more vulnerable during disruptions.

In Appendix B, the societal characteristics used in the analysis are shown. The most recent and complete dataset is the data of 2019. Data on household composition, age, income, education and ethnicity is used to classify the different groups in The Hague.

This dataset is cleaned by removing neighborhoods with no datapoints, as there are some neighborhoods in The Hague that just have a park area and no inhabitants, and scaling all the data between 0 and 1 for the further analysis.

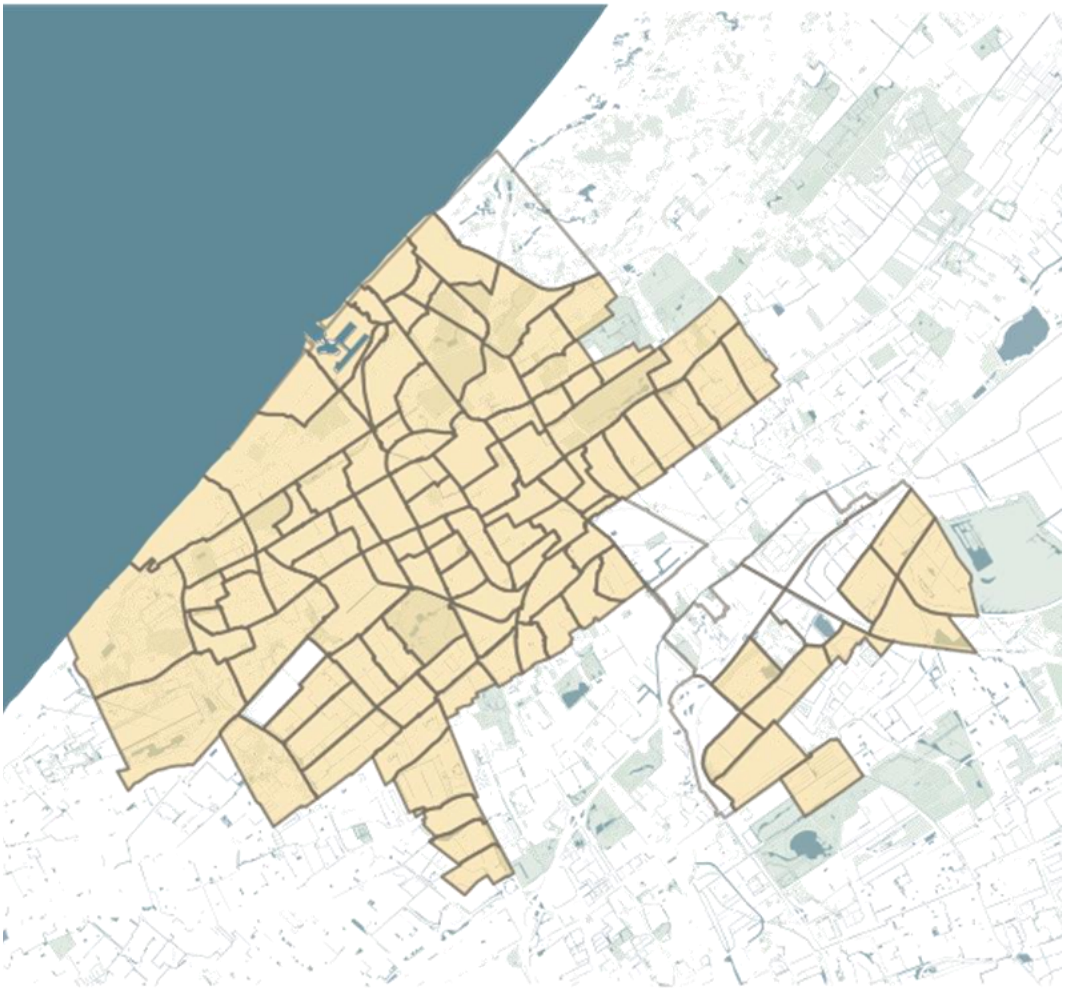

Figure 3.10 Neighborhoods in The Hague used for determining socially vulnerable groups.
After removing neighborhoods with no datapoint, some neighborhoods are left out of the analysis. The figure shows the borders of The Hague and the colored in neighborhoods are the ones used in analysis.

3.4.1.1 Determining the location of groups

3.4.1.1.1 Reducing noise in data

Once the data is cleaned, a Principal Component Analysis (PCA) was performed to reduce the noise in the dataset and bring back the number of components from 36 to a smaller number. PCA aims to reduce the dimensions of the data so that the clustering can be done more precisely and does not include variables that have a similar correlation. PCA tries to explain the variance by combining different variables together and thus creating only a few dimensions that can explain most of the variability within the variables. The PCA will create several components until 95% of the variance can be explained by the components. The Scikit-learn package will be used with the PCA function for the PCA. After the PCA, the groups will be found using the Density-Based Spatial Clustering of Applications with Noise algorithm (DBSCAN).

3.4.1.1.2 *Grouping the different neighborhoods*

The DBSCAN algorithm computes the distance between one point and every other point. All points are then placed into three different categories:

- Core point: A point that has a minimum number of other points within a certain distance around itself.
- Border point: A point that does not have a minimum number of other points within a certain distance around itself but does have a core point within this certain distance.
- Noise point: A point that is neither a core point nor a border point.

The core and border points together form different so-called clusters. The noise points are points that are not part of a cluster.

The clusters will be found by inputting the PCA component values for the neighborhoods. DBSCAN is suited for problems which require minimal knowledge of the domain to determine the input parameters and have larger databases that need good efficiency. The DBSCAN algorithm needs only three input parameters: epsilon, minimum samples and the metric. The metric is what is used to calculate the distances between points in an array (for example Euclidian distance). This is set to the Euclidian distance.

The epsilon groups together points if the distance between the points is below the threshold epsilon. The epsilon can be found by calculating the distance from each point to its neighbor with the *NearestNeighbors* function in Python. This function returns the distance to the closest neighbors. Plotting this and looking at the point of maximum curvature can tell the value for this epsilon.

The minimum samples are the number of neighbors a point should have to be considered a group. This value is set to three as there need to be three neighborhoods in a cluster for it to be considered a cluster. Otherwise, the groups would be too small.

The algorithm creates several clusters based on these variables. Points that cannot be put into a cluster are classified as noise.

After the DBSCAN algorithm, a visual analysis will be done to understand how the groups score on the variables that were used as input in the beginning (age, education, etc.). Every group will be assigned their own label for future analysis. Groups that have multiple variables aligned with what literature considers to be a main factor for vulnerability, will be marked as more vulnerable than others.

3.4.2 Quantification of equity principles

The output of the previous travel time calculations will be used as input for the quantification of equity principles. After a disruption the model outputs different travel times which can be used for this quantification. The output shows the travel time between different origins and destinations before the disruption (BAU) and the extra travel time that is needed between these origins and destinations after the disruption. It also shows the route that was taken between these origins and destinations before the disruption (BAU) and the route that was taken after a disruption. All this information is needed for the quantification of the equity principles.

Three different principles are used in this study: Utilitarianism, Rawls' Theory of Justice and Equal Sharing. The quantification of each principle will be used to mark road segments which need interventions according to this principle. This research uses the location-based interventions on the road network of The Hague as has been mentioned before in chapter 0. These interventions include infrastructural measures that prevent the previously flooded roads from flooding.

Different intervention scenarios will be analyzed. The interventions will be analyzed for the following categories (Table 3.1). The categories will be explained in the coming paragraphs:

- Based on added travel time versus total travel time
- Based on need for travel
- Based on equity principle

Table 3.1 Different categories used for the intervention sets.
These are the categories with the respective categorical variables that will determine the number of intervention sets that will be run in the analysis. In total 18 different interventions sets are created.

Equity principle	Travel time type	Destinations
• Utilitarianism • Rawls' Theory of Justice • Equal Sharing	• Added travel time • Total travel time	• Physiological needs • Safety and Security needs • Social needs

3.4.2.1 Travel time type

The added travel time versus total travel time is the difference of how the impact of an intervention is measured. The total travel time is a measurement to place an intervention based on the total travel time after a disruption (normal travel time plus extra travel time because of the disruption). The added travel time is a measurement to place an intervention based on the extra travel time because of the disruption. Both could lead to different results as the total travel time scenario might prefer interventions based on a travel time that would already by long in a BAU situation while the added travel time scenario focusses on the extra travel time because of a disruption.

3.4.2.2 Destinations

Not all destinations could be considered of equal importance to an inhabitant of The Hague. One could argue that improving one's accessibility to a restaurant is less important than improving another one's access to a supermarket. Maslow's Hierarchy of Needs (Figure 3.11) suggests five classes of needs that are hierarchically organized in importance for a human being (*Maslow, 1970*) and has been more often used in disruption-related research (*Cannon, 2008*; *Lavin, Schemmel-Rettenmeier, & Frommelt-Kuhle*). They are in a pyramid form of layers that portray the importance of every layer. The first layer is called Physiological Needs and includes everything needed for the biological survival of an individual. This entails food and water sources as well as the health for people. The second layer is for Security and Safety

Needs. This includes what is needed for an individual to live a good life: protection from elements, law, stability, etc. The third layer includes everything for Social Needs. A human does need social interaction and wants feelings of belongingness. Friendship, trust, acceptance is what can be included in this category. The fourth layer is the Esteem layer. This layer can be split up into two categories: esteem for oneself and the desire for respect from others. This layer is the most important for children and adolescents who are relatively more in the process of personal development than other people. The final fifth layer is the Self-actualization layer. This layer is realizing one's full potential, having self-fulfillment. The first two layers are considered the basic needs of human beings (*Mathes, 1981*). The last three layers are more of a luxury.

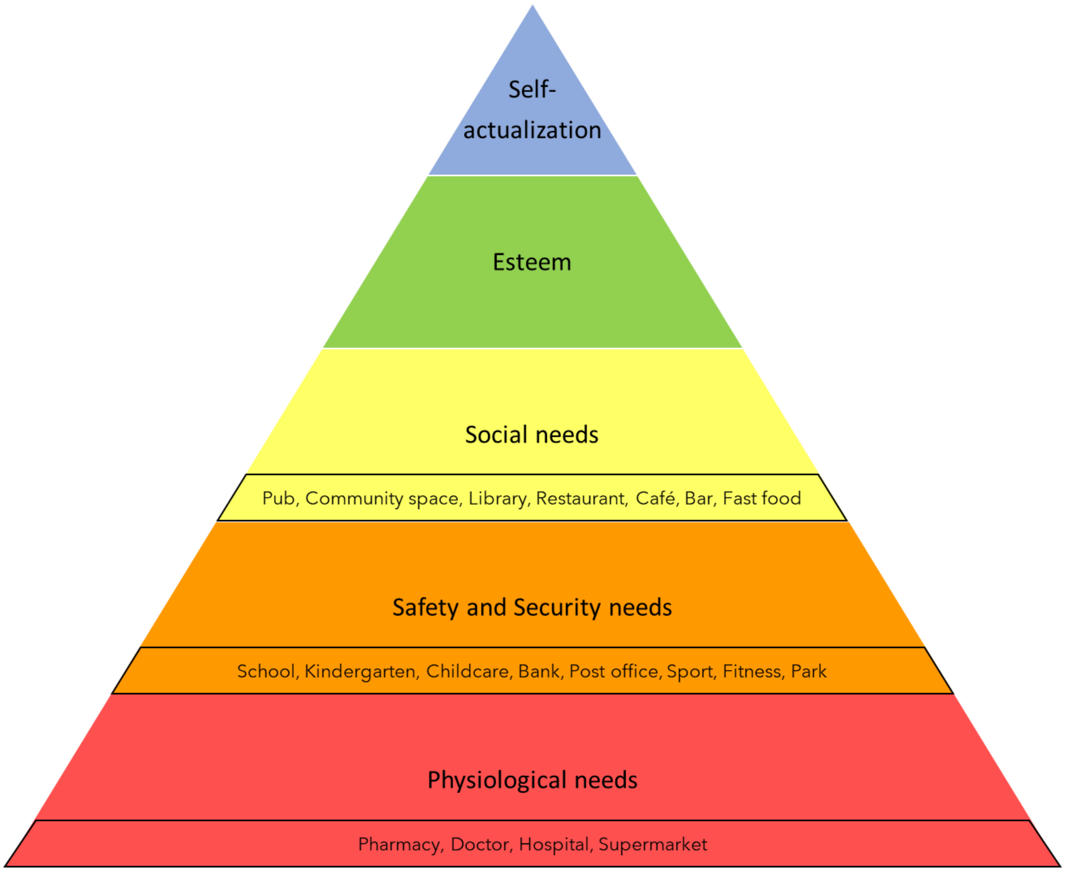

Figure 3.11 Maslow's Hierarchy of Needs with the categorized destinations. This hierarchy consists of five needs. Physiological needs include everything needed for biological survival. Safety and Security needs includes everything for a good life. Social needs include everything one needs to get a feeling of belonging. Esteem includes esteem for oneself and respect from others. The self-actualization layer means reaching one's full potential. The destinations used in this research are classified using literature and the definition of these categories. The classified destinations are shown in the box within the category of Needs.

Maslow's Hierarchy of Needs has since its original publication been altered by Maslow himself in 1970 to include three extra layers: Cognitive needs, Aesthetic needs and Transcendence needs. After this alteration there still has been a lot of critique on Maslow's model as the method and outcomes are very dependent on the researcher (*McLeod, 2007*).

However, the original idea is still often used to understand the behavior of someone to its environment as Maslow has adopted a holistic approach for this.

To classify the destinations by importance for the population in The Hague, Maslow's Hierarchy of Needs will be used. This theory can help gather a basic understanding of what the importance of the accessibility of a certain destination is for people compared to other destinations. The destinations can be classified in the first three layers: Physiological Needs, Security and Safety Needs and Social Needs. The last two layers cannot be reached with just a destination. They can be reached by using the destinations in the previous layer and by interaction with the world around a human.

The classification has been done based on the understanding of the definitions of Maslow's Hierarchy of Needs' layers as mentioned above as well as with the use of literature of *Seager et al. (2017)* and *Clark, Seager, and Chester (2018)*. These papers use the Hierarchy of Needs to tie critical infrastructure to the layers based on the definition. The first layer includes life and health infrastructure. The second layer includes public safety, financial services, information technology and control over one's environment. The third layer includes community structures and social clubs. Based on the definition of Maslow's Needs layers and these defined critical infrastructures, the classification of destinations is created as shown in Figure 3.11.

The classification of the destinations within the Hierarchy of Needs reduces the number of scenarios that need to be tested with interventions significantly. Where before 19 destinations, three equity principles and two travel time classifications had to be tested, now only three destination categories are present. Appendix A Destinations shows the location of the grouped destinations in The Hague.

3.4.2.3 Equity principles

The places of interventions are picked based on the quantification of the equity principles. In every scenario of interventions an equal number of interventions is picked to make sure the principles are comparable. The determination of road segments is done by using a transport network criticality analysis (*Jafino, Kwakkel, & Verbraeck, 2020*).

3.4.2.3.1 Utilitarianism

Utilitarianism aims to maximize benefits over society. Therefore, the societal background of the neighborhoods is not accounted for. The road segments which cause the highest increase in travel time are selected. This is done by putting all the road segments that were part of the initial routing between OD pairs and that are no longer part of the new routing after a disruption between these pairs into a list. Then, it is confirmed if this road is blocked since the water level is over 0.3 meter or if it is not blocked but no longer part of the routing because other road segments are blocked and therefore this road segment is no longer useful either. If the road segment is blocked, it will be kept in the list, if it is not blocked, it will be removed from the list. A list with blocked road segments that cause a delay is then leftover. For the road segments in this list, it is checked once again what delay these segments are causing. This delay is calculated by multiplying the number of people that would normally be travelling over this road segment towards their destination times the number of delay that the road segment is causing. Once this has been done for all road segments, the road segments with the longest total delay time are marked for an intervention to be placed.

3.4.2.3.2 Rawls' Theory of Justice

Rawls' Theory of Justice aims to maximize the total final benefits of the most socially vulnerable group(s) of the society. For the most vulnerable societal group the road segments which cause the highest number of increase in travel time are selected. For this group, the road segments that were part of the initial routing between the OD pairs and no longer part of the new routing after a disruption are once again put into a list. The same method is repeated for finding the road segments as has been done for the Utilitarian principle.

3.4.2.3.3 Equal Sharing

Equal Sharing aims to divide the benefits equally among all groups. Therefore, there are multiple lists with road segments created for every societal group in The Hague. Once again, this list is generated by comparing the road segments used before and after the disruption. The road segments that cause the highest number of travel time are generated the same way as in the Utilitarian principle but now this is done separately for every group. For every group, the same number of road segments are marked as a place for intervention.

3.5 Accessibility: after intervention

After the quantification of equity principles, certain road segments are marked as a place for intervention. The network criticality module part of RA2CE from Deltares saves the attributes of the edges, including the water level on the road segment, in a separate file. This file can be altered based on the list of road segments. The water can be removed from this segment as if an intervention was put in place. The model with Dijkstra's Algorithm is run once again for all origins and all different destinations, not destination groups. This ensures that the travel time to the same destinations is calculated after disruption and after intervention.

Once this has run, there are multiple travel times for the different groups in different scenarios. These scenarios need to be compared to understand what the impact is of a disruption is on the travel time and what the impact is of interventions that are based on the different equity principles on the travel time. This comparison is made by using the Kolmogorov-Smirnov test (KS test) and comparing the graphs visually to understand the difference.

The Kolmogorov-Smirnov test is used to understand if two samples belong to the same population group. If they belong to each other, the empirical cumulative distribution functions (ECDFs) have to be quite similar. The KS test detects the maximum distance between the two ECDFs of the samples. It then tests whether the maximum distance is large enough to claim that these to samples do not belong to the same population. The rejection level for this test will be chosen at a 0.05 level. If the test returns a value below this level, the distributions are different. This test is preferred over a T-test as a T-test only considers the differences between the averages while the KS test considers the differences in a distribution. Therefore, if average travel times are similar, the KS test can still find differences between these distributions while a T-test would consider the samples to not be significantly different.

The KS test can be used to understand if there is a significant difference in travel times between different scenarios (BAU, after disruption and after intervention) and if there is a significant difference between difference groups to state that these groups have different travel times. By using visual inspection, it can be understood what the difference between these groups is.

4 | Results

This chapter presents the results of the analysis. It first elaborates on the accessibility during a business-as-usual scenario. Secondly, the results regarding the accessibility after a disruption is shown. Thirdly, a presentation of how socio-demographic groups are clustered and how the most vulnerable group and the interventions based on the different equity principles are located is given. Finally, this chapter presents a comparison between the accessibility after the placement of interventions and the accessibility after a disruption has taken place.

4.1 Accessibility: business as usual

The differences in accessibility between the different neighborhoods (origins) and the closest five locations of specific destinations lead to a range in the travel time seen in the density plot of Figure 4.1 (all figures portraying densities are weighted to account for the number of people living in the neighborhood of origin). Figure 4.1 shows that the nearest five locations of every destination can be reached within 13 minutes by car regardless of the neighborhood of origin. This means that The Hague can be considered a 15-minute city. Additionally, three-quarters of the destinations can be reached within roughly 3.5 minutes, while the mean travel time is around 1.5 minutes.

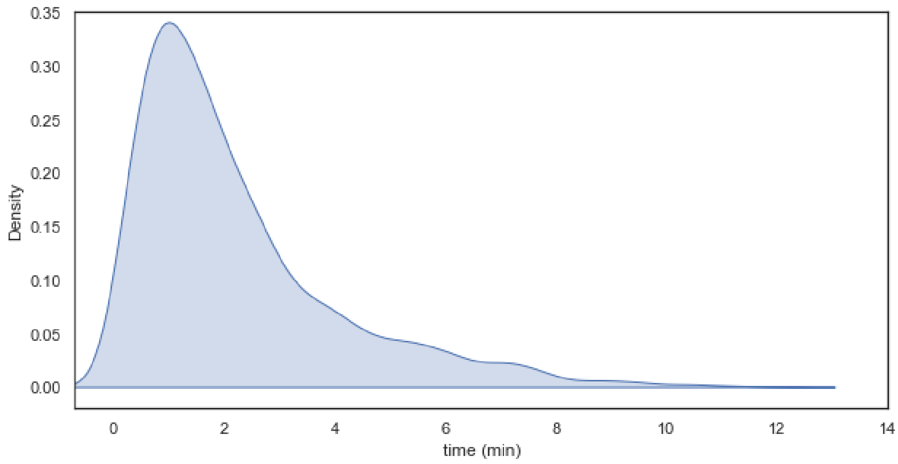

Figure 4.1 General travel time business as usual.
The travel time of all neighborhoods to the top 5 destination of every type. There are 114 neighborhoods and 19 destinations generating 10830 datapoints. The figure is weighted for the number of people living in the origin.

When examining the travel time with regards to different destination categories, a difference between the travel time distributions of Social Needs and the other categories can be seen (Figure 4.2). Social Needs destinations are shown to have a lower travel time than the other destination categories. This can be explained by looking at the high number of amenities (67% of all destinations) considered to be part of the Social Needs destination category as well as that this high number of amenities is geographically distributed in all studied areas (Appendix A Destinations). Physiological destinations have the highest outliers that are around 13 to 14 minutes of travel. In contrast to the Social Needs, the number of Physiological destinations is smaller (10% of all destinations), for example there are only two hospitals in The Hague, which means that residents of some neighborhoods have to travel further than other neighborhoods. A Kolmogorov-Smirnov test shows that the travel time distribution for Social Needs destinations does significantly differ from those of Physiological and Security and Safety destinations (Physiological: $p = 2.04e\text{-}19$, Security and Safety: $p = 8.59e\text{-}186$).

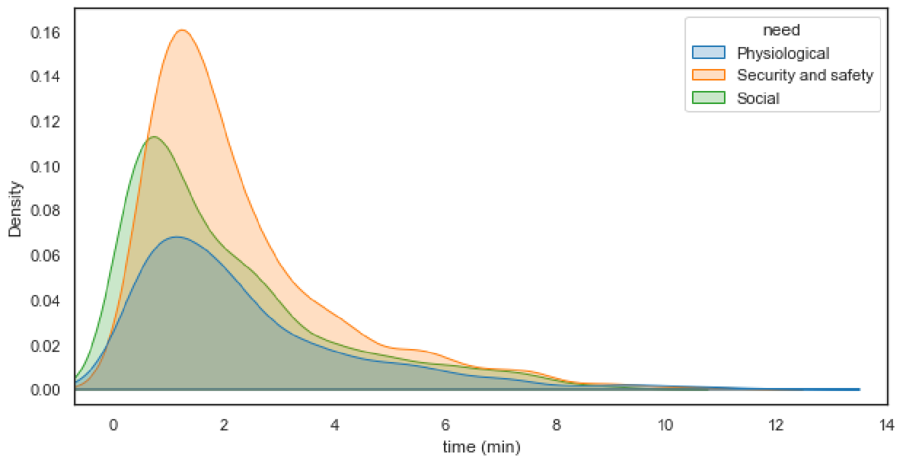

Figure 4.2 General travel time for destination types BAU.
The travel time of all neighborhoods to the top 5 destinations split for different destination types. Social needs differ in distribution from Security and safety needs (p=8.59e-186) and Physiological needs (p=2.04e-19) according to the KS test. The figure is weighted for the number of people living in the origin.

4.2 Accessibility: after disruption

The disruption used as part of this case induces a change to the routes that are taken to go from origin to destination during a BAU scenario. A route is an order of road segments to get from point the neighborhood to the destination. 40% of the routes taken are altered after the disruption has taken place because one or more road segments that were used during a BAU scenario are blocked by the disruption. This on average leads to 1.4 minutes to be added in travel time. The new average travel time is around 2.3 minutes. A KS test shows that these distributions differ from each other at a significance level of 0.05 (p = *1e-323*) (Figure 4.3).

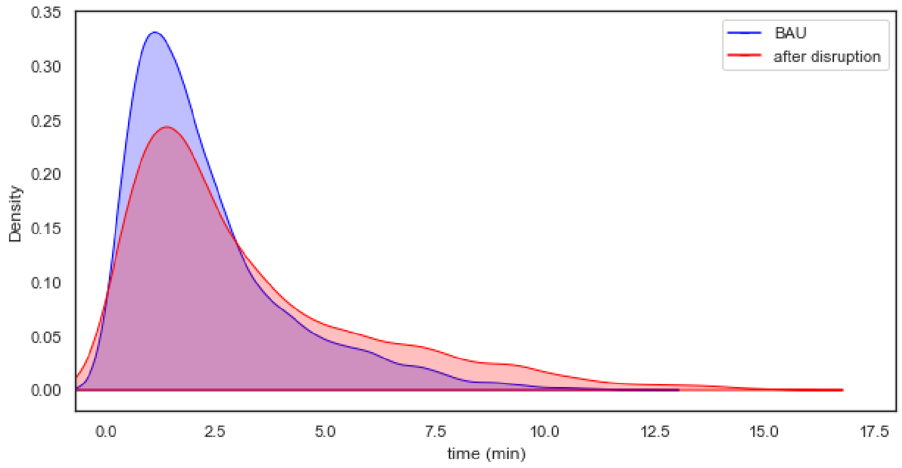

Figure 4.3 General travel time BAU and after disruption.
The travel time of all neighborhoods to the top 5 destination of every type for BAU and after disruption situations. There are 114 neighborhoods and 19 destinations generating 10830 datapoints. The distribution after a disruption is significantly different from the distribution before the disruption according to the KS test (p=1e-323). The figure is weighted for the number of people living in the origin.

While the minimum added travel time for one route is too small to make much of a difference (~0 min), the maximum extra travel time for one route is shown to be 11.4 minutes. The disruption also causes some routes to be no longer travelable as either too many roads on the route are blocked or because the origin or destinations points are flooded. In other words, there are cases where there is zero accessibility between certain origin and destination points. After a disruption has taken place, 25% of all the original (BAU) routes cannot be replaced by a detour, half of which is due to road segments being blocked and the other half of which is due to the origins and destinations being blocked.

Table 4.1 Statistics of routes after disruption.
The table shows the statistics of routes in The Hague after disruption. The statistics shown are the BAU situation compared to the after disruption situation.

Routes with extra travel time	40%
Average added time for routes with extra travel time	1.4 min
Maximum added travel time for these routes	0 min
Minimum added travel time for these routes	11.4 min
Routes with no detour	25%
No detour because route is blocked	13%

Figure 4.4 shows the number of people living in a neighborhood that is blocked from their destinations because of the routing not being there anymore. The people that are blocked from their destination because either their origin or destination is blocked, are not included in this figure. It is important to consider these groups as they currently do not have access to destinations and placing interventions can mitigate this issue.

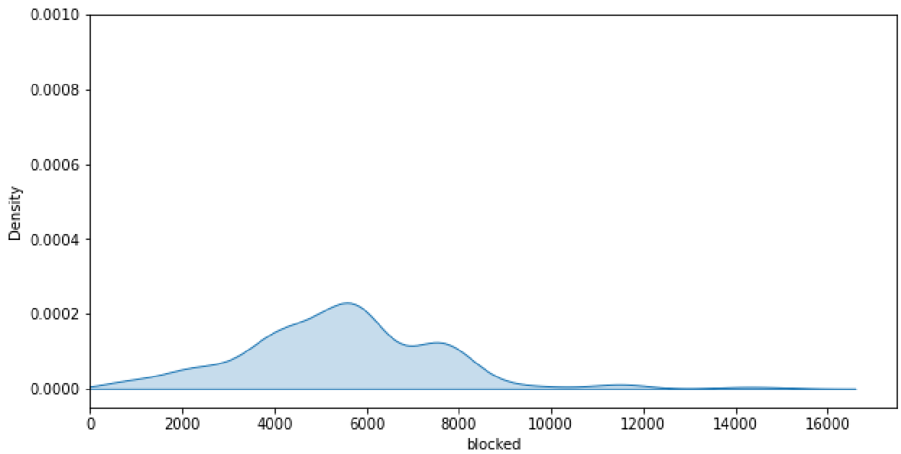

Figure 4.4 People blocked from their destination after a disruption.
The people blocked from their destination are calculated by multiplying the blocked neighborhood with the number of people living within that neighborhood.

When comparing the different destination categories on the increase in travel time after the disruption, no specific destination category seems to have a significant relatively higher increase in travel time compared to other destination categories. The same can be said about the people blocked from the different destination categories (Appendix D).

4.3 Intervention placement

While the previous subchapter analyzed the travel times with regards to the general population, to understand where to place interventions based on equity principle, further analyses need to be conducted knowing the location of the societal groups. Once the equity principles have been quantified, the socio-demographic groups in The Hague are located so that the travel times between these groups can be compared. The outcome of the clustering can be used to understand the travel time of the different groups in a BAU scenario and after a disruption has taken place. With this information, interventions can be placed based on the usage of certain roads segments by a socio-demographic group. The selection of these road segments will be discussed in paragraph 4.3.2.

4.3.1 Societal groups

At first, a principal-component analysis (PCA) was executed to reduce the number of societal characteristics (e.g., age, social benefits) that might be of interest in the analysis (Appendix B). After scaling the values of all characteristics between 0 and 1, a PCA returned eleven components which together explain over 95% of the variability of the societal characteristics.

The eleven components of the PCA are used as input for DBSCAN, which is the clustering (i.e., grouping) algorithm used in this research to group the various societal groups based on their similarity with regards to the components. To determine the grouping, a measure of how similar a neighborhood is to another needs to be established. This is also called a distance between two neighborhoods. DBSCAN measures the distance with regards to the eleven components. To get to groupings of neighborhoods that are not too similar and too dissimilar, DBSCAN needs to use a value for the distance between neighborhoods value that is adequate. This value is called epsilon. This is done by making sure that the epsilon value does not group too many or too few neighborhoods together. A graph that plots the distance between a neighborhood and its three nearest neighbors can show what value epsilon should be to achieve this. In this analysis, the epsilon value is set to 0.8 after looking at the point of maximum curvature which indicates the distance at which not too many or too few neighborhoods are similar to each other (Figure 4.5).

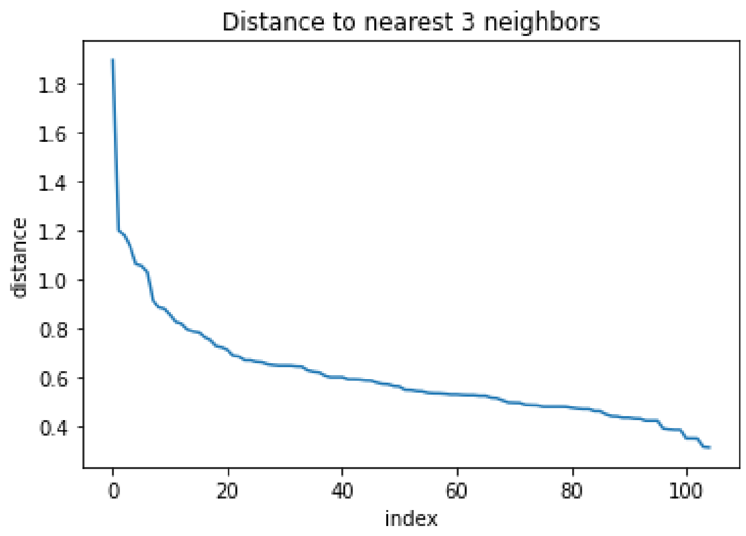

Figure 4.5 Distance to nearest 3 neighbors after PCA.
This graph is created by sorting the PCA output of distance values to the nearest neighbors. The value of 0.8 where the maximum curvature can be seen will be used as the input value of the epsilon of the DBSCAN algorithm.

In this analysis, the DBSCAN algorithm was run with an epsilon value of 0.8 and a minimum number of three near neighborhoods to be considered a grouping. This generated seven different groups and one noise category (i.e., a collection of neighborhoods that are too far away from others to be considered part of any group).

To better understand characteristics of the groups that have been generated, figures showing the composition of the seven groups based on the original societal characteristics can be found in Appendix B Societal groups. Based on these density plots, each of the seven groups has been given a descriptive name to better understand the societal characteristics of the people who live in the grouped neighborhoods. The groups are shown in Figure 4.6.

- younger children/ families
- lower educated/ less wealthy/ children
- lower educated/ less wealthy/ foreign ethnic background/ working class
- wealthy elderly
- younger working class
- foreign non-western ethnic background/ younger working class
- western ethnic background / younger working class

Figure 4.6 Different societal groups in The Hague.
The groups are located by using societal variables, removing noise with PCA and clustering the PCA values with DBSCAN algorithm. 7 different groups can be found and one noise category.

The seven groups were used to assess the differences in travel time between the different groups as part of the accessibility analysis. Based on literature, the most vulnerable group is composed of working-class people who are lower educated, have less wealth and a foreign ethnic background (*Blaikie et al., 2005*; *Cutter et al., 2000*).

4.3.1.1 Accessibility: business as usual for societal groups

Using the different societal groups which have been located, the difference in travel time for the groups could be analyzed.

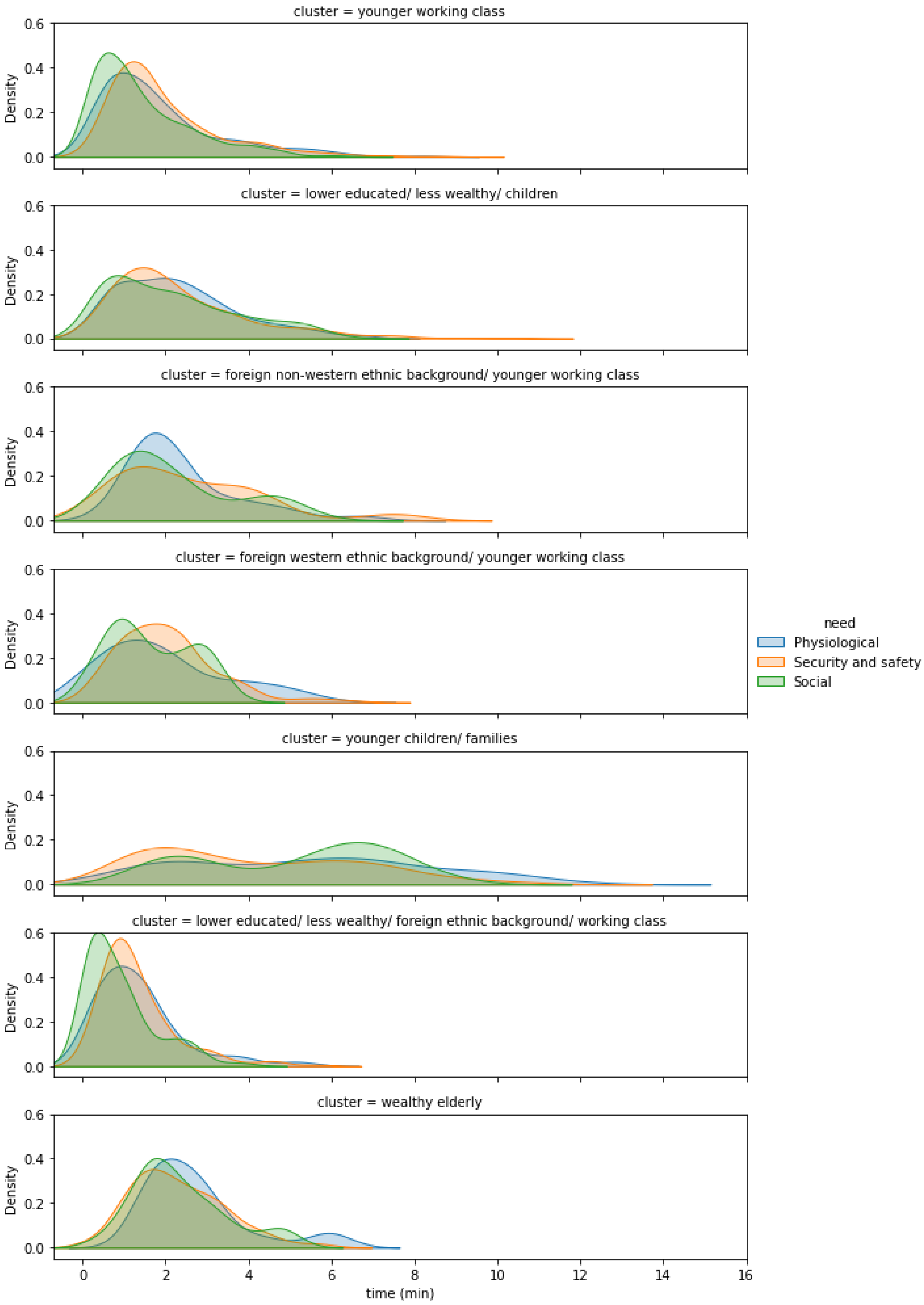

Figure 4.7 BAU travel time for societal groups and destination categories.
All groups have a significant different distribution compared to other groups according to the KS test using an alpha of 0.05. Families with younger children have two bumps in their distribution as one part is more located on the outskirts of the urban area. The figure is weighted for the number of people living in the origin.

In a BAU scenario, the distributions of the travel time to the different needs are unimodally rightly skewed for most of the groups (Figure 4.7). Only the travel times for families with young children show a bimodal distribution. This can be explained by considering the different locations of the neighborhoods in which families with young children are located. One cluster of families with young children is located directly next to the city center of The Hague, while another cluster is located on the outskirts of The Hague. There are less destinations located on the outskirts than within the city center. Therefore, the neighborhoods located nearby the city have a lower travel time than the neighborhoods located on the outside. The mean of this group will not be very telling as one could consider that these groups are separate groups.

There is also a significant difference in travel time distributions between all groups when the distributions are tested with a KS test on a 0.05 significance level. Table 4.2 shows the significance between the groups for the Physiological destination category. Other destination categories can be found in Appendix D Accessibility. Some groups travel a shorter time than other groups. These findings can be explained by considering the location of the different groups. The groups situated in or near the city center (i.e., lower educated, less wealth, ethnic background working class) have shorter travel times than the groups located on the outskirts (i.e., wealthy elderly).

Table 4.2 Outcome of KS test between different societal groups for Physiological destinations.
The darker color shows a confidence level of 0.01, the lighter color a significance level of 0.05. All groups are significantly different for one another for the Physiological destinations.

	Younger working class	Lower educated, less wealth with children class	Younger working class with non-western ethnic	Younger working class with western ethnic background	Families with younger children	Lower educated, less wealth, ethnic background working class	Wealthy elderly
Younger working class		5.9e-8	2.4e-6	1.1e-2	1.7e-15	1.1e-2	2.9e-13
Lower educated, less wealth with children class	5.9e-8		8.5e-3	1.1e-2	2.2e-16	1.3e-8	1.7e-5
Younger working class with non-western ethnic background	2.4e-6	8.5e-3		8.7e-3	8.8e-13	3.4e-8	1.8e-2
Younger working class with western ethnic background	1.1e-2	1.1e-2	8.7e-3		1.1e-20	5.1e-5	3.0e-5
Families with younger children	1.7e-15	2.2e-16	8.8e-13	1.1e-20		1.8e-25	2.2e-16
Lower educated, less wealth, ethnic background working class	1.1e-2	1.3e-8	3.4e-8	5.1e-5	1.8e-25		9.0e-14
Wealthy elderly	2.9e-13	1.7e-5	1.8e-2	3.0e-5	2.2e-16	9.0e-14	

4.3.1.2 Accessibility: after disruption for societal groups

After the disruption, travel times of the different groups change. The distributions of the travel time therefore change as well. The comparison between the BAU travel times and the travel times after disruption can be seen in Figure 4.8. The changed distributions for the different destination categories can be seen in Figure 4.9. The difference between the old and new travel times is significant for all groups according to the KS test (Appendix D Accessibility). Compared to the business-as-usual scenario, travel times increase for all groups, however, this increase is not equally distributed over the groups. Additionally, the impact on the Physiological and Security and Safety categories seems to be larger than on the Social Needs category.

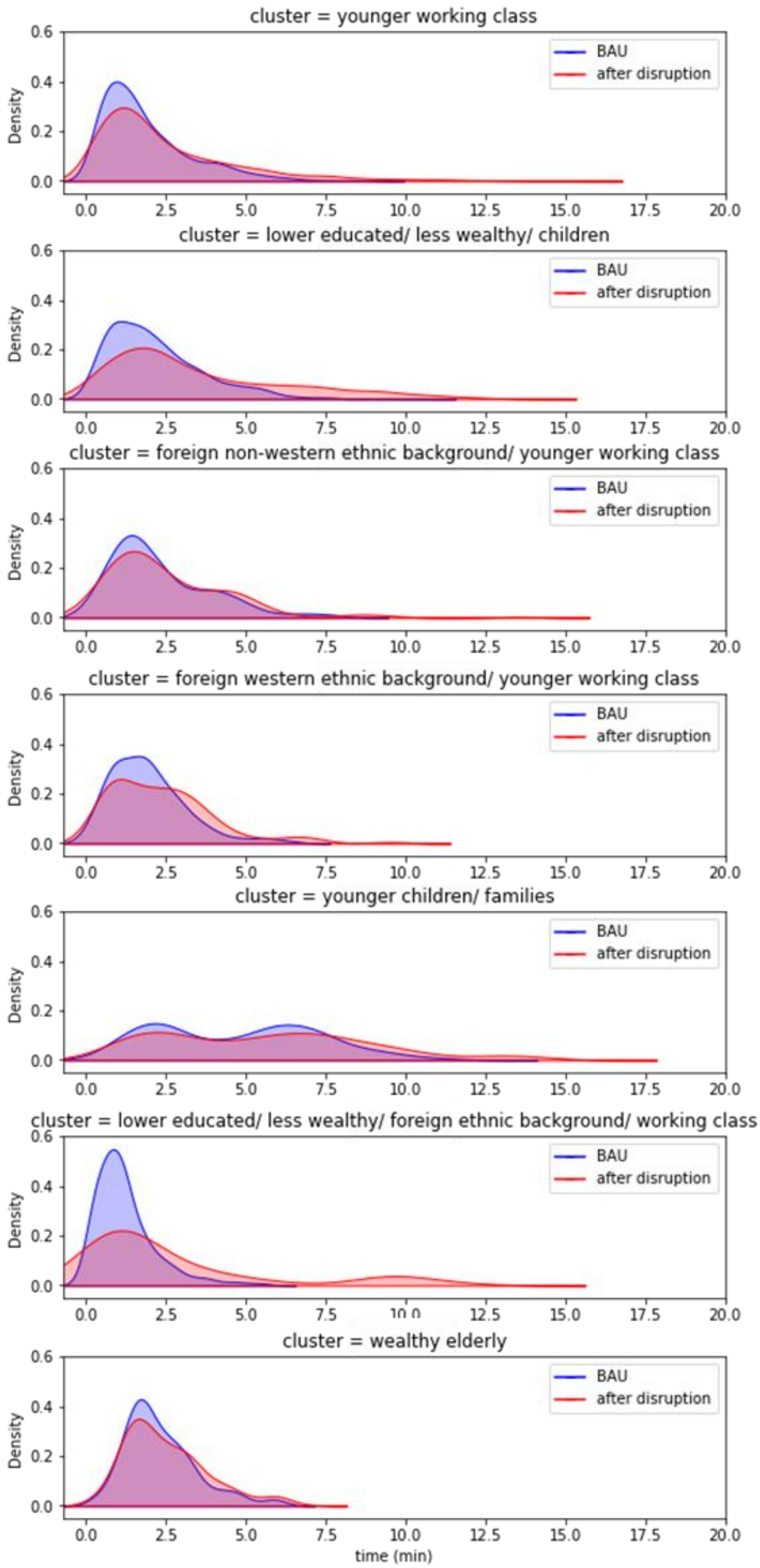

Figure 4.8 The distribution of BAU and after disruption travel time for the different socially vulnerable groups. All travel time distributions change significantly after a disruption compared to before a disruption. The travel time after disruption is longer for all groups. The figure is weighted for the number of people living in the origin.

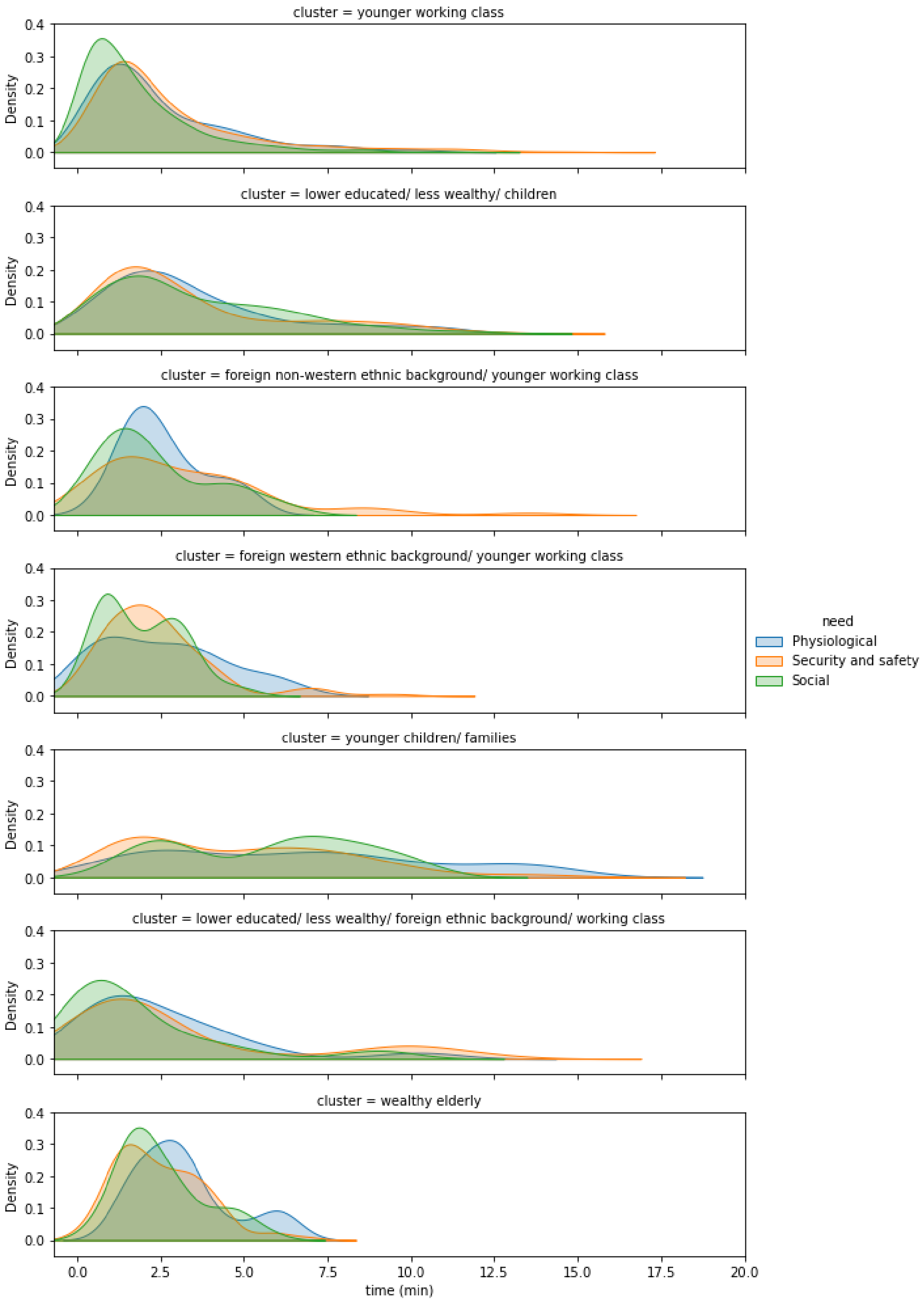

Figure 4.9 Travel time after disruption for societal groups and destination categories.
The travel time for all groups increases significantly (KS test with alpha of 0.05). The groups located near the center of The Hague where the disruption is taking place are more affected than the groups located on the outskirts. The figure is weighted for the number of people living in the origin.

The groups in the urban center, lower educated, less wealth, ethnic background working class, which can be considered as more vulnerable, seem to be more impacted by the disruption than the less vulnerable people. The most affected lower educated, less wealthy working-class people with a foreign ethnic background have an increase of 5 minutes to their travel time (from 6 minutes to 11 minutes for Physiological needs). Considering that the most affected families with younger children only have an increase in travel time of around 2 minutes (13 minutes to 15 minutes for Physiological needs) and the impact on wealthy elderly have an increased travel time of 1 minute (6 to 7 minutes), it can be said that lower educated, less wealthy working-class people with a foreign ethnic background are the most affected group.

This impact can be better seen in Figure 4.10, which shows the relative increase of travel time after a disruption has taken place compared to a BAU scenario. The figure, for instance, shows that if two groups both have an after-disruption travel time of 3 minutes, but one groups had a BAU travel time of 1 minute and the other of 2 minutes, the relative increase in travel time will be 200% and 50% respectively. The impact on the group with a BAU travel time of 1 minute is larger, namely 200%. Figure 4.10 shows that the most socially vulnerable group is the most relatively affected while the wealthier groups are least relatively affected. The average increase in travel time for the lower educated, less wealthy working-class people with a foreign ethnic background is between 100% and 150% (average of 121%). For the wealthy elderly, this increase is between 10% and 20%. The average increase of travel time for all groups, except the most socially vulnerable group, is 34%. The difference between these groups is 87%.

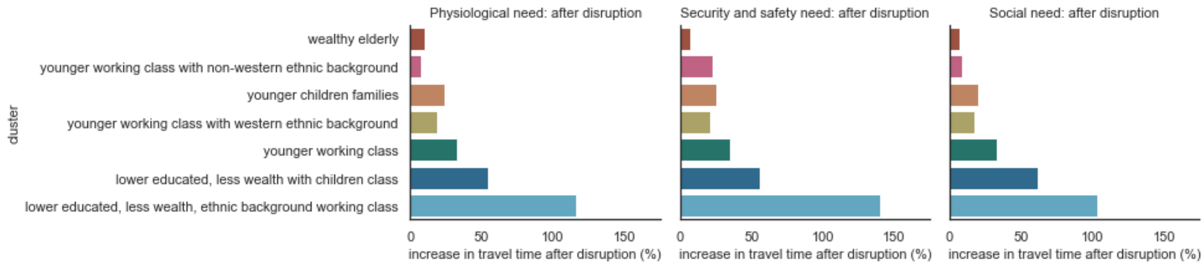

Figure 4.10 Average increase in travel time after disruption compared to BAU.
The percentage is created by dividing the BAU time by the time after disruption. People living in the center show a higher percentage increase in their travel time.

Besides the increased travel times, it is of importance to consider the people that are completely blocked from their destinations. Figure 4.11 shows that the most socially vulnerable group is more often blocked from destinations than the other groups. The disruption blocks off the greatest number of roads in the city center, where this group lives, making the group unable to access destinations in the city center. This group shows a significant increase in its travel time and has many inhabitants blocked from their destinations. The most socially vulnerable group has 69% more people blocked compared to all other groups.

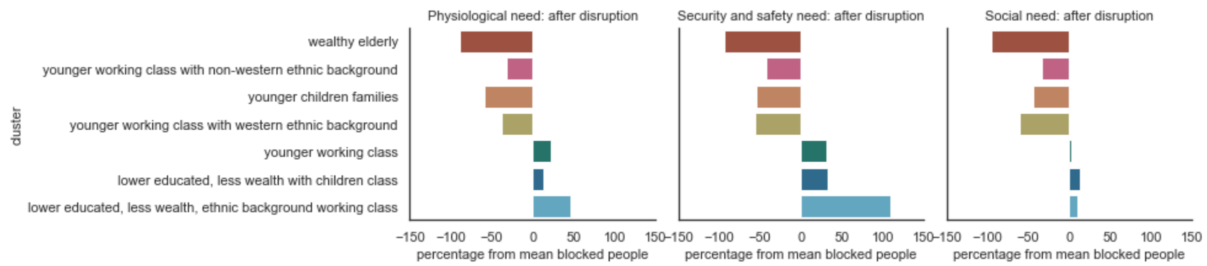

Figure 4.11 People of societal groups blocked from their destination after disruption compared to the mean of all people blocked.
The figure shows what the percentage is of the mean for the different societal groups. The mean is considered 0%. If there are more people blocked in the group, the percentage is positive, is there are less people blocked, the percentage is negative. People living in the city center are more often blocked than people living on the outskirts. The lower educated, less wealth, ethnic background working class is considered the most vulnerable group.

4.3.2 Selection of road segments

As part of this analysis, different road segments are selected for the placement of certain interventions that improve the segments susceptibility to flooding. Using the data on the various societal groups, it is possible to use certain ethical principles to distribute the interventions selectively with regards to the benefit of specific societal groups.

Figure 4.12 shows the selected road segments based on the quantification of the equity principles. In Appendix C, Intervention placement the figures of the selected road segments are split up for the different principles, for the travel time type and for the different destination categories.

4.3.2.1 Utilitarianism

Using the Utilitarian principle to select which roads should get an intervention (Appendix C), one would mainly place interventions on roads located in the center of The Hague as it constitutes the area where most people are traveling through and where most destinations are also located. When using the utilitarianism principle to guide the placement of interventions, the busy city center of The Hague gains priority.

4.3.2.2 Rawls' Theory of Justice

According to the Rawls' Theory of Justice, interventions are placed to generally accommodate the most vulnerable societal groups. The analysis shows that using the Rawls' Theory of Justice leads to road segments being selected for intervention placement near the neighborhoods that are considered the most vulnerable ones. These neighborhoods are generally located to the east of the city center of The Hague (Appendix C).

4.3.2.3 Equal Sharing

When using the Equal Sharing principle, the placement of interventions is done to benefit each societal group equally. As the different societal groups are also located in different areas of The Hague, using the Equal Sharing principle leads to the selection of road segments for the placement of interventions to be scattered throughout the entirety of The Hague (Appendix C).

Figure 4.12 Selected road segments for intervention based on different equity principles.

On 69 occasions, there is overlap between the road segments of when basing interventions on the three different ethical principles. These are duplicates based on the Needs category they try to tackle as well as the added travel time or total travel time criteria. Of these 69 overlapping road segments, 18 are selected as part of interventions based on all three ethical principles. These 18 road segments constitute 4.8% of all road segments tested within this analysis (Appendix C Intervention placement).

4.4 Accessibility: after interventions

The accessibility after interventions can be analyzed for both the general population of The Hague (all inhabitants together) as well as for the different societal groups.

4.4.1 General population

After the interventions, the general travel time for the entire population changes. Although the number of routes with extra travel time increases, this is largely due to the fact that many previously blocked routes are opened as a result of placed interventions but are subject extra travel time when compared to the BAU scenario (Table 4.3). According to a KS test, the change in the distribution of travel times between societal groups is significant regardless of how interventions are placed (Table 4.4). Using the Utilitarianism principle leads to changes in the distribution of travel time that are most significant as it also tackles the highest amount of travel time for the general population. Therefore, it is to be expected that this principle would have the largest impact on the general population. Equal Sharing shows the least amount of change as this ethical principle also impacts societal groups that were less affected in the first place.

Table 4.3 Statistics of routes after disruption and after interventions based on Utilitarianism, Rawls' Theory of Justice and Equal Sharing.

The table shows the statistics of routes in The Hague after disruption and after interventions based on Utilitarianism, Rawls' Theory of Justice and Equal Sharing. The statistics shown are the BAU situation compared to the after disruption and after interventions based on Utilitarianism, Rawls' Theory of Justice and Equal Sharing situation.

	After disruption	Utilitarianism	Rawls' Theory of Justice	Equal Sharing
Routes with extra travel time	40.0%	42.0%	41.8%	41.4%
Average added time for routes with extra travel time	1.4 min	1.3 min	1.2 min	1.4 min
Minimum added travel time for these routes	0 min	0 min	0 min	0 min
Maximum added travel time for these routes	11.4 min	11.4 min	11.4 min	11.4 min
Routes with no detour	24.6%	21.3%	22.2%	22.4%
No detour because route is blocked	13.0%	11.4%	12.0%	11.9%

Table 4.4 Significance between travel time after disruption and after interventions for the general population. The significance is tested with a Kolmogorov-Smirnov test. * shows a significance at an alpha of 0.05. ** shows a significance at an alpha of 0.01.

Equity principle	p-value
Utilitarianism	2.2e-6**
Rawls' Theory of Justice	7.1e-4**
Equal Sharing	1.9e-2*

The analysis conducted assesses the impact of interventions on the societal groups using two separate measures: total travel time and added travel time. Regardless of which ethical principle is applied, the total travel time shows a statistically significant change with regards to the travel time in a scenario without the placement of interventions. The level of statistical significance of the impact of interventions on travel time is higher when applying interventions using total travel time as a measure than when using added travel time (Table 4.6).

As the Equal Sharing principle spreads the interventions equally over the entire population, some societal groups that are less vulnerable to flooding receive interventions. However, these interventions do not provide a significant impact to the added travel time of these societal groups, as is also pointed out by the KS test. Ultimately, this leads to the impact on the general population of the interventions placed following the Equal Sharing principle to be less. All other interventions based on either total travel time or added travel time and the different equity principles are still significant (Table 4.5 and Table 4.6). However, only when placing interventions following the Rawls' Theory of Justice's principle does can the added travel time be considered statistically significant.

Table 4.5 Statistics of routes after disruption and after interventions based on Utilitarianism, Rawls' Theory of Justice and Equal Sharing split for the Total benefits and Added benefits scenarios.

The table shows the statistics of routes in The Hague after disruption and after interventions based on Utilitarianism, Rawls' Theory of Justice and Equal Sharing split for the Total benefits and Added benefits scenarios. The statistics shown are the BAU situation compared to the after disruption and after interventions based on Utilitarianism, Rawls' Theory of Justice and Equal Sharing situation.

		Total benefits			Added benefits		
	After disruption	Utilitarianism	Rawls' Theory of Justice	Equal Sharing	Utilitarianism	Rawls' Theory of Justice	Equal Sharing
Routes with extra travel time	40.0%	43.7%	42.9%	42.5%	40.2%	40.6%	40.4%
Average added time for routes with extra travel time	1.4 min	1.4 min	1.4 min	1.4 min	1.1 min	1.1 min	1.4 min
Minimum added travel time for these routes	0 min	0 min	0 min	0 min	0 min	0 min	0 min
Maximum added travel time for these routes	11.4 min	11.4 min	11.4 min	11.4 min	10.0 min	8.4 min	11.4 min
Routes with no detour	24.6%	19.0%	21.0%	21.0%	23.6%	23.6%	23.8%
No detour because route is blocked	13.0%	9.8%	11.0%	10.8%	13.0%	13.0%	13.0%

Table 4.6 Significance between travel time after disruption and after interventions for the general population for Total benefits and Added benefits intervention sets.

The significance is tested with a Kolmogorov-Smirnov test. * shows a significance at an alpha of 0.05. ** shows a significance at an alpha of 0.01.

Equity principle	Total benefits	Added benefits
Utilitarianism	4.8e-12**	7.2e-2
Rawls' Theory of Justice	2.6e-5**	1.4e-3**
Equal Sharing	4.3e-5**	0.91

4.4.2 Societal groups

The impact of the interventions for societal groups can be measured twofold as the impact on the travel time per societal group and the impact on the number of people blocked per societal group.

4.4.2.1 Travel time

Once the interventions have been placed, all societal groups have a significantly different travel time (Figure 4.13). By comparing the difference between the travel time after disruption before and after the placement of interventions, it can be concluded that Equal Sharing does not have a high impact on any of the different groups. Interventions placed according to the Equal Sharing principle have the least amount of impact, regardless of societal group as can be seen in Figure 4.13 and Figure 4.14. When placing interventions following the Utilitarianism principle and the Rawlsian principle, the travel time of some societal groups is significantly impacted. Although the travel time seems to increase after the placement of interventions, this is due to more people who were previously blocked from travelling now being able to travel to their destinations.

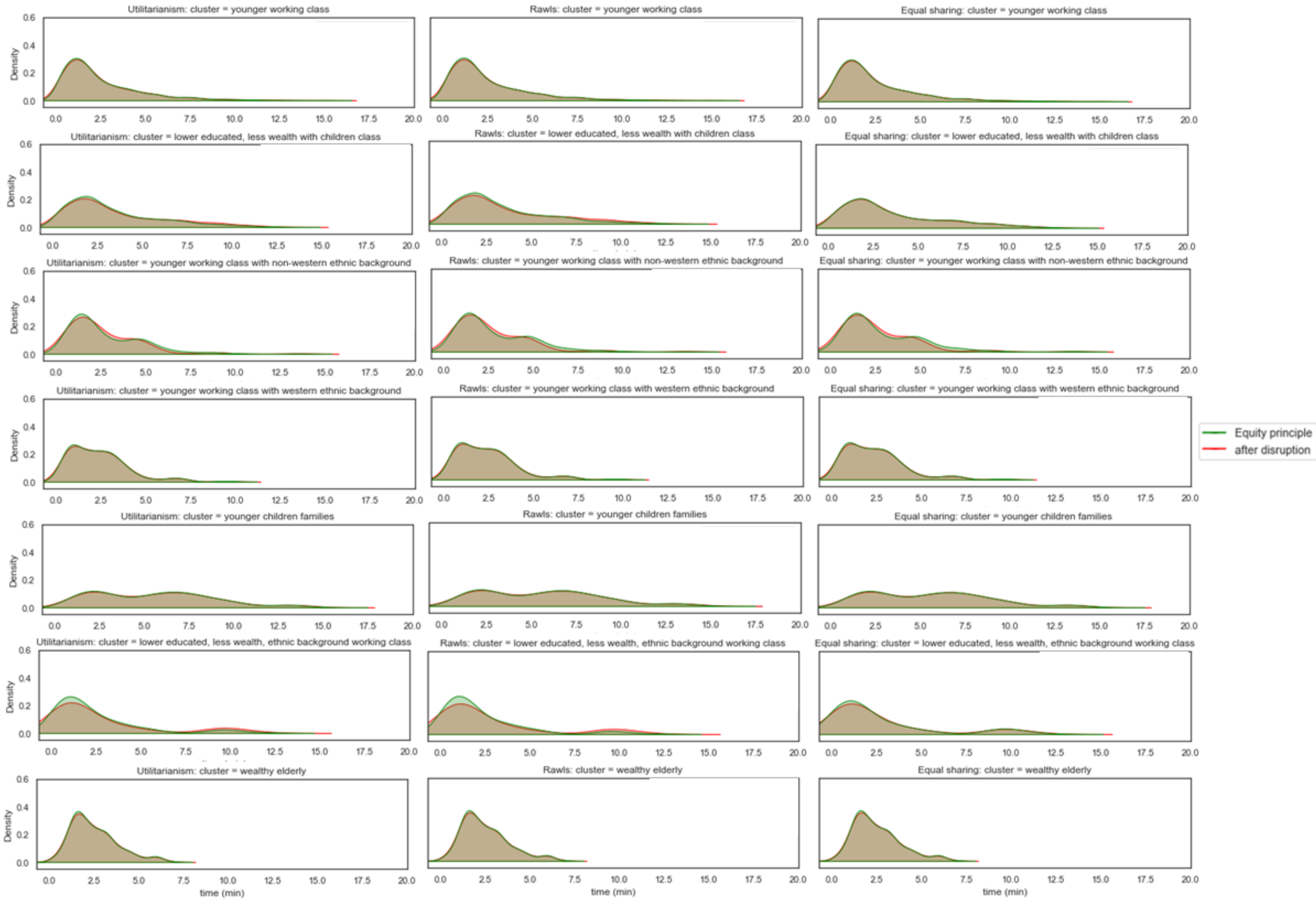

Figure 4.13 Distribution of travel time after disruption and after interventions based on equity principles for different socially vulnerable groups. All principles based interventions are significant for the Younger working class with non-western ethnic background at a 0.01 level, Utilitarianism and Rawls' Theory of Justice are significant for Lower educated, less wealth with children class and Lower educated, less wealth, ethnic background working class at a 0.01 level (Appendix D. Accessibility).

Interventions based on the Rawls' Theory of Justice mainly impacts the most vulnerable group: lower educated, less wealthy working-class people with a foreign ethnic background. Additionally, the societal groups living in neighborhoods near the most vulnerable societal group also benefit significantly from the interventions placed to help the most vulnerable group. For instance, lower educated people with less wealth and children benefit from Rawls' based interventions when trying to reach their Physiological needs, as well as the younger working class for their Security and safety needs.

Using the Utilitarianism principle to guide the placement of interventions decreases the relative added travel time for most societal groups. However, which societal groups are impacted the most is unclear. The decrease in added travel time can be mainly seen in the groups living in the center of The Hague as this is where most road segments are flooded and most people are travelling through.

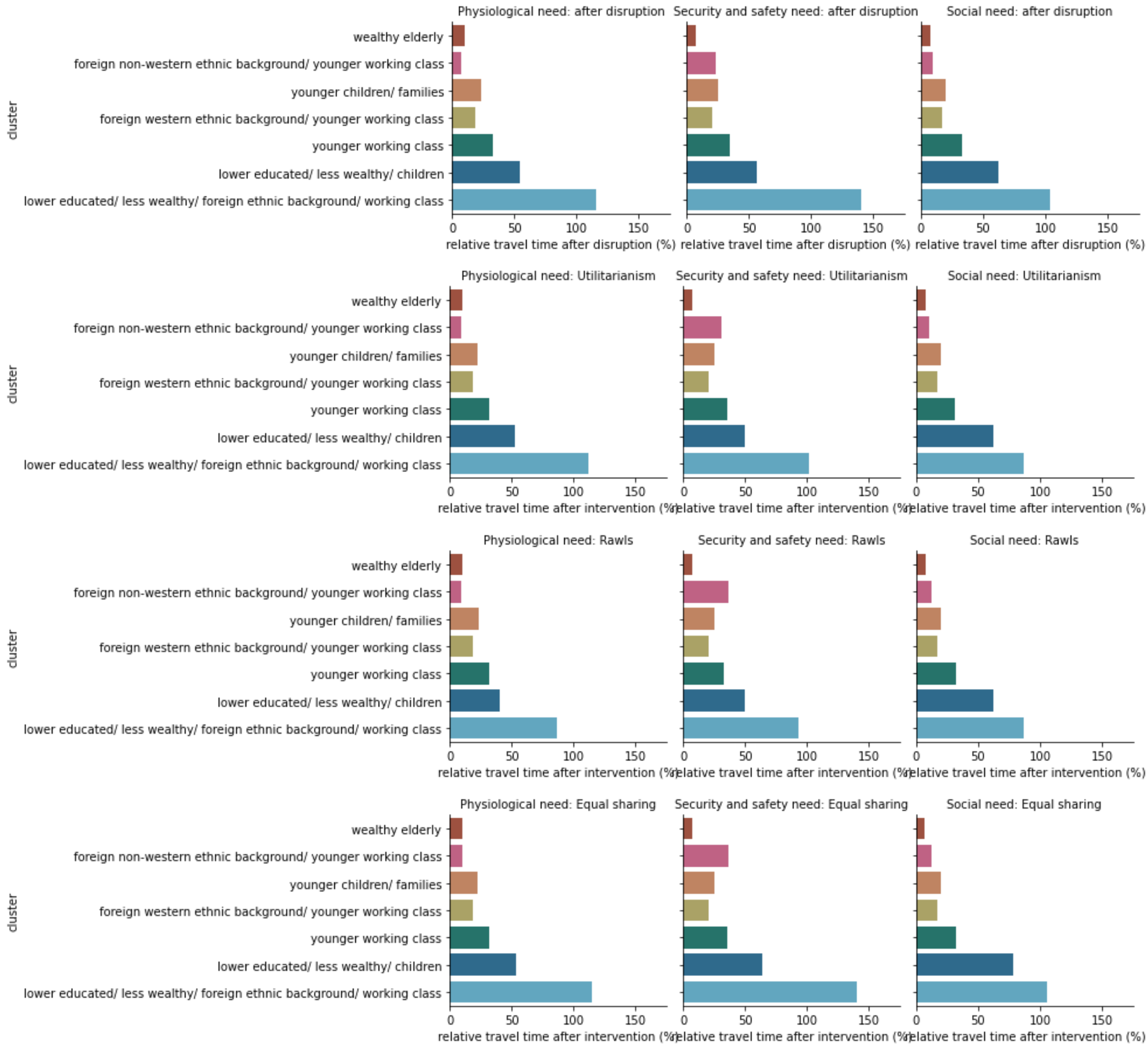

Figure 4.14 Average increase in travel time after disruption and after interventions compared to BAU. The percentage is created by dividing the BAU time by the time after disruption or time after interventions. People living in the center show a higher percentage increase in their travel time. Rawls' Theory of Justice based interventions have the most effect on the vulnerable groups. Utilitarianism shows impact for different groups. Equal Sharing based interventions show little impact.

The elasticity of travel time for every principle is shown in Table 4.7. The elasticity measures the travel time in a scenario where interventions are placed following one ethical principle relative to in a case where interventions were placed following a different ethical principle. For the general population, the Utilitarian based interventions cause the overall best travel times. The general population would lose 0.3% or 2.9% by having interventions be placed according to either Rawls' Theory of Justice or Equal Sharing. The most socially vulnerable groups have the most to gain with 3.5% when placing interventions according to Rawlsian principles. The younger working class with non-western ethnic background would have most to lose with 2.5%.

Distributing the interventions according to the Equal Sharing principle improves the travel time less for every societal group than when using other ethical principles. All societal groups are better off when using either the Utilitarian or Rawlsian based principles. The lower educated, less wealthy working-class people with a foreign ethnic background would have the most to lose when using the Equal Sharing principle. The increase in travel time when respectively chosen Utilitarian or Rawlsian interventions are 9.7% and 12.9%.

Table 4.7 Elasticity of travel time for different equity principle based interventions for general population and societal groups compared to the Utilitarian principle.

On the left the principle compared (Utilitarianism) is shown, on the top the other principle for the elasticity is shown. The elasticity is calculated by dividing the difference of travel time for a certain group between the right and on top category by the category on the left. A value of zero shows there is no difference between the interventions. A negative value shows it would be better to use the category on the left, a positive value means it would be better to use the category on top.

		Utilitarianism	Rawls' Theory of Justice	Equal Sharing
Utilitarianism	General population	0	-0,3	-2,9
	Wealthy elderly	0	-0,1	-0,1
	Younger working class with non-western ethnic background	0	-2,6	-3,8
	Younger children families	0	-0,3	-0,3
	Younger working class with western ethnic background	0	0,0	0,0
	Younger working class	0	0,6	-1,4
	Lower educated, less wealth with children class	0	1,7	-7,2
	Lower educated, less wealth, ethnic background working class	0	3,5	-10,8

4.4.2.2 Blocked inhabitants

Compared to the impact on travel times, the impact of interventions on helping blocked inhabitants is more prominent. Figure 4.15 shows the different clusters and how far away they are from the mean of all groups when taking the mean of the average amount of people blocked. This average is shown for the different needs and the different scenarios (after disruption and after interventions).

Utilitarian interventions have an impact on how many inhabitants are blocked from travelling for different societal groups. The bars are nearing the average lower educated, less wealthy working-class people with a foreign ethnic background for their Security and Safety needs, decreasing the difference between groups. However, in some situations (i.e., same group but for Physiological needs) the gap to the average could also increase. Utilitarianism does not take different groups into account. While a clear impact on the entirety on the general population of The Hague can be seen, impact on various societal groups is more irregular.

Rawls' Theory of Justice interventions have a clearer impact on specific groups. The impact on the most vulnerable group can be identified as there are less blocked inhabitants after implementing the interventions. Although the interventions do not only impact the most vulnerable group, the difference between the most vulnerable societal group and the others decreases.

Equal Sharing based interventions have a similar impact as the Utilitarian based interventions. Since these interventions are equally distributed among all groups, no clear impact on the groups can be seen. The impact could therefore be both negative in bringing a group further away from the mean or positive by bringing groups closer to the mean.

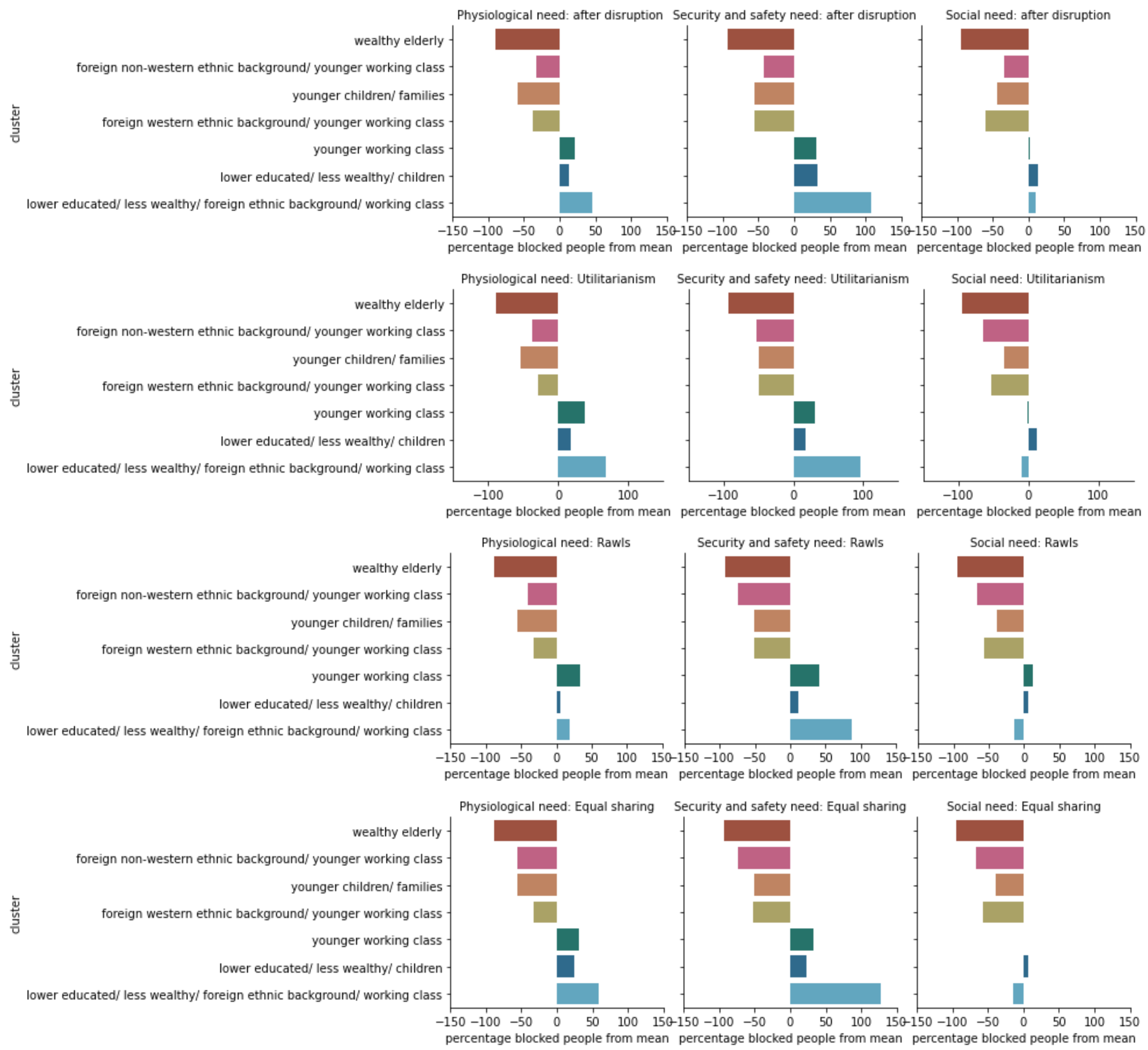

Figure 4.15 People of societal groups blocked from their destination after disruption and after interventions compared to the mean of all people blocked.
This figure shows how far (relatively) the number of blocked people is from the mean value for the different societal groups. The mean is considered 0%. If there are more people blocked in the group, the percentage is positive, is there are less people blocked, the percentage is negative. The rows show the blocked people after disruption, after Utilitarian, after Rawls' and after Equal Sharing. The columns show the different grouped destination categories.

The elasticity of blocked inhabitants for every principle is shown in Table 4.8. For the general population, the Utilitarian based interventions cause the overall least number of blocked inhabitants. The population would lose 5.7% or 5.2% by picking either Rawls' Theory of Justice or Equal Sharing based interventions. Compared to the Utilitarian principle, Rawlsian based interventions impact the most socially vulnerable group. When this principle is chosen to base interventions on, the younger working class would have most to lose with 10.7%. Equal Sharing is favored by the younger working class with non-western ethnic background as they lose 36.2% and 10.9% when the Utilitarian or Rawlsian principles are chosen. no group based on travel time as all groups can be better off when picking either the Utilitarian or Rawlsian based principles. The lower educated, less wealthy working-class people with a foreign ethnic background would have most to lose when this principle is chosen. The increase in travel time when respectively chosen Utilitarian or Rawlsian interventions are 11.8% and 17.1%.

Table 4.8 Elasticity of blocked inhabitants for different equity principle based interventions for general population and societal groups compared to the Utilitarian principle.

On the left the principle compared (Utilitarianism) is shown, on the top the other principle for the elasticity is shown. The elasticity is calculated by dividing the difference of blocked inhabitants for a certain group between the right and on top category by the category on the left. A value of zero shows there is no difference between the interventions. A negative value shows it would be better to use the category on the left, a positive value means it would be better to use the category on top.

		Utilitarianism	Rawls' Theory of Justice	Equal Sharing
Utilitarianism	General population	0	-5,7	-5,2
	Wealthy elderly	0	-0,8	-0,8
	Younger working class with non-western ethnic background	0	18,5	26,6
	Younger children families	0	0,0	-0,6
	Younger working class with western ethnic background	0	0,0	0,0
	Younger working class	0	-12,0	-6,2
	Lower educated, less wealth with children class	0	1,8	-7,5
	Lower educated, less wealth, ethnic background working class	0	6,0	-13,4

5 Verification

Verification and validation are useful steps of a research process. Verification is done to ensure the accuracy of the research. Validation is done to understand if the research is applicable for the research objective and if it is considered an accurate representation of reality. Validation of the research would be done by interviewing experts on the applicability of the trade-offs shown in this research. As there has been no contact with experts, the validation of this model is lacking. The verification of the research can be done to a certain extent. This verification is done twofold: model verification and societal groups verification.

5.1 Model verification

The output of the model cannot be verified completely as data on the travel behavior of the inhabitants of The Hague is unknown especially during a disruption. It is possible to compare the travel time in the BAU case with travel time data calculated by Google Maps. Google Maps uses a different way to calculate the travel time. It uses GPS data to analyze how long it takes to get from point A to point B. This means Google Maps can take real traffic data into account in their travel time calculations (*Wallin, 2020*).

The comparison between the model used in this research and Google Maps is done by picking 19 origin points to combine with the 19 different destinations used in this analysis. These will be used as input for the Google Maps routing calculation. The travel time given by the model and by Google Maps can be compared (Table 5.1).

Table 5.1 Validation of travel times calculated by the model and Google Maps.

The travel time of 19 origin neighborhoods and 19 different destinations as calculated by the model and calculated by Google Maps is shown. The difference between the two values is used for validation.

Origin neighborhood	Destination	Model travel time (min)	Google Maps travel time (min)	Difference (min)
Bohemen en Meer en Bos	Hospital	4.1	8	3.9
Morgenstond-Oost	Doctor	0.1	1	0.9
Morgenstond-Zuid	Pharmacy	2.2	4	1.8
Leyenburg	Supermarket	1.2	2	0.8
Bloemenbuurt-West	School	0.1	1	0.9
Laakhaven-Oost	Kindergarten	1.1	3	1.9
Laakkwartier-West	Childcare	0.5	3	2.5
Rustenburg	Bank	2.0	5	3.0
Zijden, Steden en Zichten	Post office	9.6	10	0.4
Venen Oorden en Raden	Sport	1.2	3	1.8
Hoge veld	Fitness	4.2	7	2.8
Landen	Park	3.3	5	1.7
Waterbuurt	Pub	0.9	4	3.1
Oud Scheveningen	Community space	4.8	9	4.2
Transvaalkwartier-Zuid	Library	3.1	7	3.9
Moerwijk-Zuid	Restaurant	1.9	5	3.1
Koningsplein e.o.	Bar	0.9	2	1.1
Schildersbuurt-West	Café	0.2	2	1.8
Duttendel	Fast food	2.8	5	2.2

The model always underestimates the travel time compared to the travel time of Google Maps. Google Maps takes travel time into account explaining the discrepancies. The difference between the two times is between 4.2 and 0.4 minutes. Often the travel time on shorter distances has a relatively higher discrepancy compares to the longer distances. The model used will most likely underestimate the travel time between origins and destinations.

5.2 Societal groups verification

The municipality of The Hague has created a disadvantage score of their neighborhoods. This score is based on the percentage of inhabitants with a non-western migration background, percentage of inhabitants with social benefits, average income, property valuation (WOZ) and percentage of inhabitants that moved in the last 3 years (*Den Haag, n.d.*). Higher values show a higher level of disadvantage. The values are grouped between below -12, -12 until -6, -6 until 0, 0 until 6 and higher than 6 (Figure 5.2). These 5 groups can be compared to the seven societal groups located in this research (Figure 5.1).

Figure 5.1 Different societal groups in The Hague.
The groups are located by using societal variables, removing noise with PCA and clustering the PCA values with DBSCAN algorithm. 7 different groups can be found and one noise category.

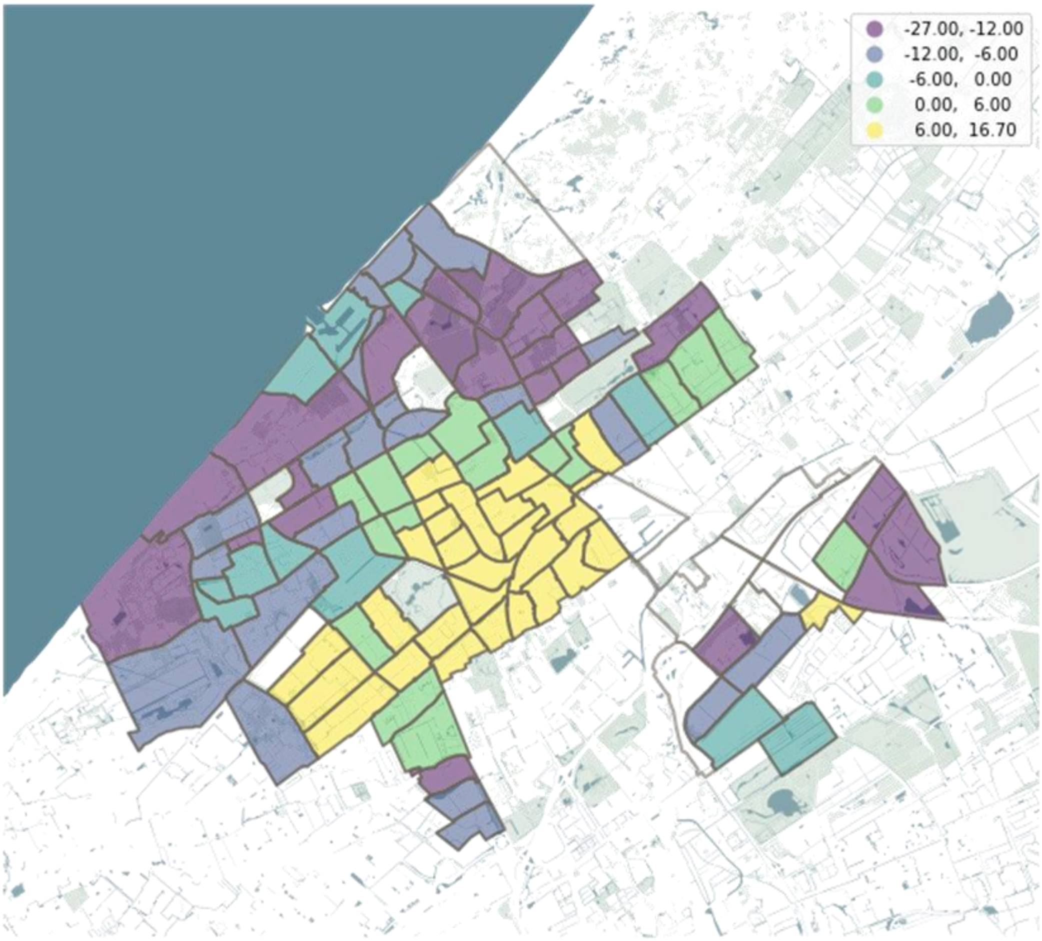

Figure 5.2 Groups based on disadvantage scores.
*The scores are based on percentage of inhabitants with a non-western migration background, percentage of inhabitants with social benefits, average income, property valuation (WOZ) and percentage of inhabitants that moved in the last 3 years (*Den Haag, n.d.*). Higher values show a higher level of disadvantage.*

The disadvantage score grouping shows similar grouping compared to the grouping used in this thesis. However, differences can be seen as the grouping in this model uses more variables relevant to weather-related disruptions. The scores of the municipality of The Hague relate more to the day-to-day life of the inhabitants. The most vulnerable groups in the city center do overlap with the disadvantage score grouping used by the municipality.

6 Discussion

This chapter discusses the interpretations of the results presented in chapter 4, the limitations of the research and the implications of the research on the academic world and society. This study assesses the impact of different equity principles on the change in accessibility for different societal groups in the urban area. This helps policymakers understand how to incorporate different equity principles in their resilient accessibility policy to potentially create more equitable accessibility in the context of a rainfall-induced disruption.

6.1 Interpretation of key findings

6.1.1 Business-as-usual accessibility

The accessibility to socio-economic opportunities in a business-as-usual scenario seems to be reasonably equally distributed for all different societal groups. With the current road network of The Hague, individuals of each societal group can access the different destination categories based on Needs within 15 minutes of travelling. Although societal groups on the outskirts of the urban area have a higher travel time compared to the other societal groups, their travel time is still within the 15-minute boundary.

Something that is important to note from the results is that there are differenced in the accessibility of different destinations. This is because the destinations that fall in the different categories (Physiological, Security and Safety & Social Needs) are not equally distributed throughout the urban area. For instance, locations that can provide social needs, such as restaurants, are located well throughout the city. However, accessibility to a hospital is often characterized by longer travel times when living on the outskirts of the city area.

6.1.2 Accessibility after a disruption

In the modelled analysis, the accessibility after a rainfall-induced disruption decreases for all societal groups in comparison to the BAU scenario. The increase in travel time is modest for most groups; on average the travel time increases by 1.4 minutes. Some individuals from certain neighborhoods are not able to reach a destination within 15 minutes of travel, however, there are no extreme outliers. However, there are individuals in some neighborhoods who are completely blocked from leaving their neighborhood and can therefore not access certain destinations outside of their neighborhood. These groups (could) suffer from lack of access to their basic needs (e.g., food). The analysis shows that the neighborhoods that are blocked are mostly located in the city center. This can be explained by the fact that the main impact (rainfall accumulation leading to disruption) on road network is in this area. Additionally, the individuals living these neighborhoods are also more dependent on accessibility to certain destinations for their basic needs as these neighborhoods are populated by societal groups that are generally lower educated, working-class and ethnically foreign. The analysis shows that although these societal groups are more vulnerable to disruptions, that they are the most impacted by a rainfall-induced disruption. The most socially vulnerable societal group experiences an increase in travel time of 87%, which is higher than the average increase in travel time for all other groups in the urban area (67%).

6.1.3 Accessibility after interventions

Certain road segments marked for interventions show overlap between the different principles. These are interventions that based on this analysis, could be placed regardless of the impact a decision maker wishes to make on the urban area. These are segments that should be considered in an analysis as this could make deciding between interventions easier.

6.1.3.1 Utilitarianism

Once interventions are placed following the Utilitarianism principle, the accessibility after a disruption can change, albeit not equally for every societal groups. The general population is mainly benefitted by using the Utilitarian principle to the placement of interventions, as the interventions based on this principle can cause the highest decrease in both the total travel time and the total number of people blocked from their destinations. Only the younger working class with a non-western ethnic background would be significantly benefitted by placing interventions using the Utilitarianism principle. These are the societal groups who are located more towards the outskirts of the urban area and who are less socially vulnerable than the groups living in the center of The Hague.

This shows that even though the impact on the general population might be the most significant, specific societal groups that are most vulnerable are not impacted enough by interventions that are placed following the Utilitarianism principle.

6.1.3.2 Rawls' Theory of Justice

The placement of interventions based on Rawls' Theory of Justice has a significant effect on the general population of the urban area, although somewhat less than the impact of the Utilitarian principle. Rawls' Theory of Justice does have a clearer impact on the most vulnerable societal groups in the city center, decreasing their travel time more than the Utilitarian principle could do. Since the principle is focused on a specific group, the effect becomes clearer. The younger working class, lower educated, less wealth with children class and the lower educated, less wealth, ethnic background working class would all prefer these interventions based on their travel time. Only the younger working class does not show a significant decrease for their travel time, the other two groups do.

The interventions show a similar effect on the people blocked from their destinations. The general population would have an increase in blocked inhabitants. However, the impact on different groups is larger. The lower educated, less wealthy families with children and the lower educated, less wealthy, working-class people with a foreign ethnic background would significantly benefit more from the placement of interventions based on Rawls' Theory of Justice.

There is a clearer focus on the more socially vulnerable groups with the Rawlsian based interventions. Although general population would benefit more from the Utilitarian based interventions, specific vulnerable societal groups would benefit more from the Rawlsian based interventions. Depending on what the focus would be of the policy, one or the other principle could be chosen.

6.1.3.3 Equal Sharing

The impact of Equal Sharing is less on the general population. There is still a significant decrease in travel time. However, both Utilitarian and Rawlsian based interventions score better on decreasing travel time than the Equal Sharing based interventions. The impact on groups is different as well. No societal group would be better off by implementing interventions following the Equal Sharing principle in comparison to using other principles.

For the blocked inhabitants, Equal Sharing does still show a significant decrease of blocked inhabitants in the general population. Furthermore, one group, the younger working class with non-western ethnic background, would prefer the interventions based on this principle over other interventions. This effect is significant as well for this group. The younger working class with non-western ethnic background is the smallest group of all societal groups determined in this research project. Since all groups get an equal number of interventions, it can be noted that this group has relatively the greatest number of interventions for the number of routes they take.

Since Equal Sharing based interventions do not focus on the distribution of the outcome of interventions but are focused on providing the distribution of placement, it is suggestable that this the principle should not be used to provide equity outcomes, but equity of intervention placement.

6.2 Limitations

This research mainly focusses on the impact that different interventions that are placed based on equity principles has on different societal groups. It is important to argue for the choices and limitations in this and recommendations can be made for future research to improve the study.

6.2.1 Data

The data used in this model is related to a case of the city of The Hague. The outcomes of the location where a disruption happens and where the vulnerable people live is dependent on the case used and outcomes could be different in different locations. The case only uses one type of disruption, e.g., pluvial flooding, in this area while other disruptions could have impact at different locations than the one used in this case. The city of The Hague is in a developed country of the Netherlands. Cases in different countries that might be in the Global South, could have different outcomes as the relationship between vulnerable groups and less vulnerable groups is different. Furthermore, the prioritization of destinations can be different for people in the Global South (e.g., fitness may be less of a priority).

The data of CBS on the societal characteristics in The Hague is provided at a neighborhood level. Therefore, the model takes the centroids of the neighborhood as an origin point and assigns the number of people living in this neighborhood to this origin point. The exact location or a closer approximation of the inhabitants is not used in this model and is harder to find. For some groups, the travel time and if they are blocked from the destinations could therefore change based on where they reside.

The data on the disruption used in this research is data of a certain moment in time. The accessibility calculated in this model in different situations are also moments in time and not a continuous model where the accessibility changes as the disruption progresses. This change could show different results in different states. Some groups might be blocked longer than other groups, changing the overall impact of the disruption for them.

The model uses data on the locations of different destinations to understand where people could want to travel to. However, data on where people actually travel to is unknown. Inhabitants might prefer certain supermarkets over others as the nearest supermarket might not carry the products they need. Accessibility is not just about the travel time between locations but also the options people have. One could argue that during a disruption, it is not about the preference but about the ability to access destinations someone would need. Then, the preferred location matters less, and the nearest locations matter more.

6.2.2 Model

The model uses Dijkstra's Algorithm to calculate the travel time on roads between the societal groups and their destinations. Dijkstra's Algorithm does not take the amount of traffic into account when calculating the routing. In business-as-usual scenarios, this traffic might play a role in how fast someone is able to travel to their destination.

The model is also created for a road network. A combination of different types of transportation networks would be a more accurate representation of the accessibility in the urban area. People do not just have the choice to drive, but could walk, cycle, take public transport or a combination of the different systems to reach their destinations. One might have better access with a bicycle than with a car to a certain destination. Some people might not be in the possession of a car which decreases their accessibility. Furthermore, it is conceivable that public transportation can continue in some form even though some road segments are blocked. For instance, buses can find detours via other road segments.

The model uses data of the disruption to decide whether to either block or leave open road segments. However, it should also be a possibility that a road segment causes a delay in travel time. When a road segment has a lower level of water, it is still possible to travel over this road segment without a loss of time in the model. However, when there is water, people are likely driving more slowly than they would be in a normal situation, decreasing their accessibility compared to the model outcomes.

The model is static so if a destination will be opened after a disruption, this impact will be immediate and has no further impact on other road segments. However, if alterations are done to a network, it is likely that the water will not simply disappear. The water will relocate to other road segments. Therefore, this impact of interventions should also be taken into account when creating a complete model showing the impact of interventions.

In the model it is only possible for people to access the destinations on their own. Yet during disruptions people are often helped by emergency services. Especially when they are locked in their houses. These services are important to consider as another aspect of what interventions could be done to help the people out in this case. Relocating inhabitants to different locations could help them have a temporary better accessibility level.

In this research, only the direct effect of the disruption on the accessibility of people is considered. But there could be more indirect effects that should also be included when determining the effect of a disruption on the accessibility. After such an event, people located at the center of the disruption could lose belongings that make their accessibility level higher. A simple example is a car that might need repairing after too much damage has been done because of this disaster. Inhabitants might also lose wealth because of everything that has to be restored after a disruption. Losing wealth could make them even more vulnerable in society. These are factors not included in a model that focuses on the direct impact of a disruption event and that should be considered for the accessibility in the long run.

6.2.3 Equity principles

The quantification of the equity principles is considerably determined by the assumptions of the modeler. There is room for how to interpret the definitions of the ethical principles found in literature, which makes quantifying these ethical principles subjective to the interpretation of the modeler. The modeler therefore already has a significant effect on what the results will be. It is important to talk through these assumptions and be open about them. The specific use will determine the way these principles will be quantified.

The current quantification tries to stay as close to the definitions of these principles as possible. However, there are some choices that could be modelled differently. The quantification of Rawls' Theory of Justice currently picks interventions only for the most vulnerable group in society. An argument could be made to include the most vulnerable two or three groups since it is hard to determine an order of vulnerable to least vulnerable.

Another possibility would be to classify the most vulnerable group as the one with the highest travel time instead of considering their societal background. This would be another definition of vulnerability. Different groups could be picked in this research and the outcomes could change.

6.3 Implications of findings

The implications of the study become clear when considering the results and its limitations. The implication of the findings will be split up into two parts: implications for academics and implications for society.

6.3.1 Implications for academics

This research combines different fields of research in both the urban data science, risk assessment, accessibility and equity fields to see what the impact would be of using equity principles to guide interventions impacting the accessibility of different societal groups in an urban area after a disruption. It shows how groups can be located by using a clustering methodology and combines the data with Dijkstra's Algorithm.

6.3.1.1 BAU scenario

This thesis uses a road network for cars for the analysis. However, 42% of the trips are executed by car by inhabitants of The Hague (*Kennisinstituut voor Mobiliteitsbeleid, 2019*). 20% of trips are executed by walking and 20% of trips by cycling towards the destination. 15% is done by travelling with public transport. This shows that not every trip is done by car and other transportation modes are a possibility for inhabitants as well. The Hague is an average city for other cities in the Netherlands, meaning that the number of people travelling by car is average for a city in the Netherlands. As this research is applicable for multiple transportation networks, the same analysis can be done for the different networks. However, not much is expected to change with regards to the outcomes of this research. Similar road segments would be blocked for the different transportation networks, therefore, it should also be difficult for people to walk towards a certain destination if they cannot drive towards it. Similar destinations and origins could be used as well. This means that perhaps the output changes slightly, but the main message of this work remains. As the methodology is applicable to multiple networks, the same analysis could be executed to confirm or deny this hypothesis.

The choice of destinations used in this research is based on literature on the need or wish to access certain destinations in an urban area as well as literature related to spatial equity issues (*Abley, 2010*; *Dempsey et al., 2011*; *Geurs & Van Wee, 2004*; *Lotfi & Koohsari, 2009*; *Taleai et al., 2014*; *Tsou et al., 2005*). A literature review has been done to finalize this list of destinations. Employment locations and cemeteries are not included based on the literature review. Cemeteries are not used daily and were excluded for this analysis. If cemeteries would be included, another destination would be added to the Social Needs category. The impact of adding cemeteries to the Social Needs category would not change the research much as cemeteries are similarly distributed across the urban area. Places of employment are part of the Security and safety category as having an income for food, shelter and clothing is essential. The place of employment is interesting to analyze but requires a different analysis and reasoning method used in this research. Not taking places of employment into account does limit this research as this is an important category in the daily lives of inhabitants of an urban area. If the exact location of work can be determined for the origin points, this method could be applied, otherwise a different method would have to be developed. This could be using centroids of neighborhoods as well and assigning the number of workplaces in that neighborhood to this centroid. But the method used in this research can be used for other destinations in other cities and countries. Depending on the spread of the destination, similar results for accessibility could be found. In developed countries this spread might be better than for developing countries. Therefore, the results of this research are more applicable to developed countries than for developed countries.

6.3.1.2 After disruption

As has been mentioned in the literature overview, a decrease of 73% of travel trips in the public transportation system is expected to happen during precipitation events (*Han et al., 2017*). For road transportation and walking, this loss of trips is respectively 9.9% and 7.8%. Most of the trips lost in public transportation and car travel are reallocated to walking trips (*Han et al., 2017*). As the urban area is dense, other options are available as shown by this analysis. Not all trips executed by car in this research are therefore expected to be executed by car. This could change the travel time of the destinations close to the origins since people might opt to walk or cycle when a destination is close. However, the destinations that are further from the origin in this research will most likely still be reached by either car or public transportation. The public transportation mode is expected to have a larger travel time compared to the car network as people would have to use multimodal transportation to get to their destination, increasing the gaps between outliers even further than has already been the case. However, as the destinations might not change for the inhabitants of an urban area, this research could be used to understand the travel time after a disruption.

The destinations used are classified for understanding the needs of the inhabitants of an urban area by using Maslow's Hierarchy of Needs. This is done to understand the importance of a destination after a disruption. This classification is applicable to any type of disruption, therefore, making it easy to use for other research purposes related to accessibility during a disruption.

For other types of disruptions, the same methodology could be applied, and similar results can be found. Depending on what the hazard map would look like, a different impact on societal groups can be found. However, as multiple studies show that the impact on more vulnerable societal groups is higher, this research is in line with this conclusion and similar results with regards to accessibility can be expected in other countries and cities (*Bolin & Kurtz, 2018*).

6.3.1.3 After interventions

The research shows a way of quantifying equity principles in a disruption scenario to understand where interventions need to be placed on road segments. This quantification method can be used by future studies to criticize and build upon. It opens doors to further understand what is important to reduce the impact of disruptions and where this impact can be seen the most. The research shows the importance of helping not only by reducing the travel time, but also by reducing the people that have no access at all as they are blocked from the destinations.

The results show that the Utilitarian principle and Rawls' principle-based interventions can have more effect for the same number of interventions on the societal groups than the interventions based on the Equal Sharing principle. However, it is important to understand what the effect is one wants to achieve. Utilitarian and Rawls' influence the outcome of the accessibility while Equal Sharing influences the distribution of the interventions. The principles are based on different ideas and are therefore hard to compare in figures.

For the current practice of policy assessments, this study can add to current risk assessment practices. This research can add to the intangible indirect damage costs which are currently still hard to quantify. This research shows a methodology which can be easily changed to fit different disruptions, different societal groups, different destinations and different origins in other urban areas or countries. As other costs are more easily quantifiable, this research can add to the quantification of a complete risk assessment. This research goes beyond the quantification and even shows how to take on the impact for different societal groups which is still lacking in current analyses.

This thesis uses the capacity to resist as the definition of resilience, however, there are other definitions mentioned in this research that were not analyzed. To understand different resilience definitions in the context of this research, this research can be altered to fit a different type of definition:

- The capacity to rebound can be used by altering this research to use more different time steps. When there is another time step added which is, for example, one hour after disruption, the capacity to rebound can be included. Different types of interventions that increase the capacity to rebound can be included based on equity principles.
- The capacity to adapt would require a larger change in the methodology. One could argue to include multiple transportation networks and include the shift of people using the different networks to understand what the total accessibility would be after a disruption based on the adaptation of people to different networks. The

interventions based on equity principles would be based on an easier shift to a different network, making this harder to include in this analysis.

- The capacity to continually adapt would include the method described for the capacity to adapt. However, instead of analyzing this for one time step, multiple time steps would have to be analyzed to understand the continuity aspect.

These different types of resilience definitions will most likely lead to different placements of interventions. However, if the outcome of this research will change is unknown. It is expected that Utilitarianism will still be most beneficial to the general population and Rawlsian will be beneficial for the most socially vulnerable group. Equal Sharing will most likely still have less impact.

6.3.2 Implications on society

The implications on society lie in understanding the effect of the choices a policymaker makes for the different societal groups in an urban area. This research shows that using different guidelines to decide where to place interventions influences the distribution of the impact. The study shows that there are multiple places to focus on for a policymaker. The focus could be on the destination type that inhabitants wish to access, the measure that is used for determining where the most effect is (just use the travel time or consider blocked groups as well) and the groups that are benefitted by the intervention.

In this case, the most vulnerable people are affected more by the disruption than the people that are less vulnerable. For society, it is necessary to understand who is being affected in these cases to help the people during a disruption that need it the most.

This thesis classifies destinations that might be of importance with Maslow's Hierarchy of Needs. This classification is useful for policymakers to understand where their time and energy should be focused on during disruption situations. Therefore, this classification can be used by policymakers for other types of analyses involving disruptions or emergency planning.

The methodology and figures used show an easy way to compare the impact of interventions based on different equity principles and is not limited to destinations, societal groups, the network used, or the urban area used in this analysis. It is therefore ready for use for decisionmakers to base their decisions on or to extent even further with new equity principles on.

The 15-minute measurement also makes it easier to understand for decisionmakers what an acceptable level of travel time for the inhabitants of their urban area can be. The figures shown here, easily show if one would have to alter something in the urban area or if the travel time could be classified as sufficient.

The research shows that there is a clear consideration to be made between focusing on the general population or the most vulnerable groups. If decisionmakers were to pick interventions based on what would be best for the general population, individual groups would notice the effect less. If the focus would be on the individual groups, the impact on the general population will be less. The allocation of the resources should be carefully determined.

6.4 Recommendations

As mentioned during the limitations, there are several ways this research can be improved.

Firstly, the model could focus on a more extensive definition of accessibility. Different transportation networks, such as walking and cycling, could be modelled and analyzed together with the road network to get a better understanding of the accessibility of different societal groups. Besides using different networks, the model could also include more accurate locations of where the people live in the urban area instead of using neighborhood centroids.

The model could be more supported by actual traffic data. Using traffic jams and the routes used by real inhabitants could be used to make a more accurate representation of the travel patterns of the inhabitants of the area. It would be beneficial for the research area if the accessibility patterns of groups are analyzed during an actual disruption to validate the model and get a better understanding of what accessibility entails during a disruption.

If data of disasters can be retrieved that are continuous in time scale, the same model could be recreated over time to not only understand accessibility before and right after a disruption. This could help with understanding the impact in different scenarios when the disruption is happening and when it has been ongoing for some time. The accessibility could then be measured over time as well instead of at discrete moments in time. This can help understand if the results show a similar impact when different definitions of resilience are used.

This research could be recreated and used for different equity principles, or a different quantification of the principles than currently used. This could show even more impact on the societal groups. Perhaps some principles that are more complex to quantify can create a different distribution of the benefits of the interventions. Equity based on the Gini- and Suits-coefficient as done by *Rubensson et al. (2020)* would be an interesting quantification. Different locations in the global south could also provide new insights by comparing this research to the research of a less wealthy country.

Lastly, more intervention types could be used to further explore the impact of choosing different interventions based on equity principles instead of choosing the location of an intervention. As mentioned, future research could explore the possibilities of creating more locations for the basic needs destinations or include emergency services as another possibility during a disruption.

7 | Conclusion

This chapter concludes on the main research question asked in Chapter 1.4 as well as the sub-questions leading to answering this main research question. The final section will explain the link to the Master program Engineering and Policy Analysis for which this thesis was conducted.

7.1 Answering research questions

The main research question for this thesis was:

What is the role of different equity principles in addressing inequalities to guide resilient accessibility policy in the context of a disaster-induced disruption?

7.1.1 Sub-question 1

What is the current accessibility to socio-economic opportunities for different societal groups?

The current accessibility to socio-economic opportunities is similar for most groups in The Hague urban area. A clear effect of the location can be seen in the travel time to the destinations. Societal groups that are located towards the outskirts, have a longer travel time to their destinations than the groups living in the center of the city. These groups are less socially vulnerable than the groups living in the city center. This travel time changes slightly between destinations that are meant to provide basic needs and destinations that are there for Social Needs. The Social Needs destinations are more spread out in the urban area while the basic needs, such as hospitals, are less spread out. Individuals therefore often have a longer travel time for their basic needs than they do for fulfilling their social needs.

7.1.2 Sub-question 2

What is the impact of a disaster-induced disruption on the accessibility to these opportunities?

The rainfall-induced disruptions affect societally vulnerable groups more than they affect the wealthier groups. The vulnerable groups have a larger increase in their travel time and are more often blocked from the destinations they wish to reach. These groups experience an 87% increase in their travel time compared to all other groups in The Hague and are 69% more likely to be blocked from their destination compared to other groups. This can be explained by the fact that the more vulnerable groups live in an area which is affected more by the disruption.

7.1.3 Sub-question 3

How does the decision regarding the placement of interventions change when different equity principles are considered?

The interventions are based on the quantification of each equity principle. Utilitarianism focuses on what is best for the most inhabitants in the urban area. Rawls' Theory of Justice focuses on the most vulnerable group within this urban area. Equal Sharing places an equal number of interventions for all societal groups in the urban area.

Based on these principles, Utilitarian based interventions are mainly placed in the city center as this is the location where most people are travelling through and where most destinations are located. Rawlsian based interventions are located near the neighborhoods where the most vulnerable group is located as this principle is helping this group of people. Equal Sharing based interventions are spread out through the entire urban area and can be found near neighborhoods of all different societal groups.

7.1.4 Sub-question 4

What is the accessibility after a disaster-induced disruption mitigated by interventions for different societal groups?

The accessibility level increases for most groups after interventions are put in place. The interventions based on equity principles do have an effect in how this accessibility changes. These interventions are unable to bring the accessibility back to the current accessibility level. More interventions would need to be placed to achieve this.

The Utilitarian based interventions show a significant decrease in travel time for all inhabitants in the urban area. They also have a significant impact on certain societal groups but which societal groups benefit because of what intervention scenario is not clear. This principle also changes the number of people blocked from their destination because of the disaster-induced disruption but what group benefits is likewise not clear.

The Rawlsian based interventions show a significant decrease in travel time for the general population, albeit a slightly smaller decrease than when using Utilitarianism to guide intervention placement. The travel times do show some clear groups that are benefitting from these interventions. The most vulnerable group on which this principle focuses has a reduction in both travel time (3.5%) and number of people blocked (6.0%).

The Equal Sharing principle would not be favored by different societal groups when considering the decrease in travel time. Either the Rawlsian principle or the Utilitarian principle would generate a larger decrease in travel time for the different societal groups. Only if the groups are very small, an impact of the interventions can be seen on the number of blocked inhabitants. It should be noted that it is more difficult to compare the outcomes of this principle to the outcomes of the previous principles as this intervention does not focus on the effect of the intervention but more on the assignment of the intervention.

7.1.5 Main question

Based on the sub-questions, the main research question can be answered.

What is the role of different equity principles in addressing inequalities to guide resilient accessibility policy in the context of a rainfall-induced disruption?

The use of different equity principles has different impacts on different societal groups. The effect can be noted both in the travel time after a rainfall-induced disruption and in the number of people blocked from their destinations.

Basing these interventions on different measurements which different policymakers can find important, such as the destinations one wishes to reach, focusing on total accessibility or the decrease in accessibility in combination with these principles show different locations for the interventions. These different interventions show different travel times for different societal groups. This shows that simply changing the underlying assumptions of why a certain intervention is placed at a certain location can have an impact on the societal groups living in the urban area. Placing an intervention based on the Utilitarian principle could generate a lower travel time and less people blocked for the general population but less individual groups benefit for these interventions. Placing an intervention based on the Rawlsian principle could generate a slightly less substantial decrease in travel time for the general population but does have a clear impact on the socially vulnerable groups. Placing an intervention based on the Equal Sharing principle could generate a lower decrease in travel time for the general population and all groups but could be considered more equal as all groups get their share. To reduce inequalities, decisionmakers should keep the impact of these different policies in mind and choose the guidelines that influence where interventions are placed carefully.

7.2 Link to Master program

The Engineering and Policy Analysis program focuses on two themes: policy & politics and analytics, modelling & simulation. The program tries to teach students how to analyze and solve complex problems that do not have a clear solution. These problems require a link between both the technological as well as the societal and political aspect. This research has created a technical model using the techniques learned in the program and has applied this to a societal problem, therefore, fulfilling the expectations.

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Appendices

A. Destinations

Table A.1 Destinations and the OSMnx tag.

Destination	Amenity tag
Pharmacy	chemist
Doctor	doctors
Hospital	hospital
Supermarket	supermarket
School	school
Kindergarten	kindergarten
Childcare	childcare
Bank	bank
Post office	post_office
Sport	sports_centre, sports_hall
Fitness	fitness_centre
Park	park
Pub	pub
Community space	community_centre
Library	library
Restaurant	restaurant
Café	cafe
Bar	bar
Fast food	fast_food

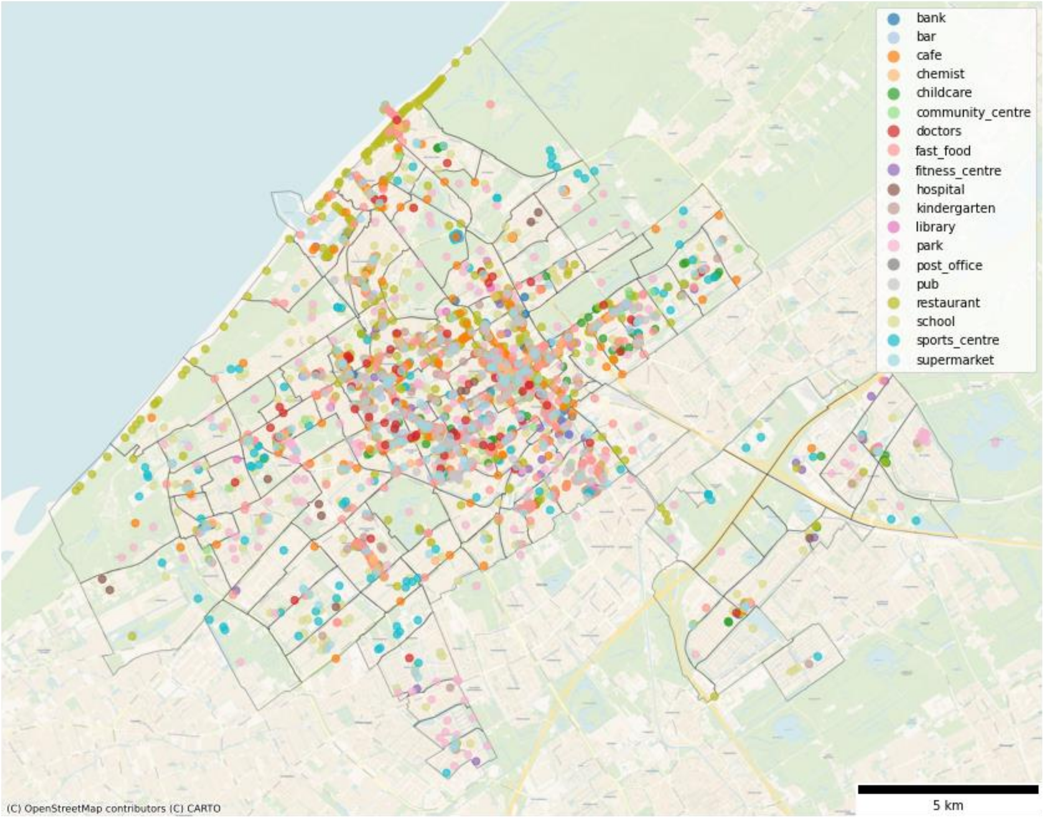

Figure A.1 All destinations for the accessibility calculation

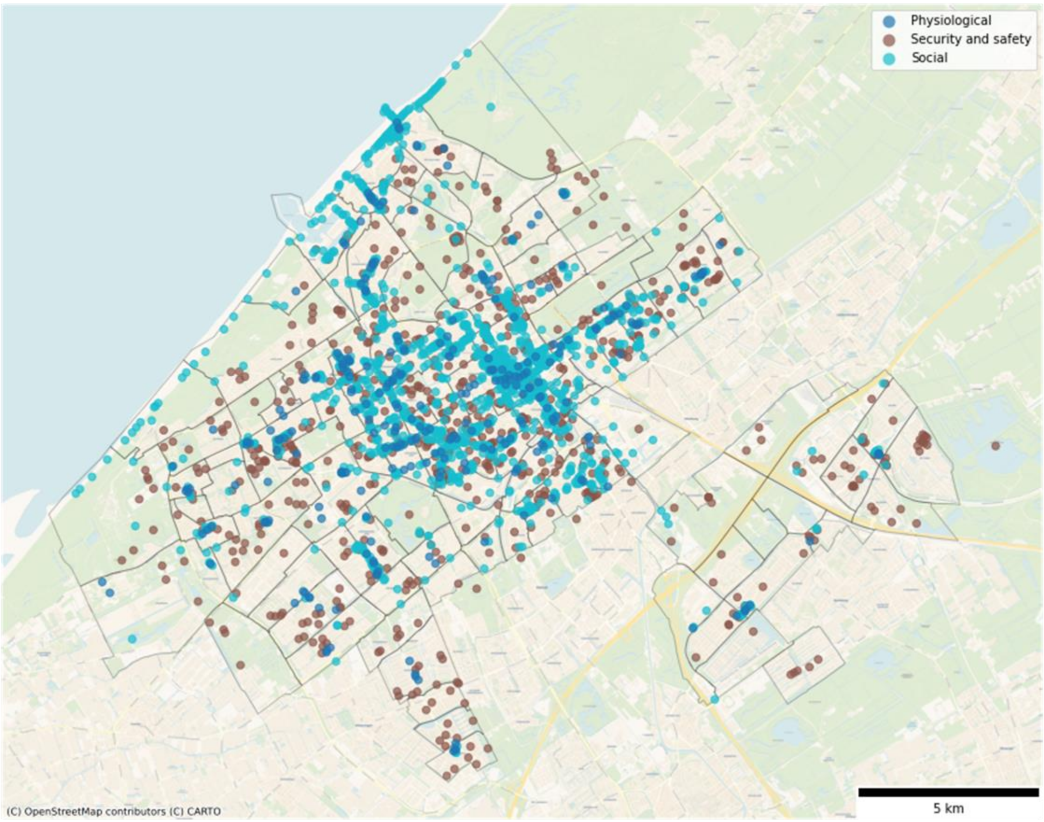

Figure A.2 Grouped destinations for the intervention sets

B. Societal groups

Table B.1 Societal variables at neighborhood level.
These variables will be used for determining the different societal groups in The Hague. The variables will be scaled and used as input for a PCA analysis.

Variable	Data type
Men	percentage
Women	percentage
0-14 years old	percentage
15-24 years old	percentage
25-44 years old	percentage
45-64 years old	percentage
65 years old and older	percentage
Unmarried	percentage
Married	percentage
Divorced	percentage
Widowed	percentage
Western ethnicity	percentage
Non-western ethnicity	percentage
Moroccan ethnicity	percentage
Dutch Antilles or Aruba ethnicity	percentage
Suriname ethnicity	percentage
Turkish ethnicity	percentage
Other non-western ethnicity	percentage
One person household	percentage
Household without children	percentage
Household with children	percentage
Average household size	float number
Average number of people with income in household	percentage
Average income per person with income	float number
Average income per person	float number

Households below lowest 40% income threshold	percentage
Households above highest 20% income threshold	percentage
Households with low income	percentage
Households with income below or around social minimum	percentage
People with social benefits	percentage
People with disability benefits	percentage
People with unemployment benefits	percentage
People with state pension	percentage
People with lower education level	percentage
People with middle education level	percentage
People with higher education level	percentage

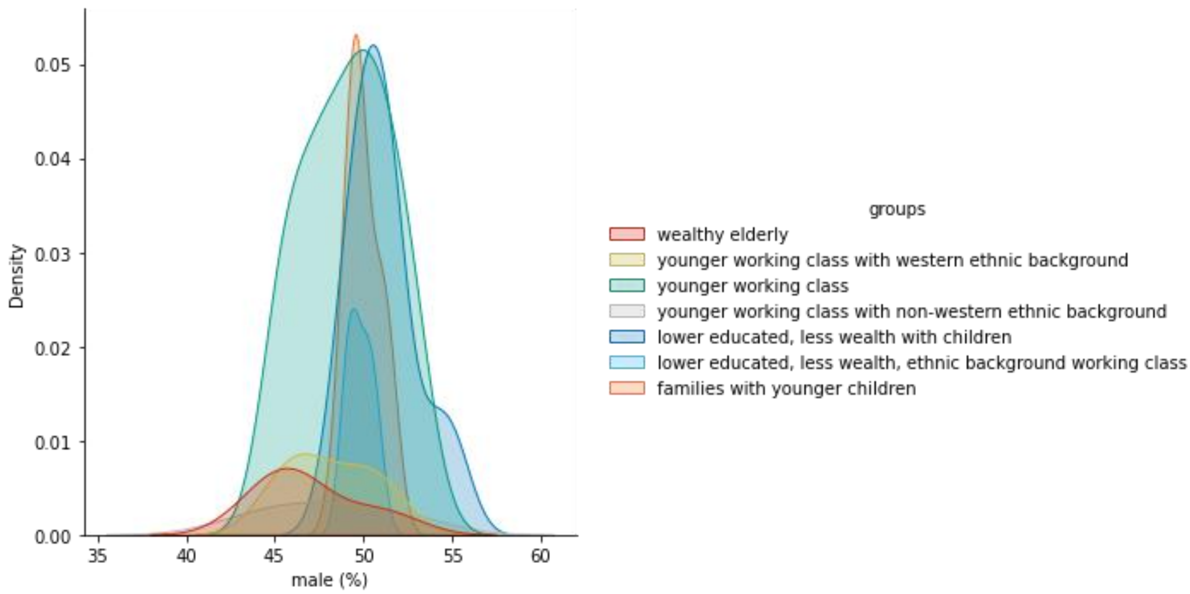

Figure B.1 Density plot for male percentage in groups

Figure B.2 Density plot for female percentage in groups

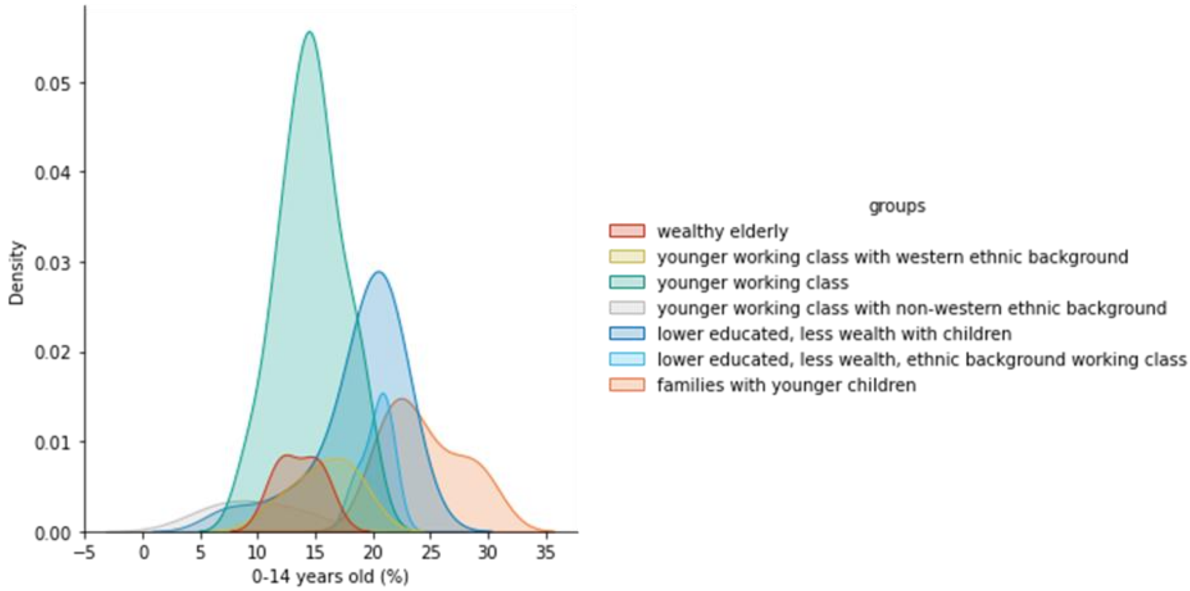

Figure B.3 Density plot for 0-14 years old percentage in groups

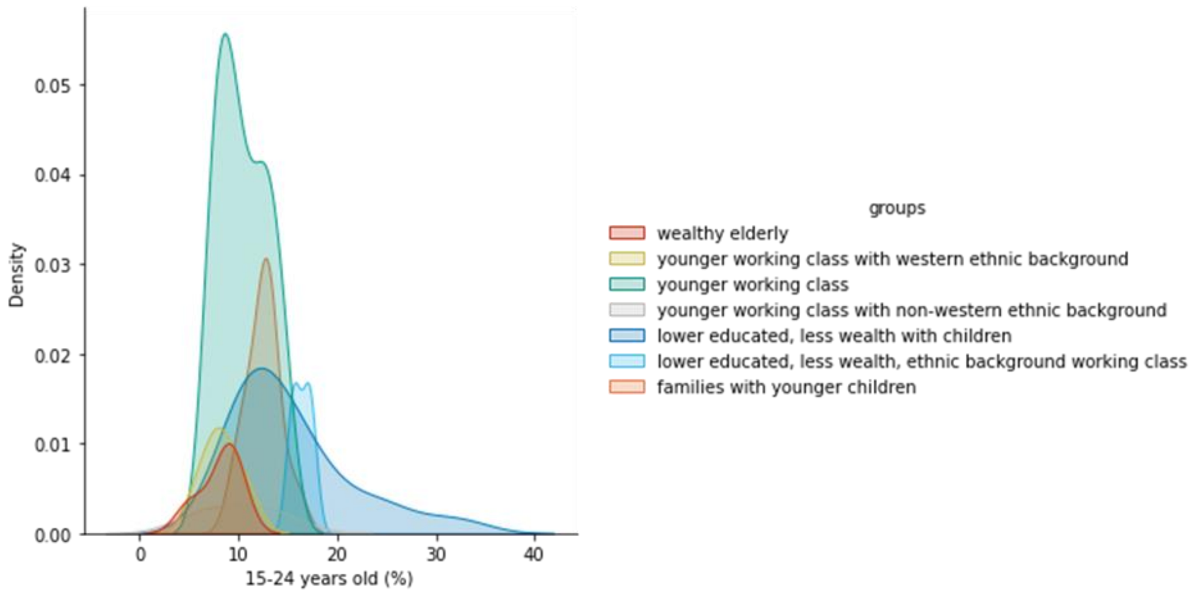

Figure B.4 Density plot for 15-24 years old percentage in groups

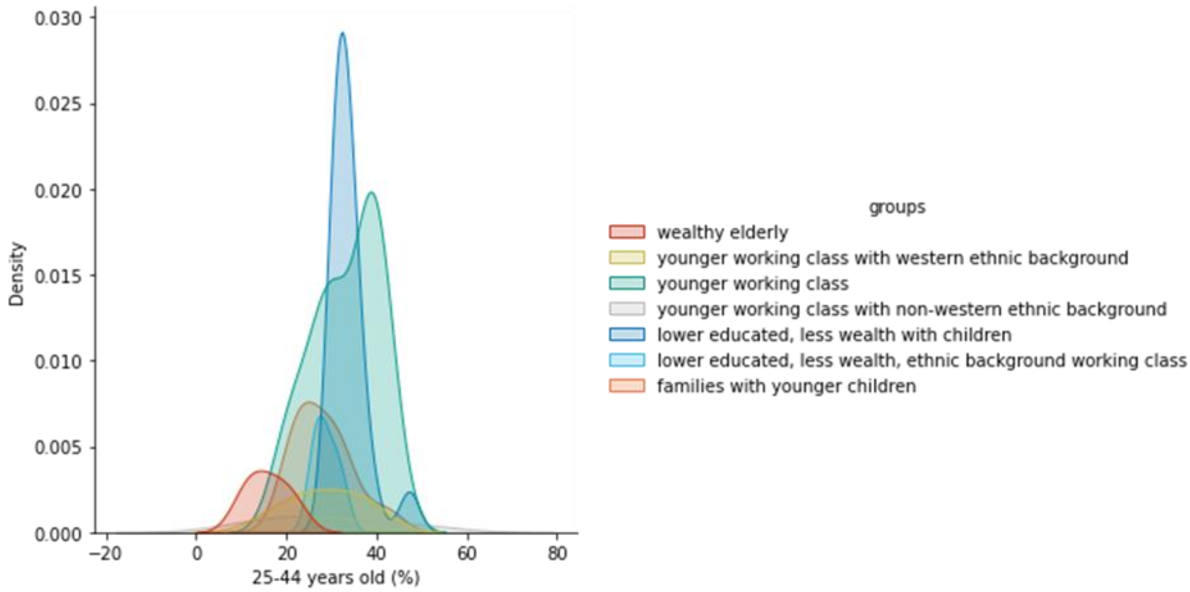

Figure B.5 Density plot for 25-44 years old percentage in groups

Figure B.6 Density plot for 45-64 years old percentage in groups

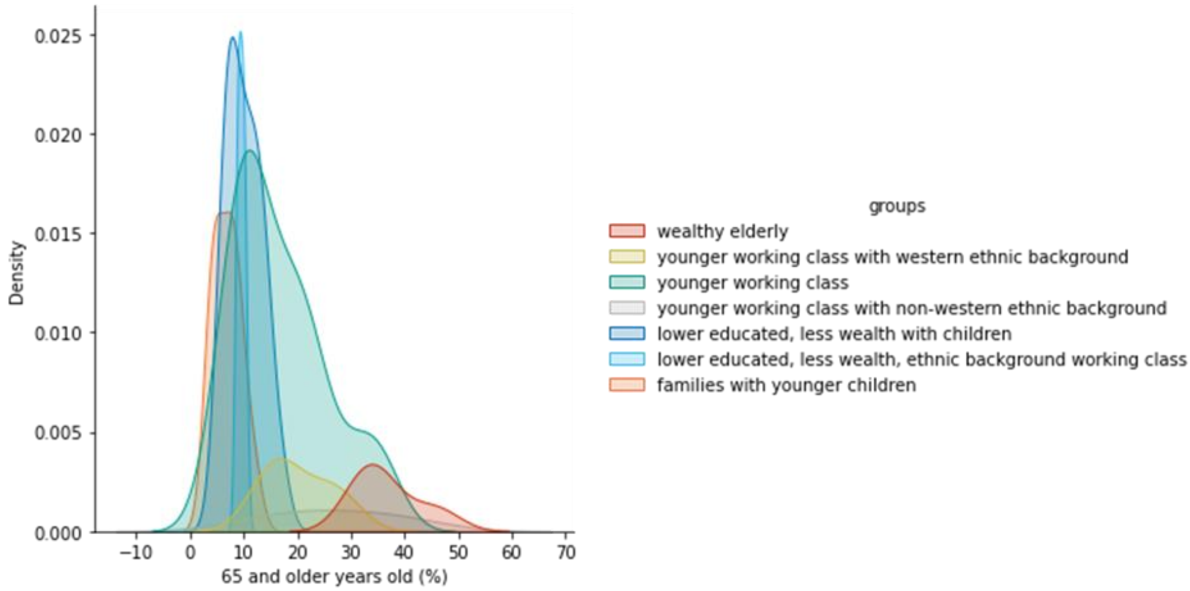

Figure B.7 Density plot for 65 and older years percentage in groups

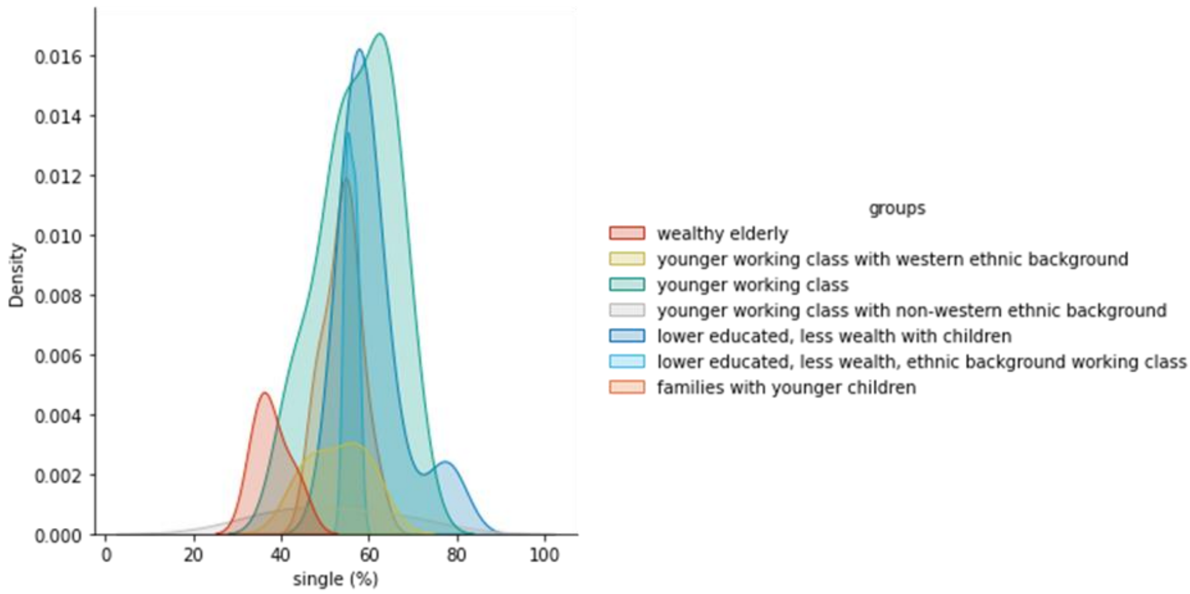

Figure B.8 Density plot for single people percentage in groups

Figure B.9 Density plot for married people percentage in groups

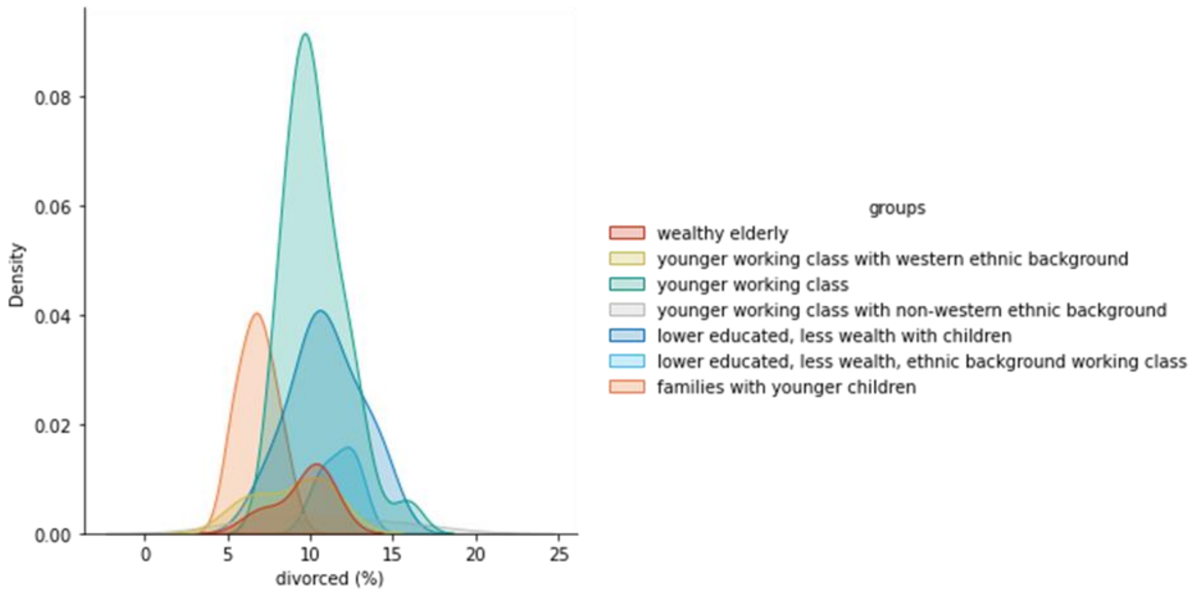

Figure B.10 Density plot for divorced people percentage in groups

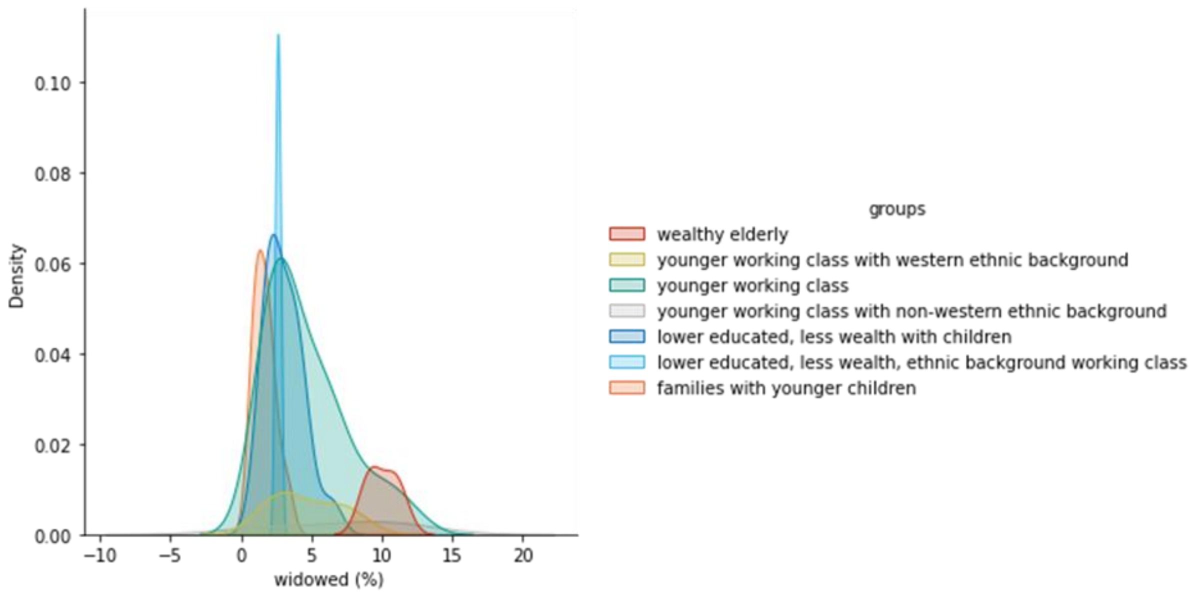

Figure B.11 Density plot for widowed people percentage in groups

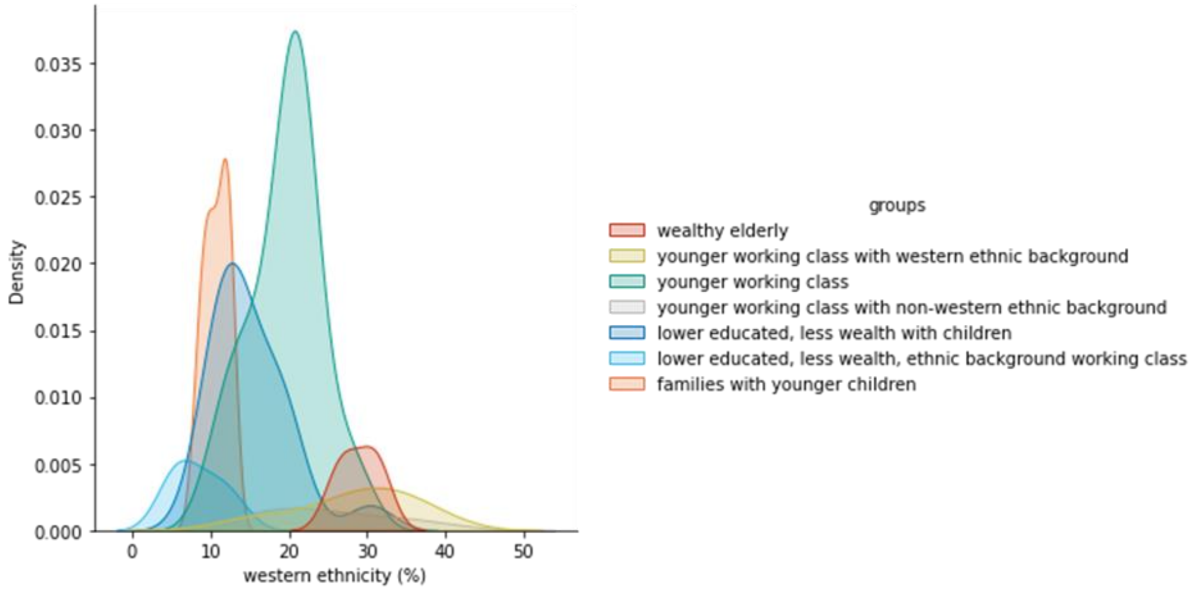

Figure B.12 Density plot for percentage people of western ethnicity in groups

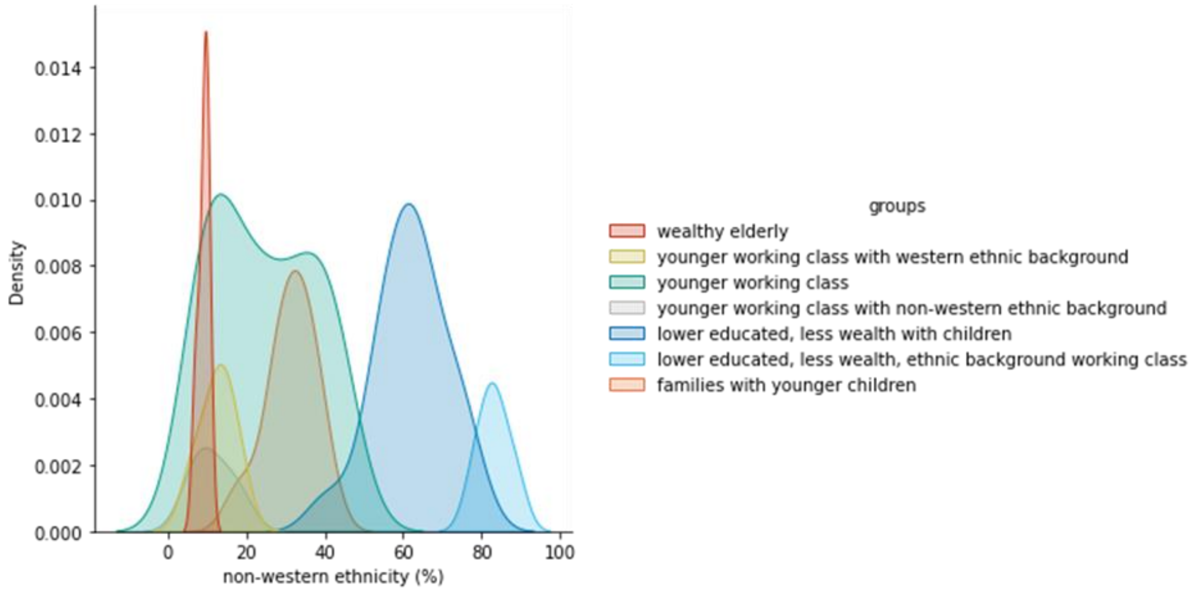

Figure B.13 Density plot for percentage people of non-western ethnicity in groups

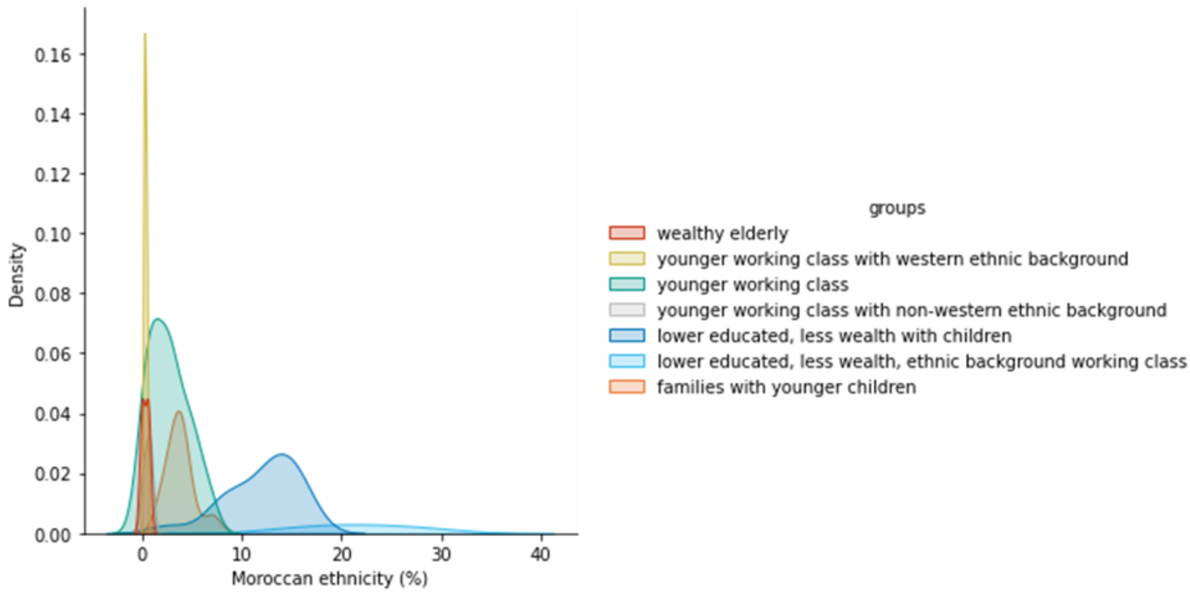

Figure B.14 Density plot for percentage people of Moroccan ethnicity in groups

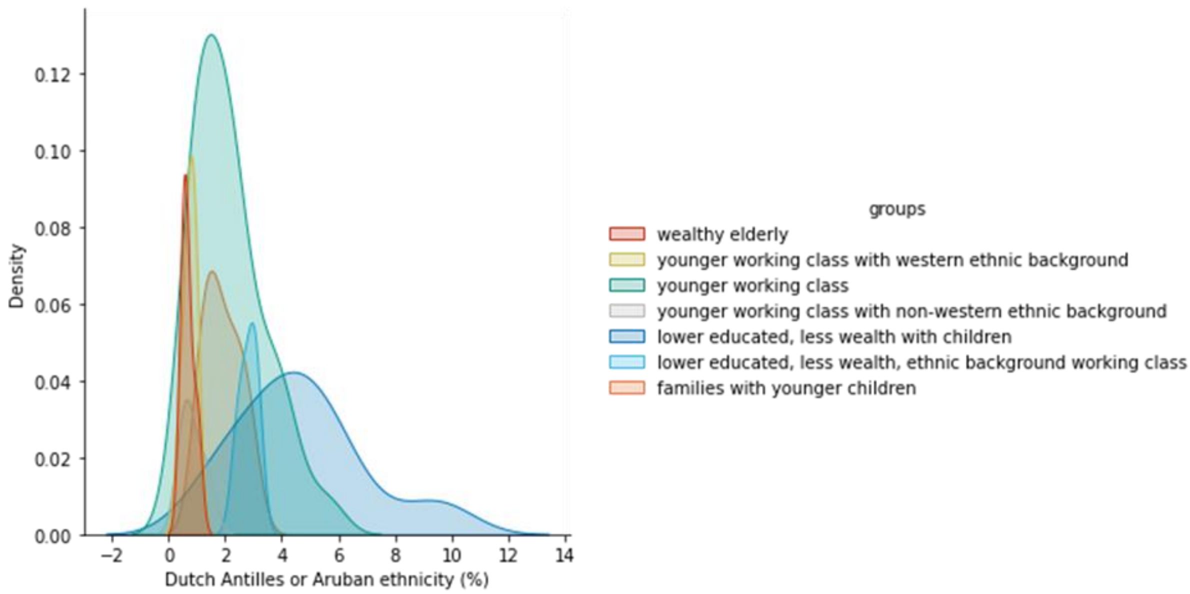

Figure B.15 Density plot for percentage people of Dutch Antilles or Aruban ethnicity in groups

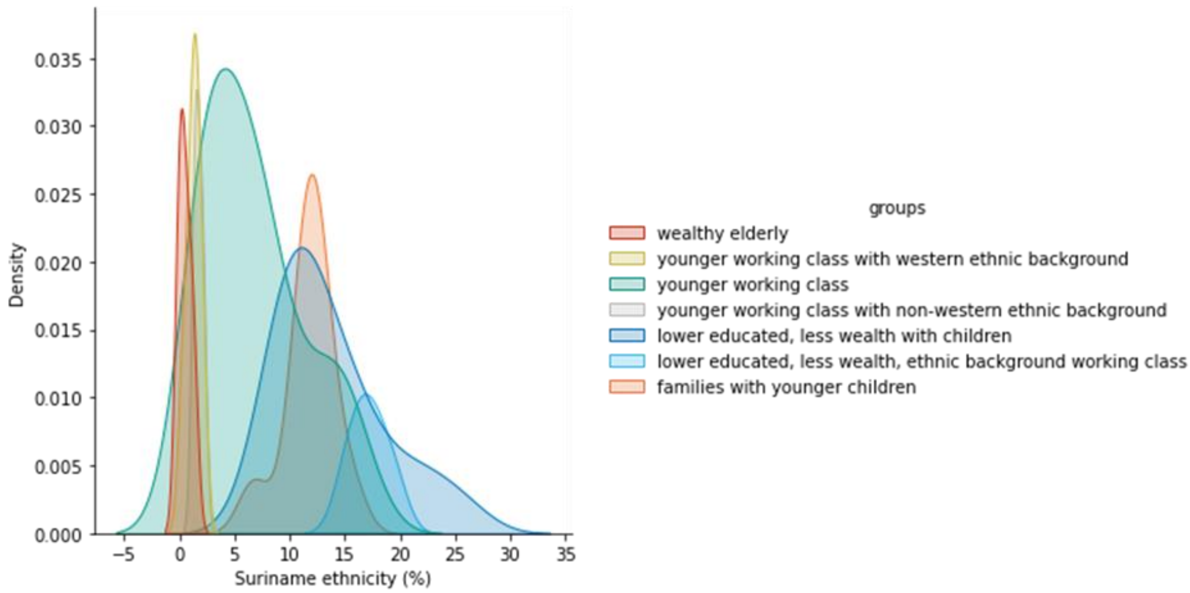

Figure B.16 Density plot for percentage people of Suriname ethnicity in groups

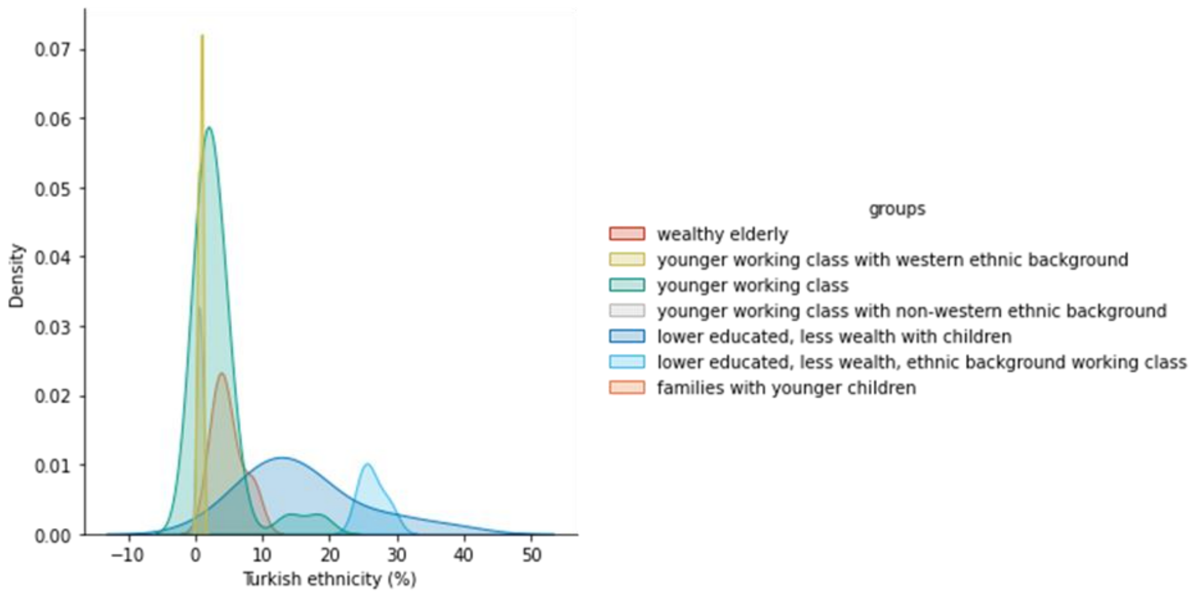

Figure B.17 Density plot for percentage people of Turkish ethnicity in groups

Figure B.18 Density plot for percentage people of other non-western ethnicity in groups

Figure B.19 Density plot of one person household percentage in groups

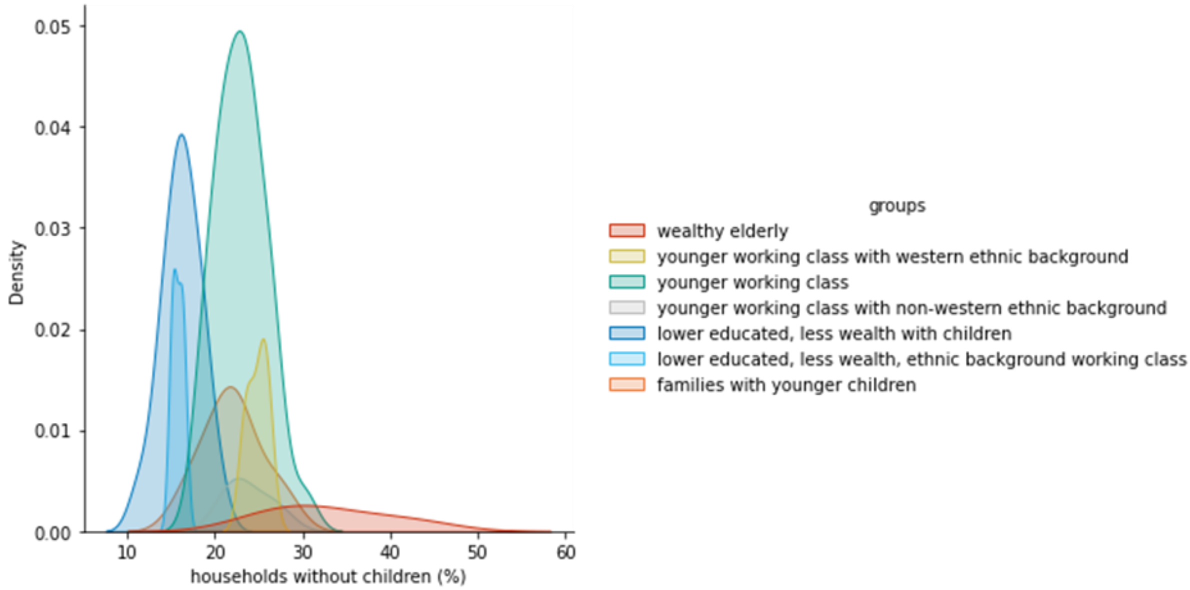

Figure B.20 Density plot of household without children percentage in groups

Figure B.21 Density plot of household with children percentage in groups

Figure B.22 Density plot of average household size in groups

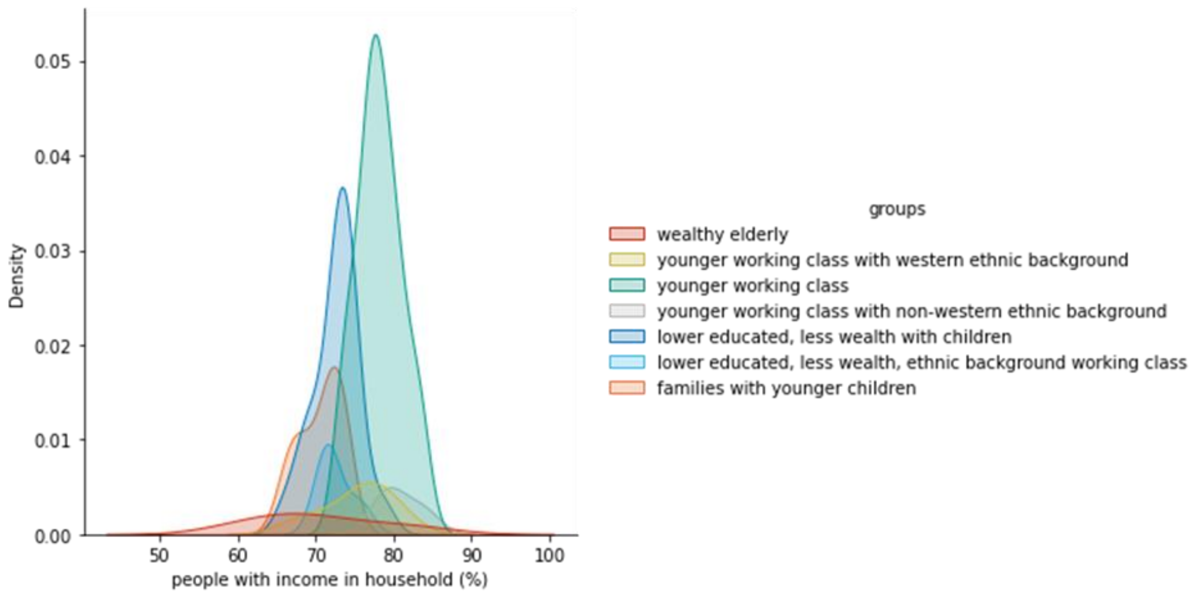

Figure B.23 Density people of people with income in household percentage in groups

Figure B.24 Density plot of average income per person with income in groups

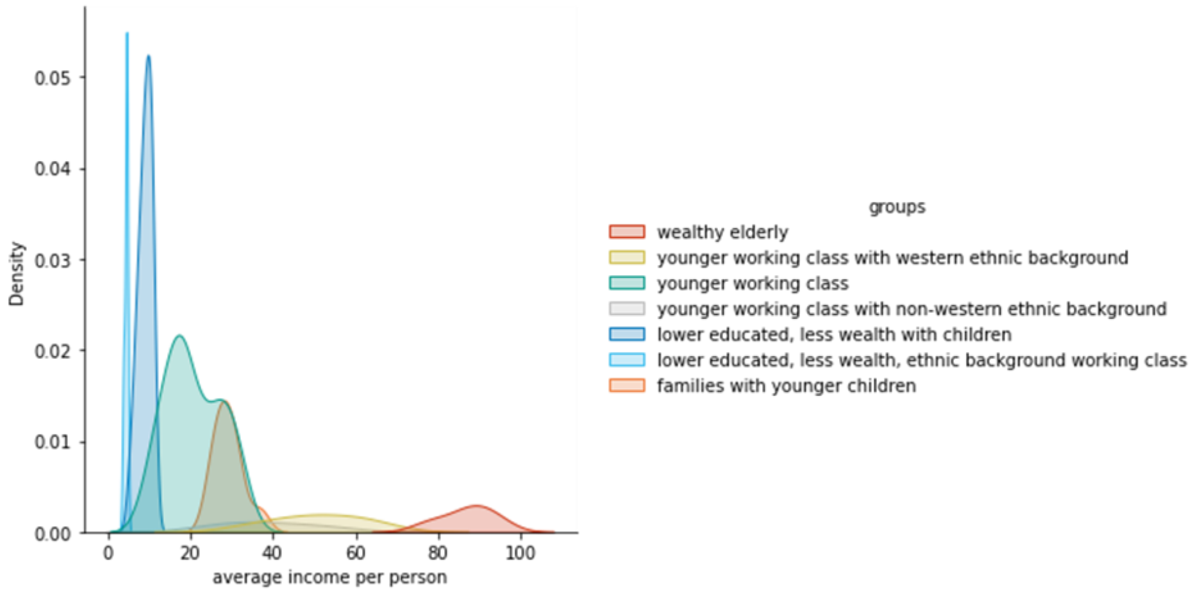

Figure B.25 Density plot of average income per person in groups

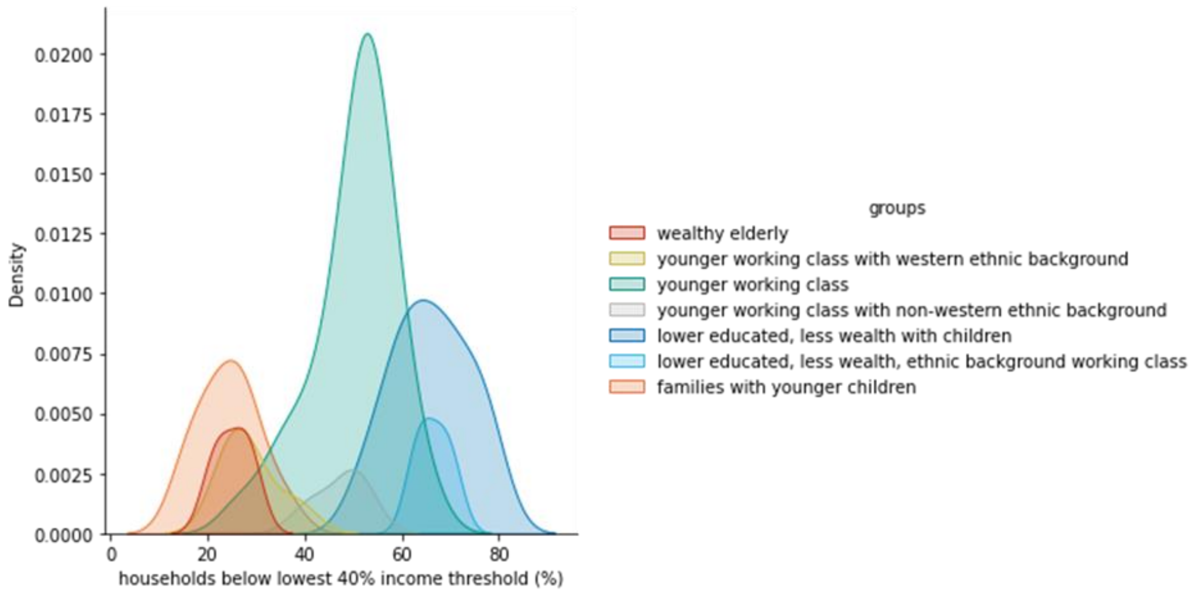

Figure B.26 Density plot of households below lowest 40% of income percentage in groups

Figure B.27 Density plot of households above highest 20% of income percentage in groups

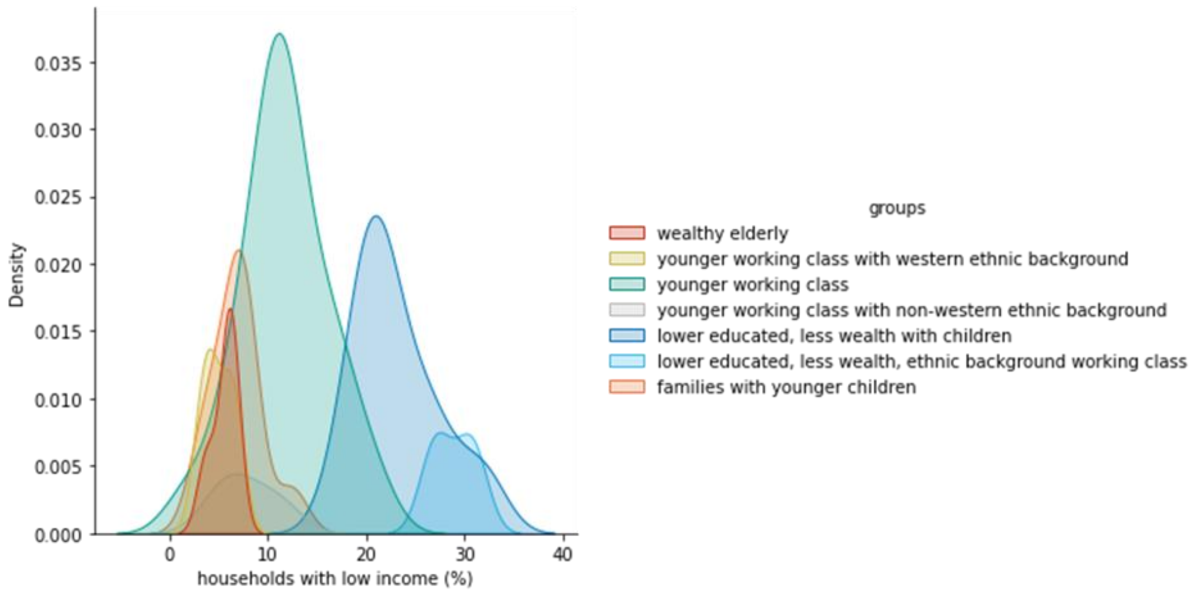

Figure B.28 Density plot of households with low-income percentage in groups

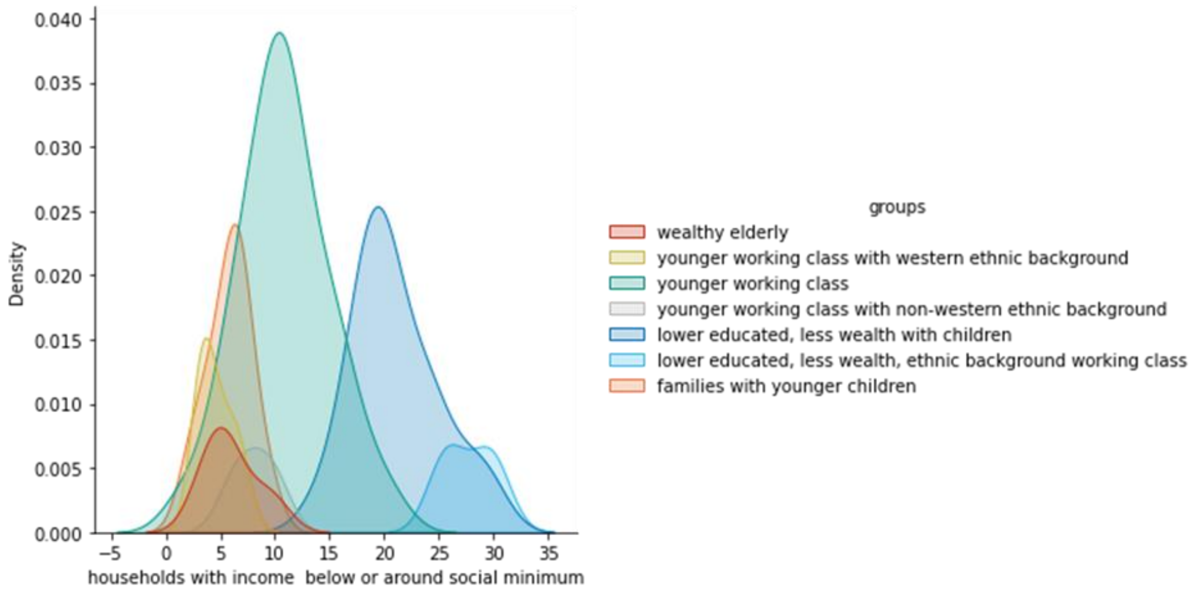

Figure B.29 Density plot of households with income below or around social minimum percentage in groups

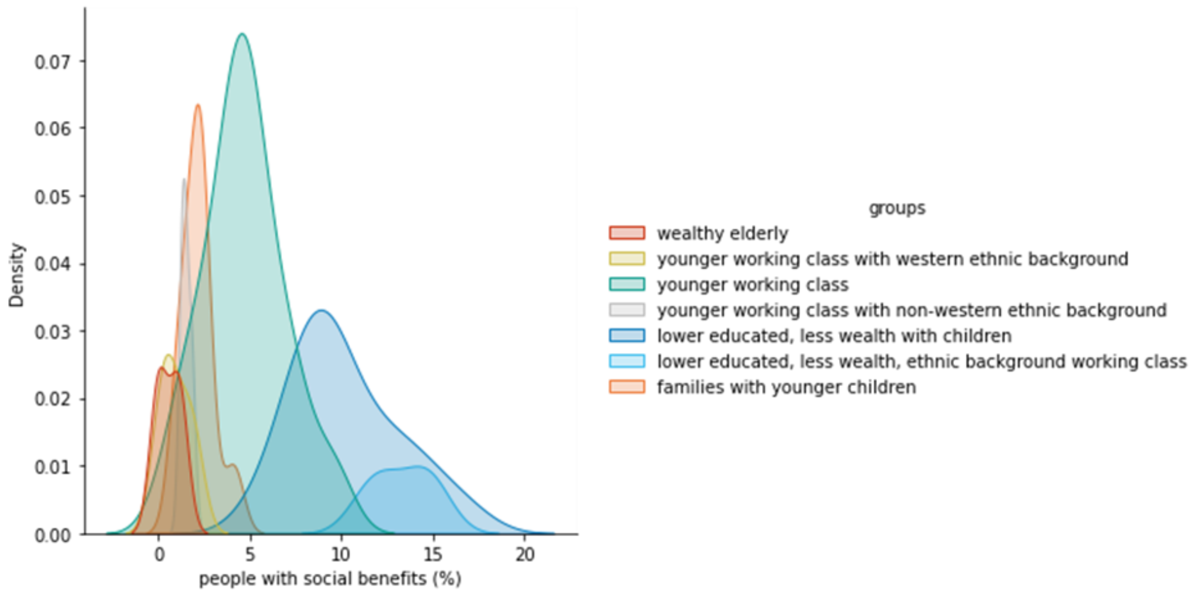

Figure B.30 Density plot of people with social benefits percentage in groups

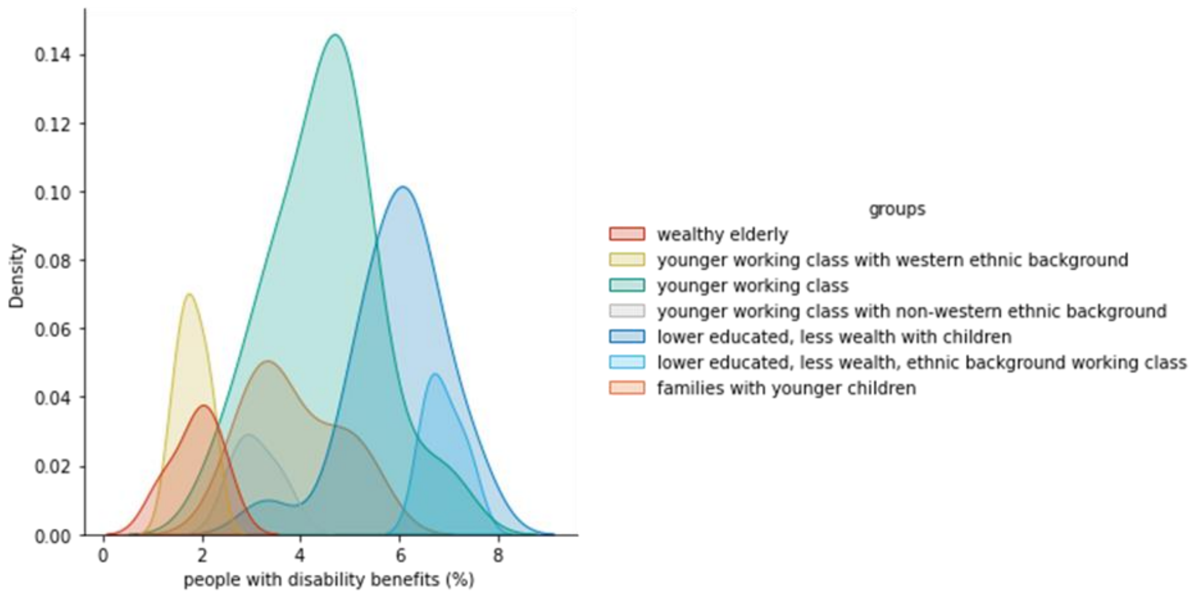

Figure B.31 Density plot of people with disability benefits percentage in groups

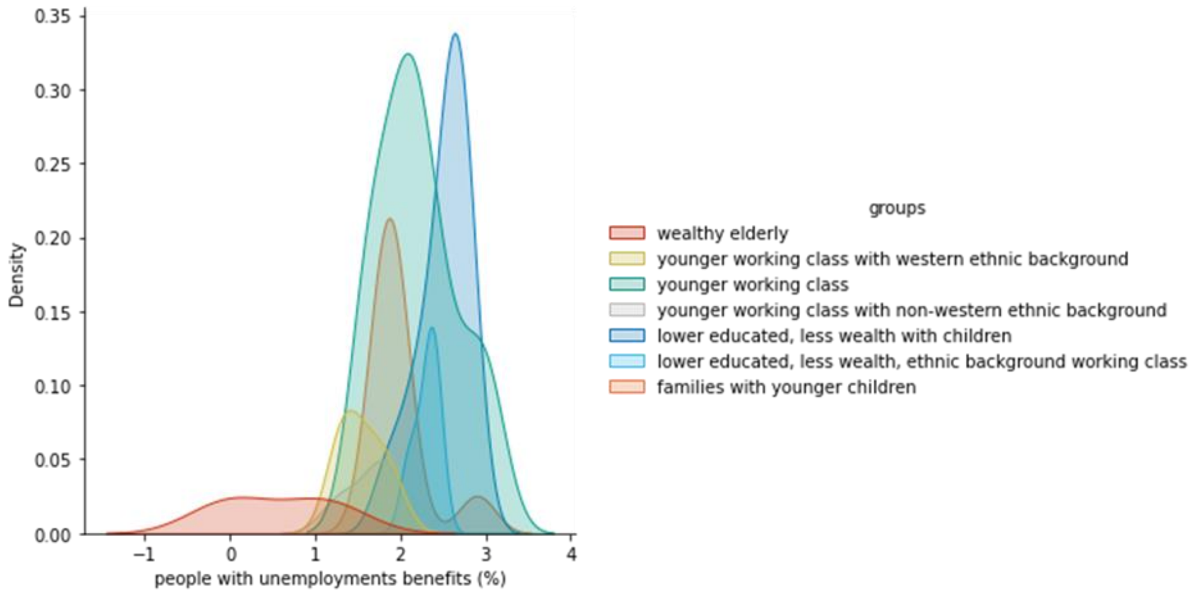

Figure B.32 Density plot of people with unemployment benefits percentage in groups

Figure B.33 Density plot of people with state pension percentage in groups

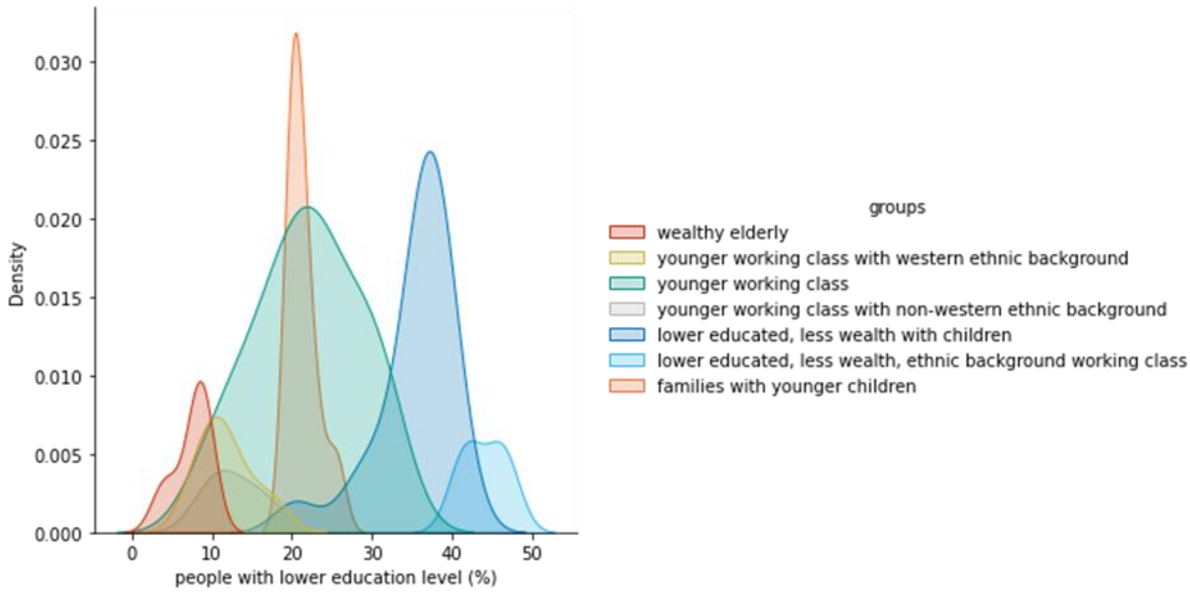

Figure B.34 Density plot of people with a low education level percentage in groups

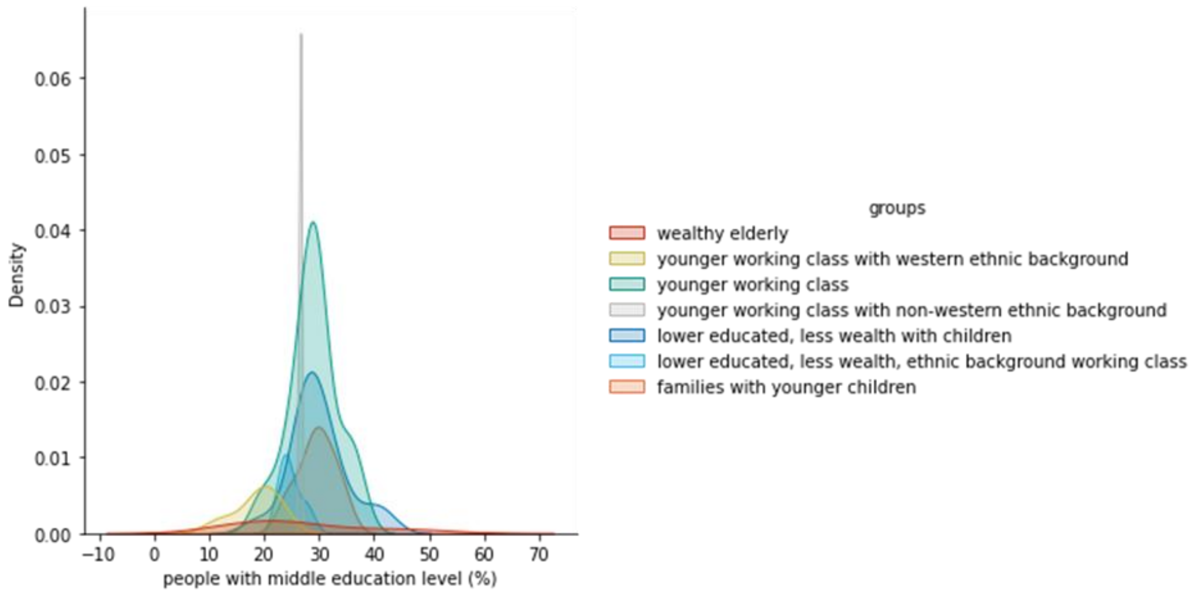

Figure B.35 Density plot of people with a middle education level percentage in groups

Figure B.36 Density plot of people with a high education level percentage in groups

C. Intervention placement

Figure C.1 The selected road segments for the intervention set Utilitarianism, Total benefits, Physiological needs.

Figure C.2 The selected road segments for the intervention set Utilitarianism, Total benefits, Security and Safety needs.

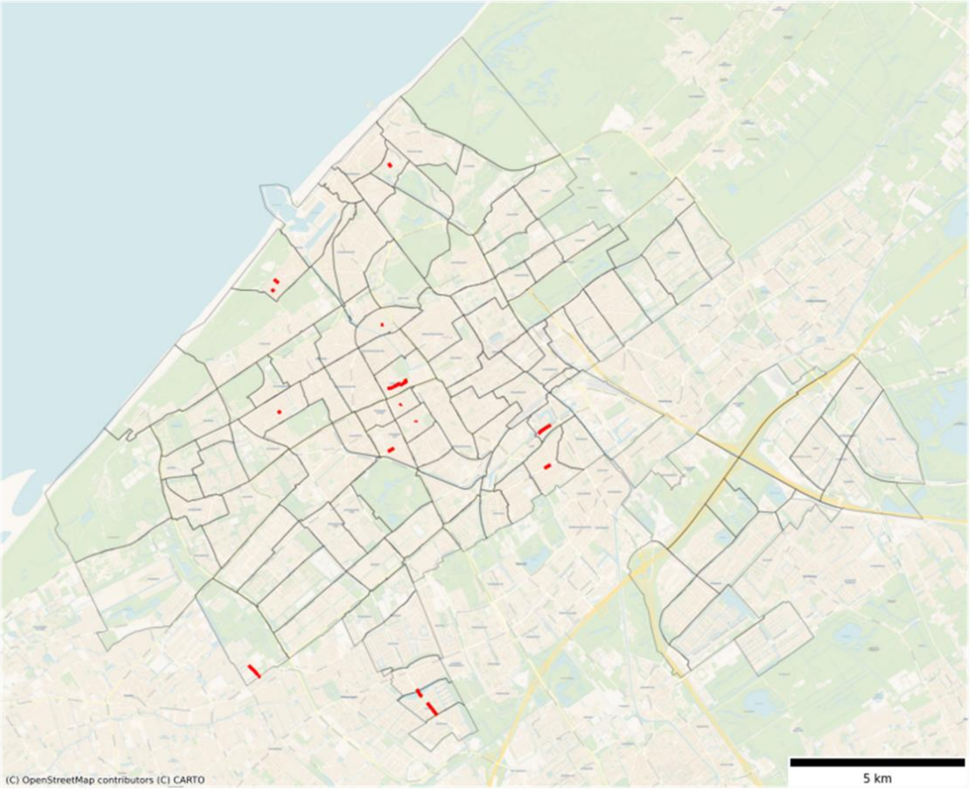

Figure C.3 The selected road segments for the intervention set Utilitarianism, Total benefits, Social needs.

Figure C.4 The selected road segments for the intervention set Utilitarianism, Added benefits, Physiological needs.

Figure C.5 The selected road segments for the intervention set Utilitarianism, Added benefits, Security and Safety needs.

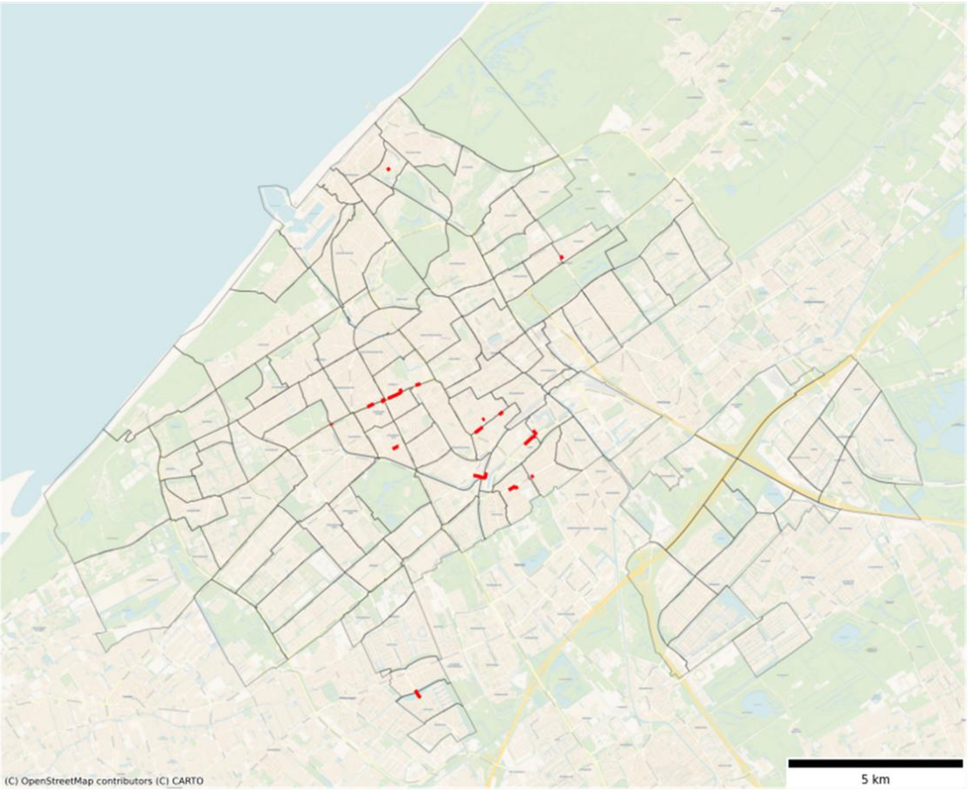

Figure C.6 The selected road segments for the intervention set Utilitarianism, Added benefits, Social needs.

Figure C.7 The selected road segments for the intervention set Rawls' Theory of Justice, Total benefits, Physiological needs.

Figure C.8 The selected road segments for the intervention set Rawls' Theory of Justice, Total benefits, Security and Safety needs.

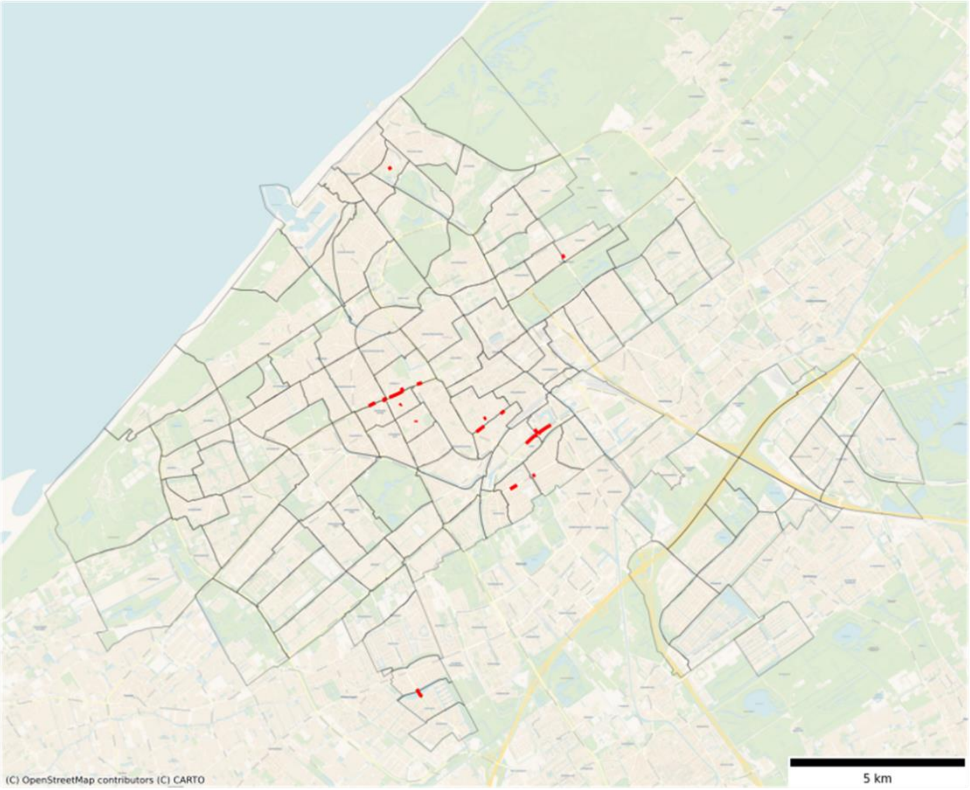

Figure C.9 The selected road segments for the intervention set Rawls' Theory of Justice, Total benefits, Social needs.

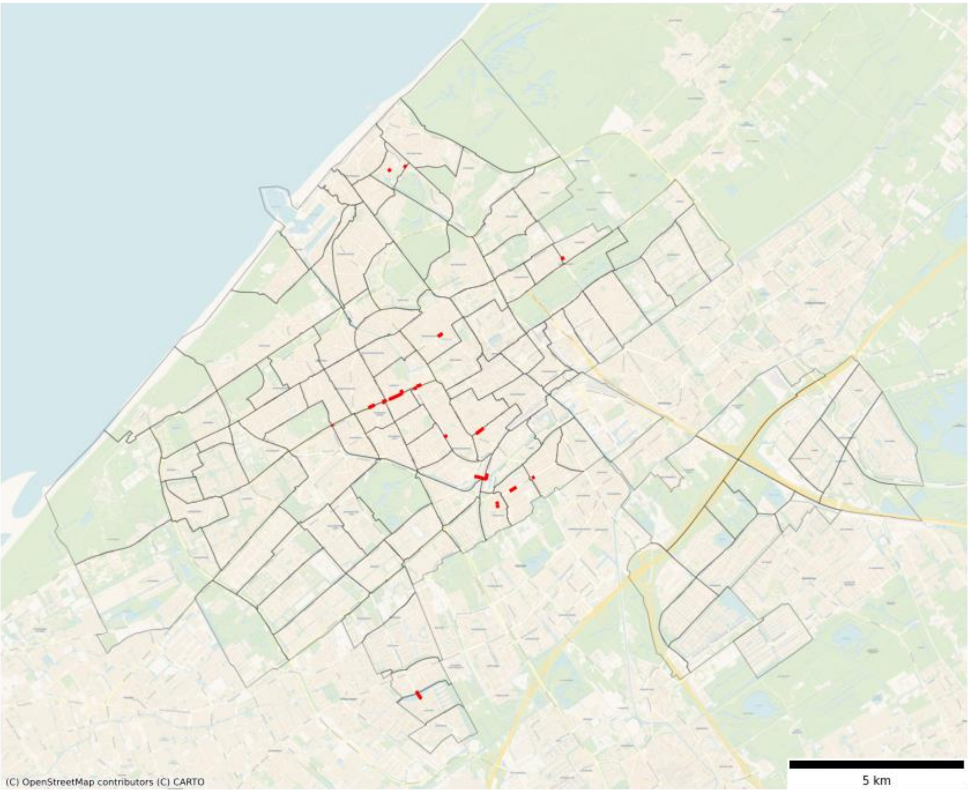

Figure C.10 The selected road segments for the intervention set Rawls' Theory of Justice, Added benefits, Physiological needs.

Figure C.11 The selected road segments for the intervention set Rawls' Theory of Justice, Added benefits, Security and Safety needs.

Figure C.12 The selected road segments for the intervention set Rawls' Theory of Justice, Added benefits, Social needs.

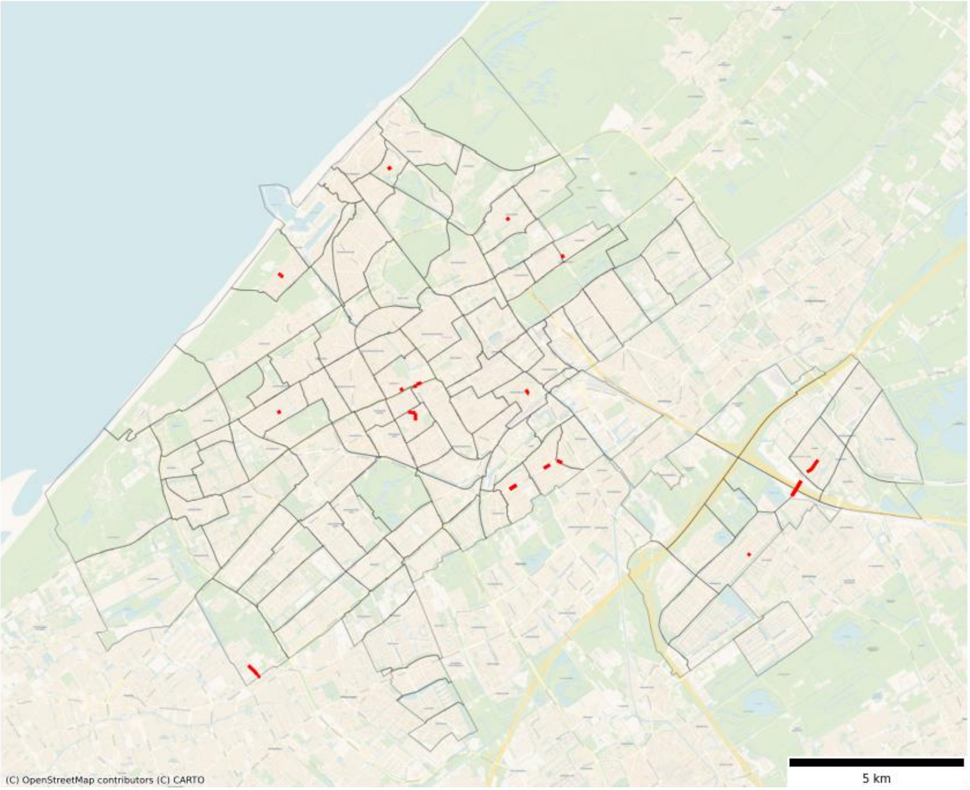

Figure C.13 The selected road segments for the intervention set Equal Sharing, Total benefits, Physiological needs.

Figure C.14 The selected road segments for the intervention set Equal Sharing, Total benefits, Security and Safety needs.

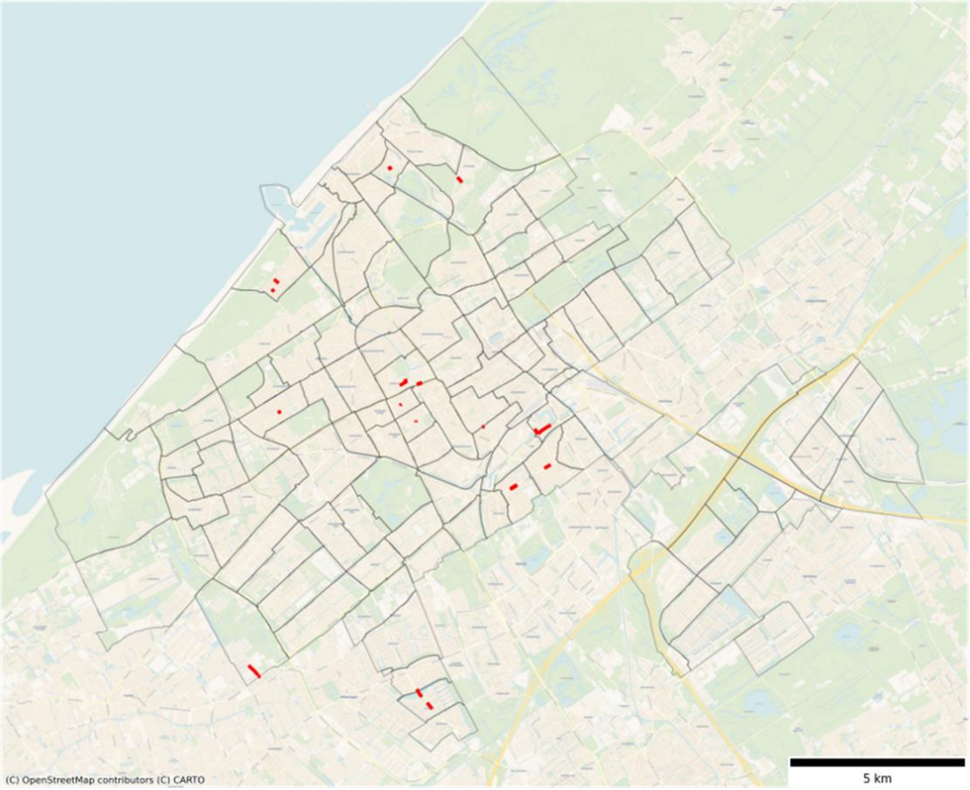

Figure C.15 The selected road segments for the intervention set Equal Sharing, Total benefits, Social needs.

Figure C.16 The selected road segments for the intervention set Equal Sharing, Added benefits, Physiological needs.

Figure C.17 The selected road segments for the intervention set Equal Sharing, Added benefits, Security and Safety needs.

Figure C.18 The selected road segments for the intervention set Equal Sharing, Added benefits, Social needs.

D. Accessibility

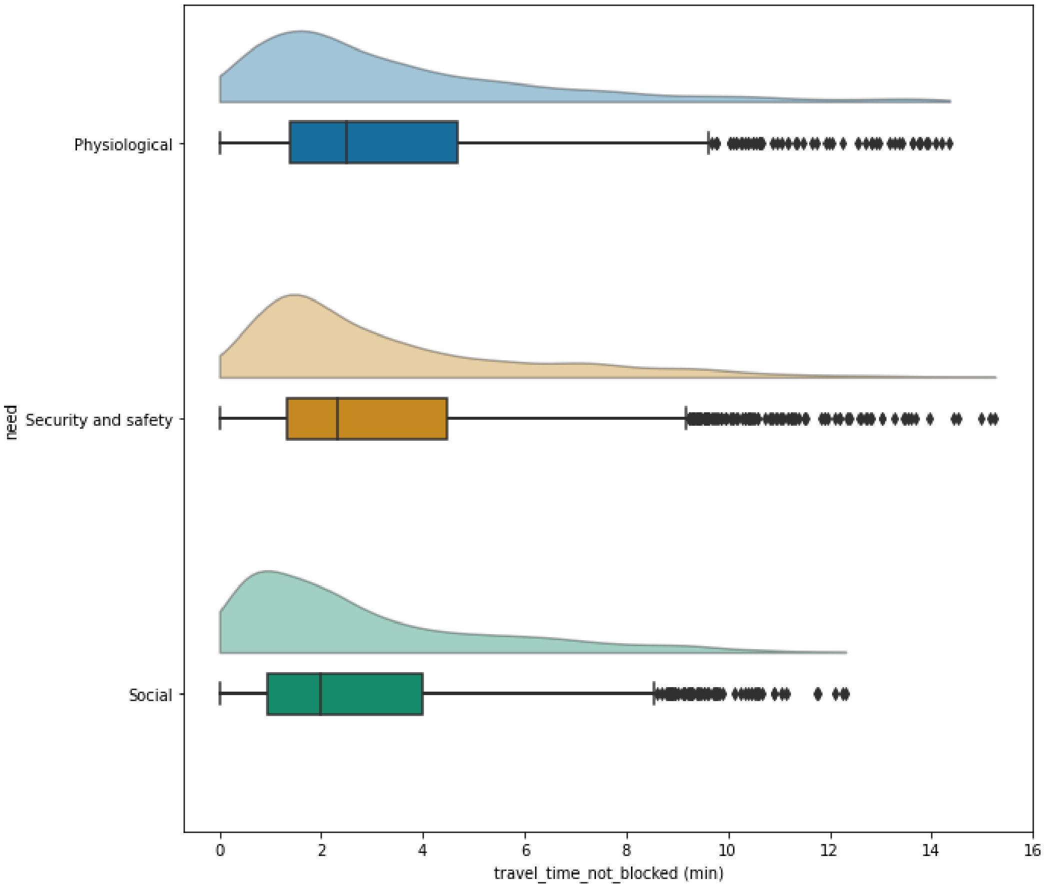

Figure D.1 Travel time after disruption for the different destination groups for the general population

Table D.1 Outcome of KS test between different societal groups for Security and Safety destinations.

The darker color shows a confidence level of 0.01, the lighter color a significance level of 0.05. All groups are significantly different for one another for the Security and Safety destinations.

	Younger working class	Lower educated, less wealth with children class	Younger working class with non-western ethnic background	Younger working class with western ethnic background	Families with younger children	Lower educated, less wealth, ethnic background working class	Wealthy elderly
Younger working class		3.5e-3**	2.3e-2*	3.6e-2*	1.2e-11**	1.2e-11**	4.1e-4**
Lower educated, less wealth with children class	3.5e-3**		2.5e-2*	2.1e-2*	9.9e-25**	1.0e-14**	6.7e-3**
Younger working class with non-western ethnic background	2.3e-2*	2.5e-2*		3.5e-2*	3.8e-9**	4.0e-8**	9.0e-3**
Younger working class with western ethnic background	3.6e-2*	2.1e-2*	3.5e-2*		2.5e-19**	8.0e-11**	1.5e-2*
Families with younger children	9.4e-34**	9.9e-25**	3.8e-9**	2.5e-19**		1.1e-16**	4.3e-15**
Lower educated, less wealth, ethnic background working class	1.2e-11**	1.0e-14**	4.0e-8**	8.0e-11**	1.1e-16**		2.9e-14**
Wealthy elderly	4.1e-4**	6.7e-3**	9.0e-3**	1.5e-2*	4.3e-15**	2.9e-14**	

Table D.2 Outcome of KS test between different societal groups for Social destinations.

The darker color shows a confidence level of 0.01, the lighter color a significance level of 0.05. All groups are significantly different for one another for the Social destinations.

	Younger working class	Lower educated, less wealth with children class	Younger working class with non-western ethnic background	Younger working class with western ethnic background	Families with younger children	Lower educated, less wealth, ethnic background working class	Wealthy elderly
Younger working class		2.3e-8**	5.4e-4**	5.6e-4**	8.9e-16**	1.2e-4**	1.8e-15**
Lower educated, less wealth with children class	2.3e-8**		4.4e-2*	4.9e-3**	6.7e-16**	3.7e-11**	6.9e-7**
Younger working class with non-western ethnic background	5.4e-4**	4.4e-2*		4.0e-2*	2.2e-16**	6.6e-9**	7.8e-4**
Younger working class with western ethnic background	5.6e-4**	4.9e-3**	4.0e-2*		1.9e-42**	1.2e-8**	4.9e-4**
Families with younger children	8.9e-16**	6.7e-16**	2.2e-16**	1.9e-42**		1.0e-4**	1.0e-3**
Lower educated, less wealth, ethnic background working class	1.2e-4**	3.7e-11**	6.6e-9**	1.2e-8**	1.0e-4**		5.1e-20**
Wealthy elderly	1.8e-15**	6.9e-7**	7.8e-4**	4.9e-4**	1.0e-3**	5.1e-20**	

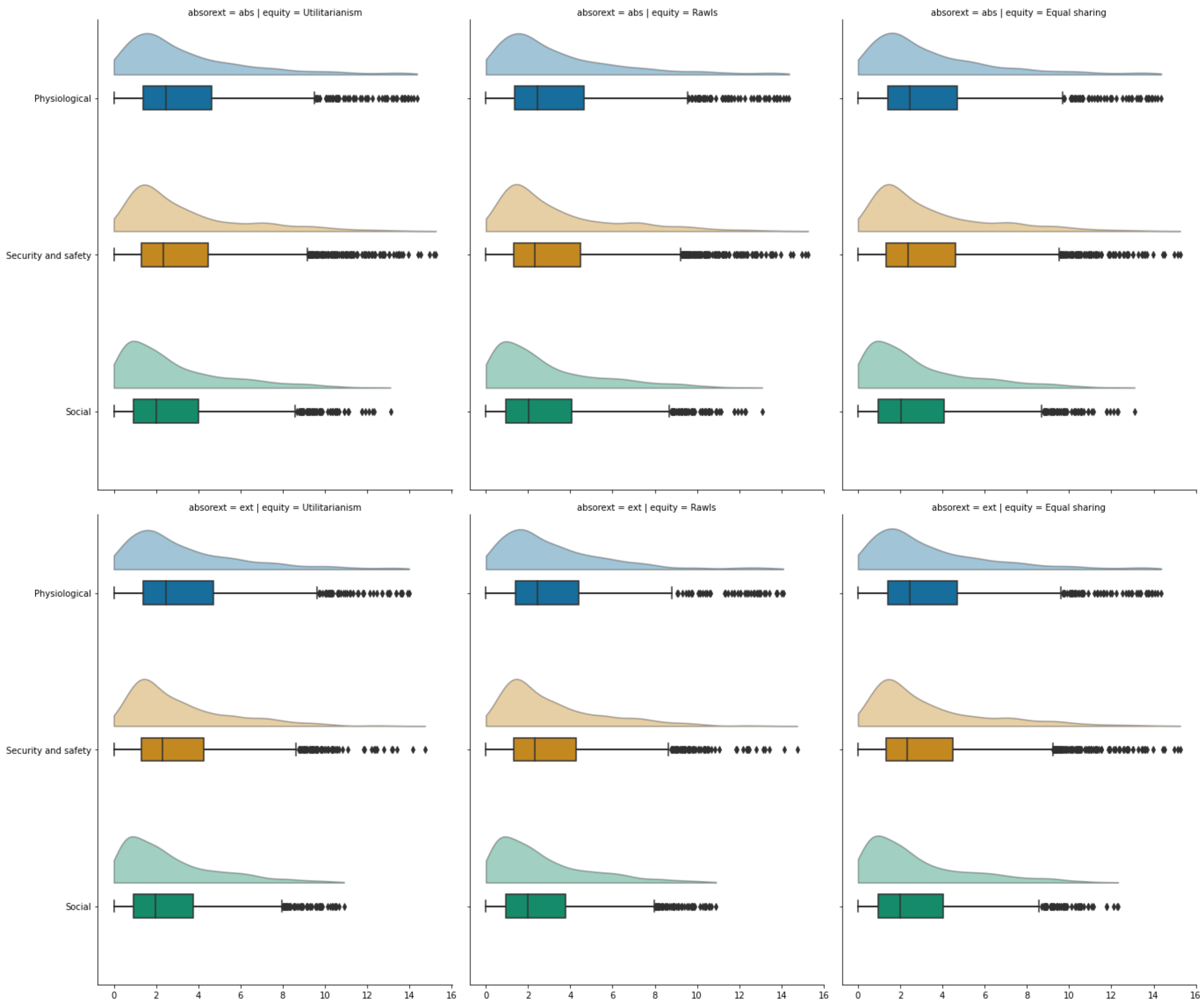

Figure D.2 Travel time after interventions for the different destination groups for the general population

Table D.3 Significance between BAU travel time and travel time after disruption for the societal groups and the different destination categories.

The significance is tested with a Kolmogorov-Smirnov test. * shows a significance at an alpha of 0.05. ** shows a significance at an alpha of 0.01.

Group	Physiological need	Security and Safety need	Social need
Younger working class	5.2e-25**	3.3e-56**	4.9e-26**
Lower educated, less wealth with children	3.9e-58**	1.1e-42**	4.3e-22**
Younger working class with non-western ethnic background	8.0e-12**	7.3e-7**	1.6e-5**
Younger working class with western ethnic background	1.8e-6**	2.0e-4**	1.6e-5**
Families with younger children	3.6e-6**	1.6e-9**	4.9e-10**
Lower educated, less wealth, ethnic background working class	6.0e-21**	1.0e-9**	6.7e-4**
Wealthy elderly	1.5e-2*	3.0e-2*	5.0e-3**

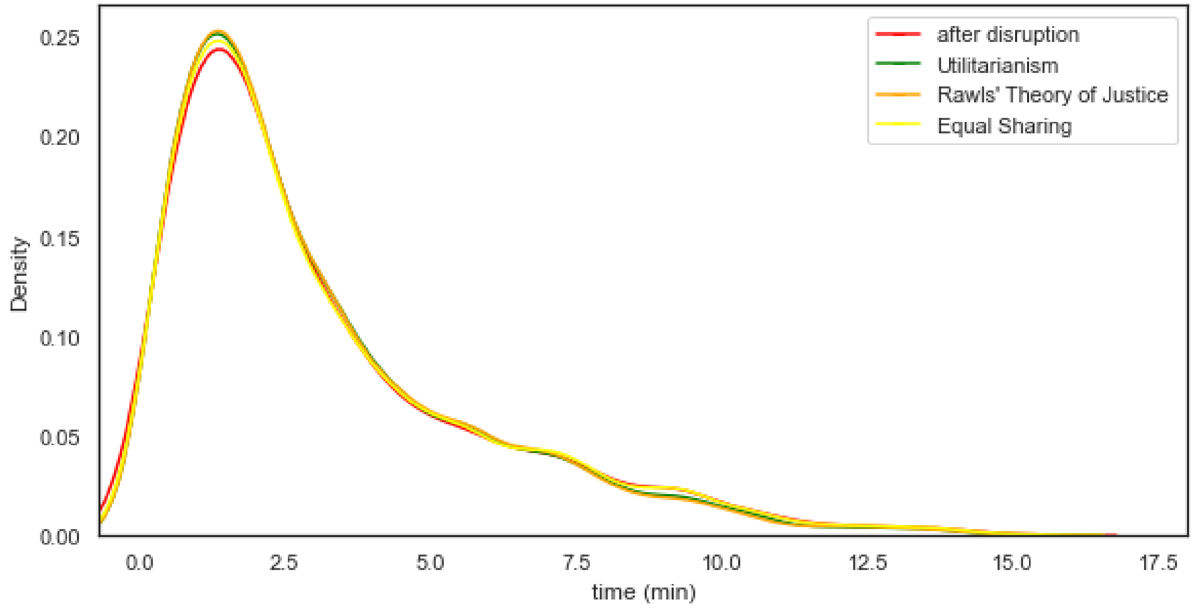

Figure D.3 Density plot of after disruption and different equity principles for the general population.

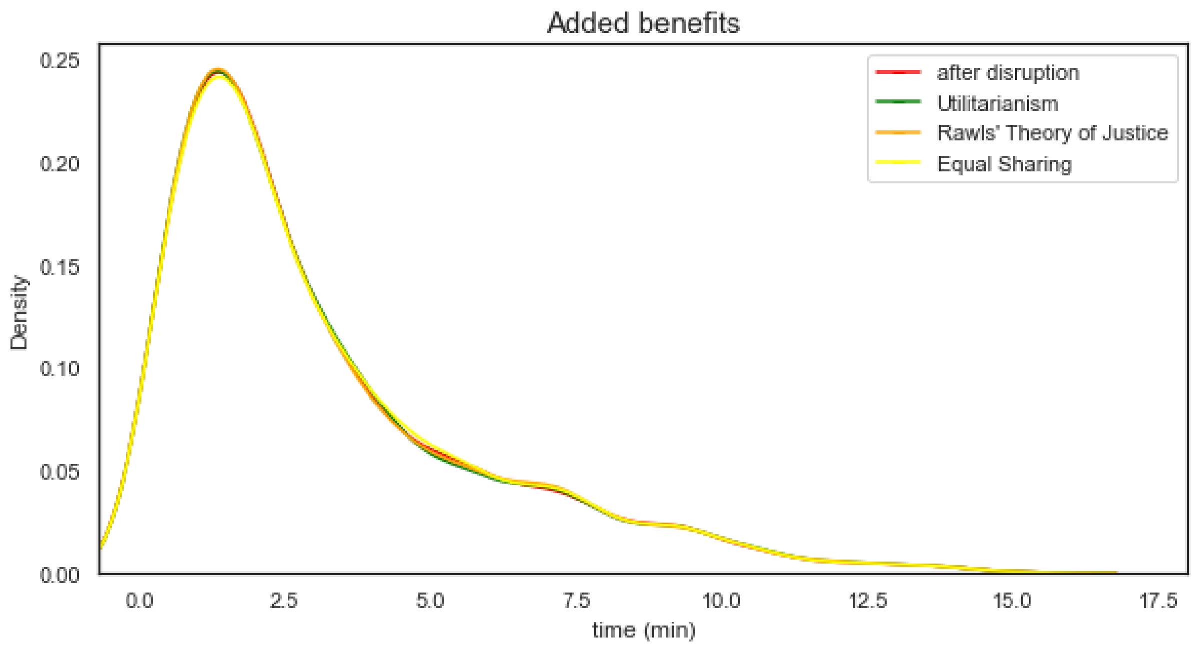

Figure D.4 Density plot of after disruption and different equity principles for the general population for the added travel time.

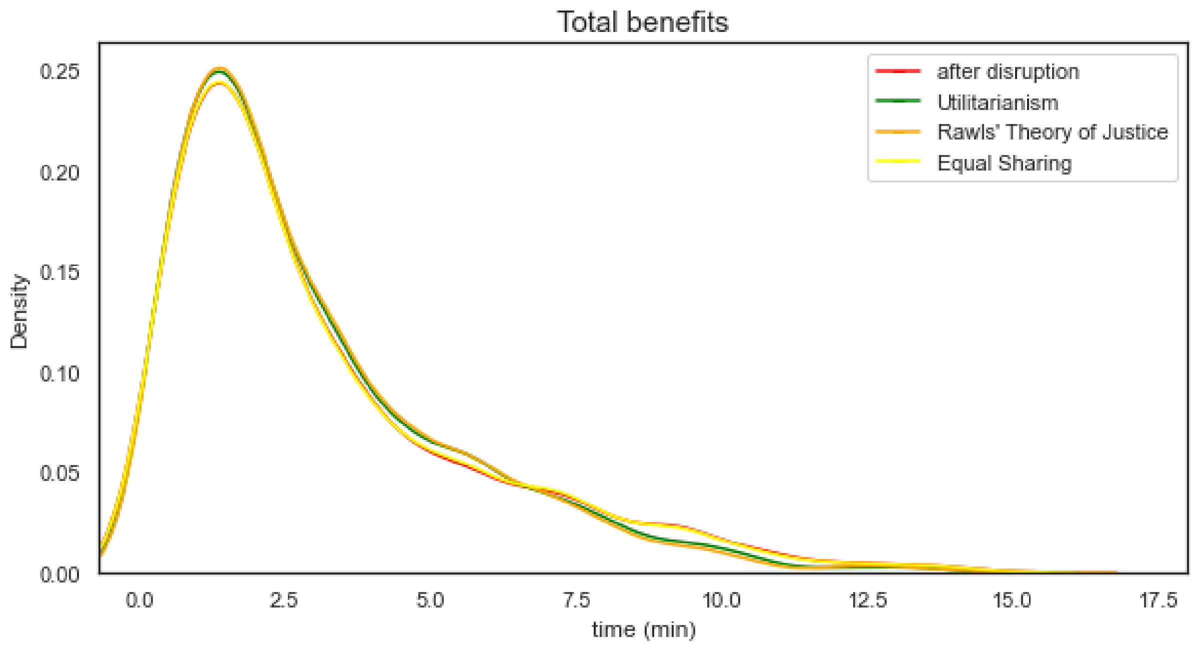

Figure D.5 Density plot of after disruption and different equity principles for the general population for the total travel time.

Table D.4 Significance between travel time after disruption and after interventions for different groups and the intervention sets based on equity principles.

The significance is tested with a Kolmogorov-Smirnov test. * shows a significance at an alpha of 0.05. ** shows a significance at an alpha of 0.01.

Group	Utilitarianism	Rawls' Theory of Justice	Equal Sharing
Younger working class	0.12	1.0	0.99
Lower educated, less wealth with children	1.6e-5**	2.1e-7**	0.16
Younger working class with non-western ethnic background	3.6e-5**	6.8e-9**	1.1e-10**
Younger working class with western ethnic background	1.0	1.0	1.0
Families with younger children	1.0	1.0	1.0
Lower educated, less wealth, ethnic background working class	7.1e-3**	2.1e-4**	0.92
Wealthy elderly	1.0	1.0	1.0

Table D.5 Elasticity of travel time for different equity principle based interventions for general population and societal groups.

On the left the principle compared is shown, on the top the other principle for the elasticity is shown. The elasticity is calculated by dividing the difference of travel time for a certain group between the right and on top category by the category on the left. A value of zero shows there is no difference between the interventions. A negative value shows it would be better to use the category on the left, a positive value means it would be better to use the category on top.

		Utilitarianism	Rawls' Theory of Justice	Equal Sharing
Rawls' Theory of Justice	General population	0,3	0	-2,6
	Wealthy elderly	0,1	0	0,0
	Younger working class with non-western ethnic background	2,5	0	-1,2
	Younger children families	0,3	0	0,0
	Younger working class with western ethnic background	0,0	0	0,0
	Younger working class	-0,6	0	-2,0
	Lower educated, less wealth with children class	-1,8	0	-9,1
	Lower educated, less wealth, ethnic background working class	-3,7	0	-14,8
Equal Sharing	General population	2,8	2,5	0
	Wealthy elderly	0,1	0,0	0
	Younger working class with non-western ethnic background	3,7	1,2	0
	Younger children families	0,3	0,0	0
	Younger working class with western ethnic background	0,0	0,0	0
	Younger working class	1,3	2,0	0
	Lower educated, less wealth with children class	6,7	8,4	0
	Lower educated, less wealth, ethnic background working class	9,7	12,9	0

Table D.6 Elasticity of blocked people for different equity principle based interventions for general population and societal groups.

On the left the principle compared is shown, on the top the other principle for the elasticity is shown. The elasticity is calculated by dividing the difference of travel time for a certain group between the right and on top category by the category on the left. A value of zero shows there is no difference between the interventions. A negative value shows it would be better to use the category on the left, a positive value means it would be better to use the category on top.

		Utilitarianism	Rawls' Theory of Justice	Equal Sharing
Rawls' Theory of Justice	General population	5,4	0	0,5
	Wealthy elderly	0,8	0	0,0
	Younger working class with non-western ethnic background	-22,8	0	9,9
	Younger children families	0,0	0	-0,6
	Younger working class with western ethnic background	0,0	0	0,0
	Younger working class	10,7	0	5,3
	Lower educated, less wealth with children class	-1,8	0	-9,5
	Lower educated, less wealth, ethnic background working class	-6,3	0	-20,6
Equal Sharing	General population	5,0	-0,5	0
	Wealthy elderly	0,8	0,0	0
	Younger working class with non-western ethnic background	-36,2	-10,9	0
	Younger children families	0,6	0,6	0
	Younger working class with western ethnic background	0,0	0,0	0
	Younger working class	5,8	-5,5	0
	Lower educated, less wealth with children class	7,0	8,6	0
	Lower educated, less wealth, ethnic background working class	11,8	17,1	0

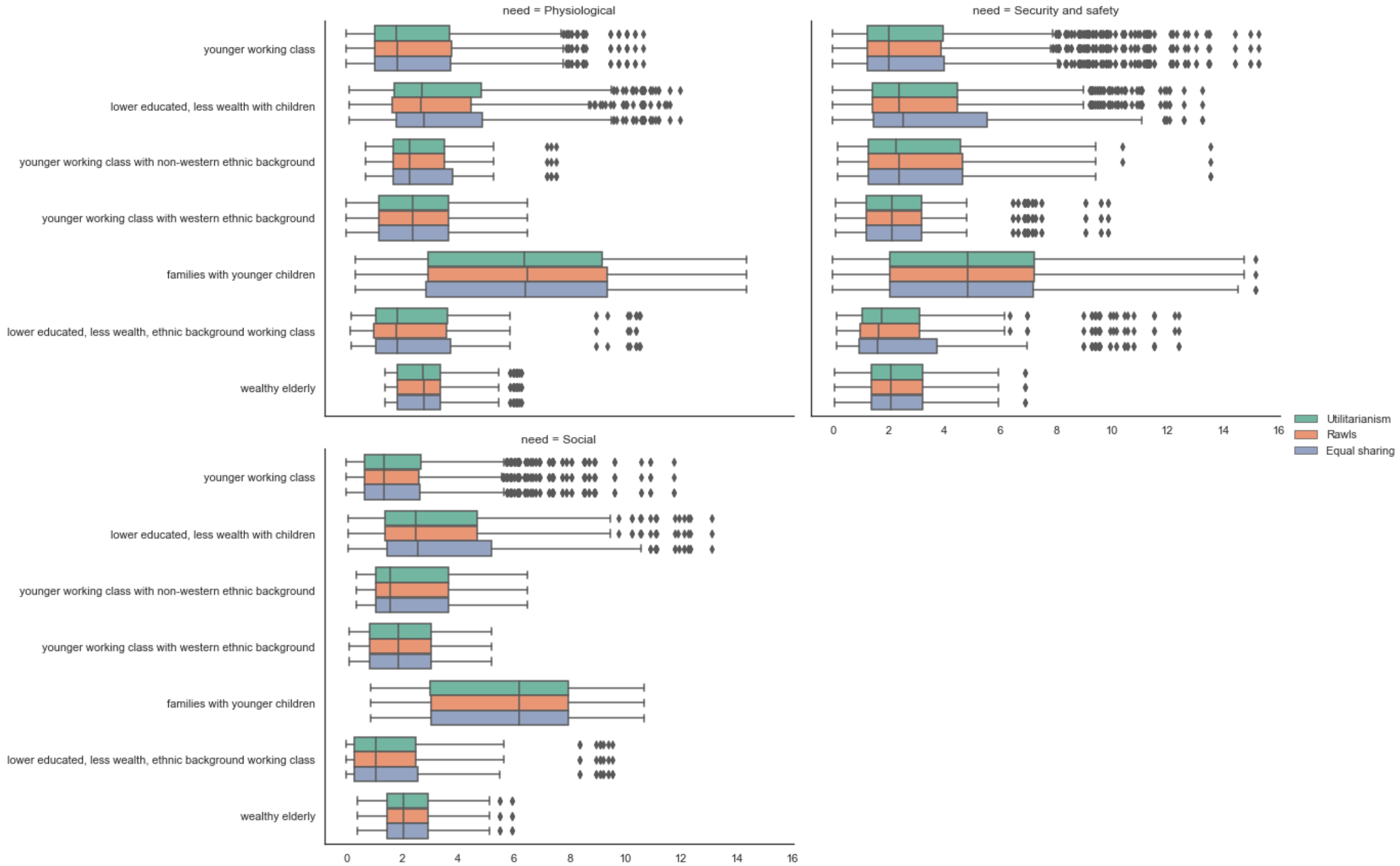

Figure D.6 Distribution of travel time after interventions for different societal groups and destination categories. The Utilitarian based interventions sometimes do well for groups but not for specific groups. The Rawlsian based interventions do well for the most vulnerable groups. Equal Sharing based principles are often not significant and often do not impact the distribution of the groups enough to have impact. The Utilitarian principle has the highest significant difference between the travel times after disruption and after the intervention. Three groups show a significant difference at a 0.01. These groups are still located in the city center of The Hague as this is where most opened road segments were located. For some groups, the Utilitarian principle scores the best. For the younger working class to reach their physiological destinations, the Utilitarian principle would likely be preferred. The same applies for the families with younger children as they are also mainly benefitting from the Utilitarian principle.