SPATIAL ANALYSIS OF ROAD TRAFFIC CRASHES AND ASSESSMENT OF ROAD SAFETY ISSUES FROM ROAD USERS' PERSPECTIVE: A CASE STUDY OF ROTTERDAM AND THE SURROUNDING URBAN CONURBATION

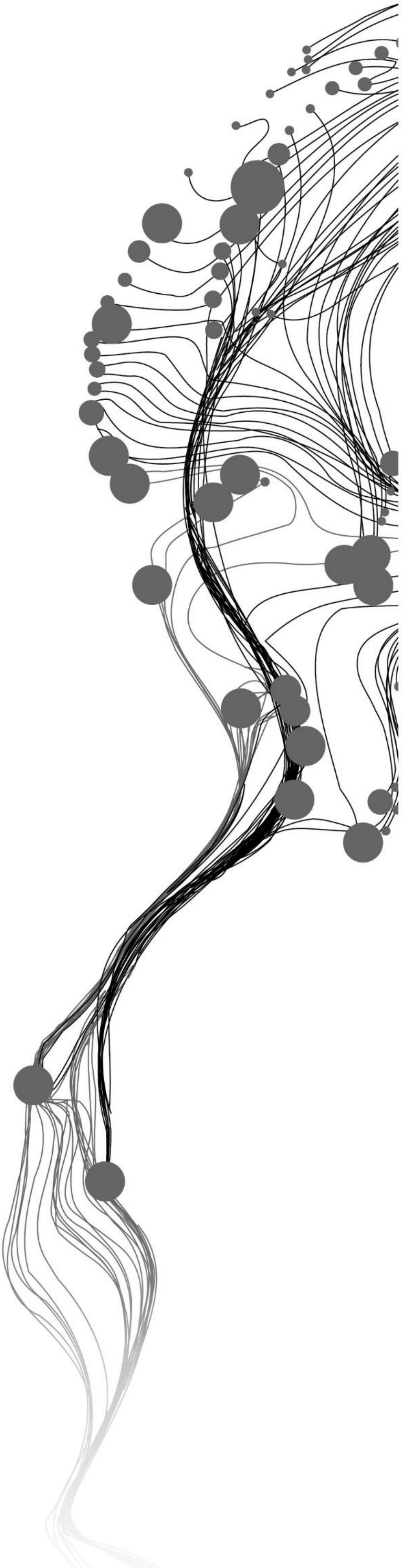
Sachita Shahi
June 2022

Supervision team
Ir. Mark J. G. Brussel
Dr. Anna B. Grigolon

Thesis Assessment board
Prof. Dr. Karin Pfeffer (Chair)
Dr. Ir. M.B. Ulak (External Examiner)

ITC UNIVERSITY OF TWENTE.

UNIVERSITY OF TWENTE.



SPATIAL ANALYSIS OF ROAD TRAFFIC CRASHES AND ASSESSMENT OF ROAD SAFETY ISSUES FROM ROAD USERS' PERSPECTIVE: A CASE STUDY OF ROTTERDAM AND THE SURROUNDING URBAN CONURBATION

SACHITA SHAHI

Enschede, The Netherlands, June 2021

Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfillment of the requirements for the degree of Master of Science in Spatial Engineering.

Research Theme: PLUS

SUPERVISORS:
Ir. Mark J. G. Brussel (ITC, PGM)
Dr. Anna B. Grigolon (ITC, PGM)

THESIS ASSESSMENT BOARD:
Prof. Dr. Karin Pfeffer (ITC, PGM)
Dr. Ir. M.B. Ulak (ET, UT)

ABSTRACT

Transport infrastructure is one of the essential commodities needed for accessing opportunities spread across urban areas. Road infrastructure, in particular, is one of them. Along with the advancements in other technological fields, there has also been significant progress in improving the quality of road networks in the past years. Various physical and non-physical interventions have been implemented on roads to improve their safety and serviceability. However, Road Traffic Crashes (RTCs) still occur yearly, claiming a substantial proportion of lives and properties. RTCs can be considered a wicked problem in our society that does not have a fixed solution. They encompass multi-sectoral stakeholders such as the public and policymakers. However, different stakeholders can take some steps to tame the wickedness of RTCs.

Dutch roads are known to be one of the safest road networks globally. However, this does not imply a total absence of RTCs. Especially in major Dutch cities, where there is an ever-increasing population and vehicles, RTCs continue to occur. Many initiatives have been taken to reduce the occurrence and severity of RTCs. Those measures have been proven successful to some extent. However, there is still room for improvement. In 2020, there were slightly more than 100000 RTCs in the Netherlands. Among them, 19700 resulted in serious injuries, and 610 resulted in deaths. But, the acceptable limit for 2020 was set to a maximum of 10600 serious injuries and 500 deaths by the government. More than a quarter of total RTCs occurred in the South Holland province in 2020. Among the cities in South Holland, Rotterdam had the highest numbers (slightly more than 6000).

The accurate data of crash distribution patterns along the road network are essential for developing road safety plans and programs. Furthermore, these initiatives are based on the road users' perspective and policy makers' insightfulness on the issue of RTCs. This study is focused on the spatial analysis of RTCs and appraisal of road safety issues from road users' perspectives.

In this research, spatial data of RTCs in the past three years in Rotterdam are taken as the object of the analysis. Global Moran's I, Local Moran's I, and Network Kernel Density Estimation was used for spatial analysis. The analysis identified RTC hotspots. Among them, four zones were selected to understand road users' perception of road safety. This was done by conducting a survey to identify road users' behavior, perception of road parameters, and road safety policies. At the same time, road users' perception of possible recommendations for improving road safety was also collected. Key informants currently involved in various road safety programs/research in the Netherlands were also interviewed to consider stakeholders' opinions from different sectors.

The synthesis of findings unveiled why road users perceive some areas as dangerous and which road policies need to be revised to increase their social acceptability. Various road safety enhancement strategies and measures were discussed in the key-informant interview to determine if they could be implemented in the future. The main points of improvement can be summed up as - increasing the awareness of road users and upgrading road infrastructure in identified problem areas. The recommendations can be implemented to assist the government and other road safety authorities in improving road safety in Rotterdam or any other city.

ACKNOWLEDGMENTS

Firstly I would like to express my wholehearted thankfulness to my supervisors**, Ir. Mark J. G. Brussel** and **Dr. Anna B. Grigolon**, for their invaluable guidance and continuous support from before the time I started writing the proposal for this thesis. I could not have asked for kinder or more supportive people as my supervisors other than Mark and Anna. I want to say thank you to **Dr. Ir. M.B.Ulak**. His class on traffic safety was the place where I got the inspiration, idea, and knowledge required to take on this thesis. I would also like to show my appreciation to **Prof. Dr. Karin Pfeffer** for providing me with valuable insights from an external perspective during the proposal and mid-term presentations. Next, I would like to mention **Professor Dr. Atsu Okabe** from the University of Tokyo, Japan. His assistance in using the SANET tool for spatial analysis and his solutions to my numerous questions about SANET is significantly appreciated. I also want to express thanks to my key informants, from **SWOV**, **Rotterdam Municipality**, and **TeamAlert**, for taking the time to talk to me and acknowledge my findings. I had very insightful discussions with all of them and got the chance to observe the societal significance of my work. I am indebted to the **residents of Rotterdam** who were kind enough to participate in the road user perception survey. This thesis would be incomplete without their responses.

I also want to let my parents, **Prof. Dr. Padma Bahadur Shahi** and **Prof. Dr. Thusitha Chandani Shahi,** know that I am grateful, as always, for their role of being both my parents and unofficial mentors throughout the past two years (and my whole life so far!). I cannot express how grateful I am for my friends who went to Rotterdam with me for the road user perception survey. **Nilay**, **Vaibhav**, **Prashant**, **Julia**, and **Lisa,** thanks a lot for dedicating the time from your busy schedules to help me. As much as working hard is important, it is equally essential to have a support system. **Sharai**, **Sahara**, **Binita, Biman, Enzo, Lynette, Nitesh, Diana, Ashok, Om**, and all my friends in the Netherlands and Nepal (I could fill an entire thesis if I started mentioning everyone!). You guys have been my mental and social support system since we became friends. I am lucky to have you. I could not have made it this far without you guys telling me to breathe and not stress. Cheers to my sister **Suyama Shahi** and my German Shepherd **Nikki,** who always reminds me that my problems are temporary and "to chill more." Finally, **Sagar Basnet,** you have always been the calm to my storm. Thank you.

Table of contents

1 **Introduction** **1**

1.1 Background 1

1.2 Problem analysis 2

1.2.1 Current scenario of the problem 2

1.2.2 The wickedness of the problem 4

1.3 Research identification 6

1.4 Research Objective and questions 7

1.5 Research hypothesis 7

1.6 Thesis structure 8

2 **Literature review** **10**

2.1 RTC trend over the years 10

2.2 Levels of RTC severity 11

2.3 Spatial analysis of RTCs 11

2.4 Effect of road parameters on the occurrence and severity of RTCs 13

2.5 Human behavior in RTC causation 13

2.6 Risk perception towards road parameters and RTCs 14

2.7 Measurement of risk perception 15

2.8 Road safety approaches and policies 16

2.9 Road safety in the Netherlands 17

2.10 Road safety policies for motorized transport 18

2.11 Road safety measures for non-motorized transport 19

2.12 Intelligent Transport System for road safety 20

3 **Research design** **21**

3.1 Study area 21

3.2 Data used 22

3.3 Research matrix 23

3.4 Ethical considerations and data management 24

4 **Methodology** **25**

4.1 Spatial Pattern of road traffic crashes 25

4.2 Global Moran's I 25

4.3 Local Moran's I 27

4.4 Network Kernel Density Estimation 28

4.5 Road users' perception of road safety issues 30

4.6 Data collection 31
4.7 Data saturation 32
4.8 Data processing 33
4.9 Key-informant interview 33
4.10 Summary of methodology 33

5 Results and discussion 35
5.1 Spatial Pattern of road traffic crashes 35
5.2 Road users' perception survey 41
5.3 Self-perception of road users 42
5.3.1 Involvement in RTC and optimism bias 42
5.3.2 Self-declaration of risky behavior 43
5.3.3 Human factors responsible for RTC 44
5.4 Perception of road users towards selected zones 45
5.4.1 Perception in RTC hotspot zones 45
5.4.2 Perception in RTC coldspot zones 46
5.5 Road users' understanding of the specific road parameters and their relation with RTCs 47
5.6 Road users' perception of the prevailing road safety policies 49
5.6.1 Attitudes towards existing policies 49
5.6.2 Attitudes towards possible recommendations 50
5.6.3 Attitudes towards the government/ authorities 51

6 Conclusion 53
6.1 Reduction in wickedness 54
6.2 Limitations 55
6.3 Recommendations for the Municipality of Rotterdam 55
6.4 Recommendations for further studies 56

LIST OF FIGURES

Figure 1-1: Problem framework diagram. 3

Figure 1-2: The wickedness framework 4

Figure 1-3: Categorization of the wickedness 5

Figure 1-4: Primary and secondary stakeholders 6

Figure 1-5: The research hypothesis 8

Figure 2-1: Average road deaths per billion vehicle km in different EU countries, 2018-2020 10

Figure 2-2: Annual road traffic crashes in the Netherlands, 2010-2020 11

Figure 3-1: Road traffic crashes at a provincial level in the Netherlands in 2020 21

Figure 3-2: Road traffic crashes in Rotterdam, 2010-2020 21

Figure 3-3: The study area map 22

Figure 4-1: Road network vs. Euclidean distance 26

Figure 4-2: Diagrammatic representation of the calculation of Global Moran's I 27

Figure 4-3: Diagrammatic representation of the calculation of Local Moran's I 28

Figure 5-1: Spatial distribution of RTCs in 2018 35

Figure 5-2: Spatial distribution of RTCs in 2019 35

Figure 5-3: Spatial distribution of RTCs in 2020 36

Figure 5-4: Network Spatial Weight Matrix 37

Figure 5-5: Spatial autocorrelation report 37

Figure 5-6: Incremental spatial autocorrelation 38

Figure 5-7: Local Moran's I 38

Figure 5-8: Network Kernel Density Estimation of RTCs in 2018-2020 39

Figure 5-9: Zones 1 and 4 40

Figure 5-10: Zone 2. 40

Figure 5-11: Zone 3 40

Figure 5-12: Percentage of responses 42

Figure 6-1: Synthesis of results 53

LIST OF TABLES

Table 1-1: Thesis structure 8

Table 2-1: Overview of different methods and description for spatial analysis of RTCs........ 12

Table 2-2: Road parameters and their effect on RTCs........ 13

Table 2-3: Overview of risk perception measures........ 15

Table 2-4: Principles in the sustainable safety approach........ 17

Table 3-1: Research matrix........ 23

Table 4-1: Question categories in the questionnaire........ 30

Table 4-2: Number of respondents 31

Table 4-3: Improvements applied for the second fieldwork 32

Table 4-4: Assigning numeric values to Likert responses........ 33

Table 4-5: Various results correlating to respective research objectives and questions........ 34

Table 5-1: RTC counts 2018-2020........ 36

Table 5-2: Causes of road users' annoyance........ 45

Table 5-3: Road parameters vs. severity of RTCs from 2018-2020 47

Table 5-4: Time of the day vs. crashes from 2018-2020 48

LIST OF ABBREVIATIONS

AAMS	Association for the Advancement of Automotive Medicine
AIS	Abbreviated Injury Scale
ANOVA	Analysis of Variance
APA	American Psychological Association
BAC	Blood Alcohol Content
BRON	Bestand geRegistreerde Ongevallen in Nederland
CBD	Central Business District
CBS	Centraal Bureau voor de Statistiek
COVID	Corona Virus Disease
EMA	Educational Measures Alcohol
ESRI	Environmental Systems Research Institute
ETSC	European Transport Safety Council
EU	European Union
GDP	Gross Domestic Product
GIS	Geographic Information System
HH	High-High
HL	High-Low
ITC	International Institute for Geo-Information Science and Earth Observation
ITF	International Transport Forum
ISA	Incremental Spatial Autocorrelation
ITS	Intelligent Transport System
KDE	Kernel Density Estimation
LBZ	Landelijke Basisregistratie Ziekenhuiszorg
LEMA	Light Educational Measures Alcohol
LH	Low-High
LISA	Local Indicators of Spatial Autocorrelation
LL	Low-Low
LPTV	Landelijk Parket Team Verkeer
MAIS	Maximum Abbreviated Injury Scale
NKDE	Network Kernel Density Estimation
OM	Openbaar Ministerie
PIN	Road Safety Performance Index
PKDE	Planar Kernel Density Estimation
QR	Quick Response
RD	Rijks-Driehoek
ROV	Regionaal Orgaan Verkeersveiligheid
RTC	Road Traffic Crash
SANET	Spatial Analysis Along Network

SD	Standard Deviation
SDG	Sustainable Development Goals
SPSS	Statistical Package for the Social Sciences
SWM	Spatial Weight Matrix
SWOV	Stichting Wetenschappelijk Onderzoek Verkeersveiligheid
UN	United Nations
VVN	Veilig Verkeer Nederland
WHO	World Health Organisation

1 INTRODUCTION

1.1 Background

A road traffic crash implies a situation in which there is a collision that involves a vehicle(s) on the road and causes damage or injury to either a person, an animal, or a property (Law and Martin, 2009). Road Traffic Crashes (RTCs) can be differentiated in their degree of severity – fatal, major, minor, and minimal injuries (Mao et al., 1997). According to WHO (2021), RTCs cause approximately 1.3 million deaths and 50 million injuries making it a leading cause of death of children and young people worldwide. One factor that affects a country's socioeconomic status is the occurrence and severity of RTCs. As a result, governments are determined to make road safety strategies to reduce the number of casualties (Jadaan et al., 2018). RTCs pose a more significant problem in countries where most citizens fall into low or middle-income groups, and deaths due to RTCs are three times higher than in high-income countries (Cabrera-Arnau et al., 2020). According to Zeng et al. (2019), increased levels of urbanization and rapid development of traffic in cities are directly related to RTCs. Cabrera-Arnau et al. (2020) confirmed that severe and minor RTCs occur more frequently in urban areas than in rural areas due to stressors such as traffic congestion.

Road crashes do not follow an equal distribution along the road network as they are rare occurrences. However, they tend to be clustered at specific points, which depend on time (temporal) and place (spatial) (Wang et al., 2021). Identifying and estimating such clusters or hotspots are important in traffic safety initiatives (Choudhary et al., 2015). In this process, Geographical Information Systems (GIS) have great potential to recognize areas where hotspots occur (Bíl et al., 2019). The hotspots provide knowledge about factors causing crashes and ultimately improve road safety (Benedek et al., 2016). GIS technology is a popular tool transport planners use to visualize collisions for analyzing hotspots (Prasannakumar et al., 2011). Spatially analyzing the crashes allows for recognizing the patterns and reasons for the formation of hotspots (Shafabakhsh et al., 2017). Anderson (2007) has investigated three spatial analysis methods of traffic accidents: kernel density estimation, network analysis, and area-wide analysis. Similarly, there have been many studies regarding hotspot analysis of traffic crashes (e.g., Bíl et al., 2019; Choudhary et al., 2015; Prasannakumar et al., 2011; Safarpour et al., 2020). Bíl et al. (2019) performed a spatial analysis of traffic crashes and provided road administrators with recommendations for safety improvement. Shafabakhsh et al. (2017) analyzed and compared crash severity levels. Choudhary et al. (2015) compared different methods of hotspot analysis using GIS technology. Prasannakumar et al. (2011) investigated hot and cold spot clustering. Other spatial methods to analyze RTCs are discussed further in the literature review, section 2.3.

According to Othman et al. (2009), another factor affecting the occurrence and severity of RTCs is the presence or absence of some road parameters. In the mentioned study, non-operational road parameters such as carriageway width, curvature, superelevation, road roughness, and wheel rut depth were analyzed and compared with crash records to see the relationship between road features and crash occurrence. Another paper by Ozturk (2018) has concluded that road parameters like road materials, number of lanes, exits, intersection legs, directions, and the existence of traffic lights are some of the non-operational factors involved in traffic crashes of varying levels of severity (property damage, injury, and death). A similar example can be taken from a study by Othman et al. (2009), where accident history, presence of accident-prone spots like an intersection, or narrow road width were the chosen road parameters.

Identifying hotspots and their relation to road parameters can efficiently aid in dividing the budget for traffic safety, thus, leading to a sustainable system (Sajed et al., 2019). The success of a sustainable traffic system depends significantly on the road users' perception of policies (SWOV, 2018). Additionally, the occurrence of RTC depends on the human risk perception factor (Guerrero et al., 2020). Studies have indicated that risk perception varies on demographic variables such as gender and maturity (Lund and Rundmo, 2009).

Another factor that significantly influences risk perception is optimism bias. Optimism bias is the tendency in which people tend to be overly unrealistic and optimistic when judging the level of personal risk in certain conditions or situations (DeJoy, 1989; Weinstein, 1987, as cited in Sjöberg et al., 2004). A report by Musselwhite et al. (2010), which includes a literature review of 72 articles, also concludes that there is a perception among road users that "other" drivers and "other" pedestrians are at risk, but not themselves. Some research also suggests that females tend to overestimate risks related to traffic accidents compared to males (Sjöberg et al., 2004). Mainly, younger males are less sensitive to risks caused by dangerous traffic situations (Lund and Rundmo, 2009).

According to WHO (2004), one of the least used road safety interventions was making policies to reduce the exposure of risks to road users. Some examples include reducing traffic volume, providing short and safe networks, encouraging people to shift from high-risk to low-risk transport modes, and using restrictions on motor vehicle users. The ETSC (2007) recommended that policies should be developed to reduce social disparities between road users. Cost-benefit analyses of road safety programs can be performed to demonstrate their benefits to society. Road safety should not be considered an individual issue but should be incorporated into policymaking to achieve sustainable development (WHO, 2021).

1.2 Problem analysis

1.2.1 Current scenario of the problem

According to Cabrera-Arnau et al. (2020), the ratio of the world population to the number of fatalities has stabilized in recent years. However, Cabrera-Arnau et al. (2020) had stated that if the same trend of RTCs is followed in the future, the Sustainable Development Goals (SDGs) target 3.6 to halve the deaths due to RTCs by 2020 will not be achieved. The data on deaths from the past decade indicate that in 2010, there were 1.28 million road deaths, and at the end of 2020, the number had dropped only to 1.20 million. Thus, the SDG target was not met. According to the UN decade of Global Action Plan for Road Safety 2021-2030, the crash rates have been relatively consistent for the past 20 years despite nations' efforts put into road safety policies. If RTCs follow the same trend, they will cause 13 million deaths and 500 million injuries in the next decade and directly hamper sustainable development goals (WHO, 2021). Furthermore, the number of vehicles on the road has increased in recent years, but the serviceability and safety levels have not reached the desired standard in many countries worldwide (Shafabakhsh et al., 2017). This research intends to suggest measures to reduce dangerous spots in road segments so that the future population can safely make their trips.

Many research studies have been carried out to inspect factors contributing to the frequency and severity of crashes. Still, few researchers have studied the influence of street patterns at a community level (consisting of local and collector roads) (Rifaat et al., 2011). Many studies that perform hotspots do not include how the results are related to road parameters or what can be improved on roads to prevent crashes in the future. Although it is known that road crashes occur near an intersection, the analyses related to crashes and road geometry are stereotypically done separately without considering road segments between the intersections (Briz-Redón et al., 2019). Consequently, unreliable results are produced where the critical spatial relationships are missed. This is the knowledge gap this research aims to bridge.

Human factors also contribute to the frequency and severity of RTCs (Bucsuházy et al., 2020). A study by Andersson (2011) concludes that individuals believe risks of RTCs are exogenous or beyond their control, thus leading to under-assessment of a potentially risky situation. Therefore, it becomes essential to look at the problem from a road user perspective by considering their psychology when aiming to reduce the occurrence and severity of RTCs. The problem framework shown in Figure 1-1 explains the problems from three different perspectives (RTCs, psychology of road users, and road safety policies) in the red box, and suggestions to reach the solution are mentioned in the green box.

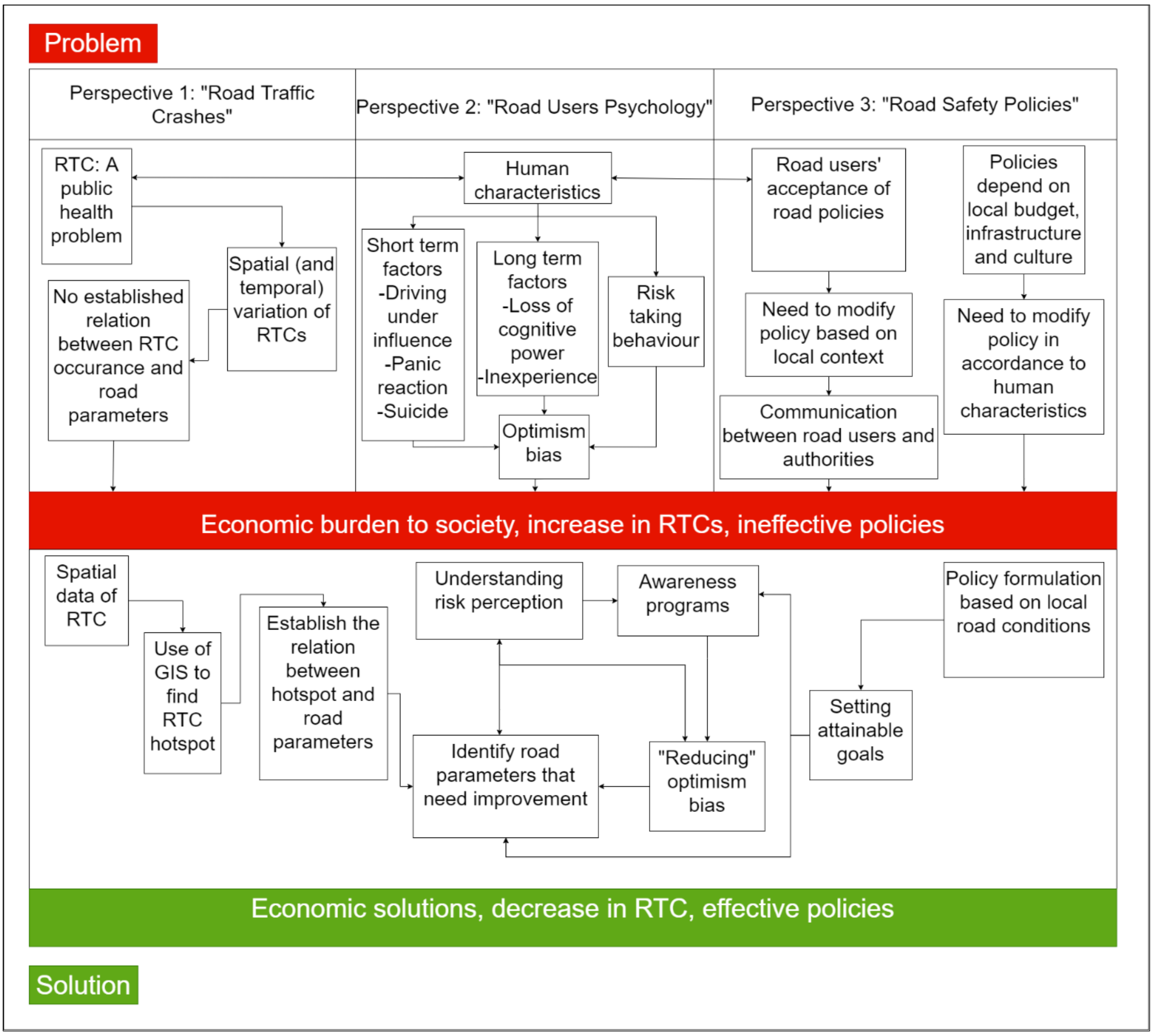


Figure 1-1: Problem framework diagram. Three perspectives are used to explain the problem and different ways to lead to a solution.

The countries in the European region consider road injuries a public health problem and aim to develop relevant information systems from different perspectives by translating the risk of accidents to the risk of public health concerns (Racioppi et al., 2004). RTCs are one of the most common reasons for the death of people living in European regions, particularly in the younger age group. Studies to find the spatial distribution and severity of RTCs are important in RTC prevention and planning of roads (Briz-Redón et al., 2019). As discussed above, most studies that conduct spatial analysis of RTCs do not consider different road parameters that may affect the formation of accident hotspots. The second perspective is that of road users. According to a review by Petridou and Moustaki (2000), the behavioral effects of road users are responsible for the causation of 95% of accidents. The remaining 5% include non-human characteristics like vehicular and environmental factors. These effects can be divided into behaviors that reduce capability and behaviors that increase risk-taking, divided into long-term and short-term factors. Few of the factors mentioned in Petridou and Moustaki (2000) are mentioned in the diagram and discussed further in the literature review. The third point of view to explore the occurrence and severities of RTCs is the road safety policies and approaches. The policies need to be adjusted in such a way to accommodate human errors (SWOV, 2018) and also consider local road conditions when being brought into implementation (Johansson, 2009).

Another problem is that there are different definitions of what "serious injury" means from country to country and the prevalence of underreporting of accidents (Adminaité-Fodor et al., 2021). This does not allow for proper comparison for the policymakers to formulate new policies and approaches to tackle RTC properly. The problem arising from "loopholes" in those perspectives causes an economic burden to society, increased RTCs, and ineffective policies. The analysis of the current situation indicates different levels of "wickedness" involved in the problem. They are explained and categorized in the following section.

1.2.2 The wickedness of the problem

Wicked problems are claimed as having these characteristics: unique and challenging to define, have no stopping rule, have only "good" or "bad" solutions (that either tame or increase the complexity of wickedness), instead of "true" or "false" answers, have no test for the solutions, and maybe a symptom of another problem (Peters, 2017, as cited in Termeer et al., 2019). From the problem framework in the previous section, the research problem can be visualized from three perspectives. The wickedness of those problems and potential wickedness that might arise from the solutions are shown in Figure 1-2.

.

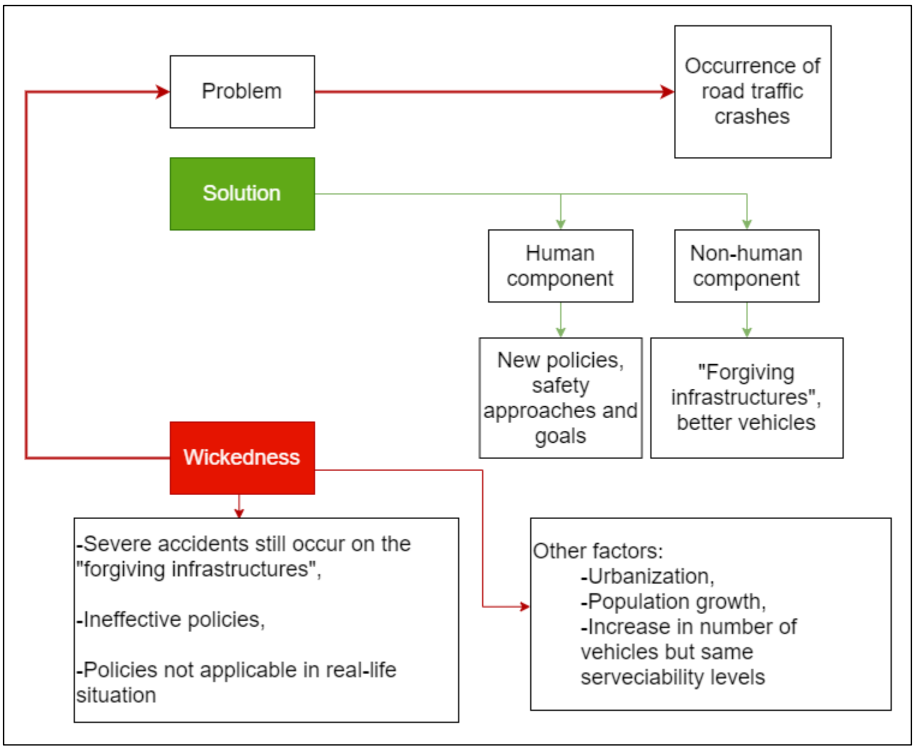


Figure 1-2: The wickedness framework diagram shows the factors causing wickedness and how they can be tamed.

As shown in Figure 1-2, the main problem is the occurrence of RTCs. The wickedness led to by this problem (the symptom) is that there are still RTCs occurring both in urban and rural areas, even when new policies and approaches have been implemented over many years. The wicked issue is because of road accidents' uncertain and unpredictable nature (Kumar and Toshniwal, 2016). The solutions to prevent road accidents can be related to either human or non-human characteristics. On the one hand, policies and approaches can directly influence human characteristics to modify their behavior. Target behavior and factors that influence current behavior are considered to help the road users maneuver the roads safely (Kirley, 2017). The non-human components, on the other hand, can be made safe to use with the help of forgiving infrastructures and by initiating more intelligent vehicles and traffic systems (SWOV, 2018). However, these solutions are not always fully effective in mitigating road accidents down to the aimed numbers while establishing the goals for a fixed period, such as the failure to meet target 3.6 of SDG. Other factors that add to the wickedness are urbanization, increased mobility, lack of enforcement, and human errors that cannot be fully mitigated or controlled (SWOV, 2018; WHO, 2018). The combination of these factors leads to the main problem of the occurrence of RTCs. This study intends to reduce the wickedness in policy implementation and road users' risk perception. The four identified "wickedness" in the previous sections have been categorized in Figure 1-3. These factors are considered in this research.

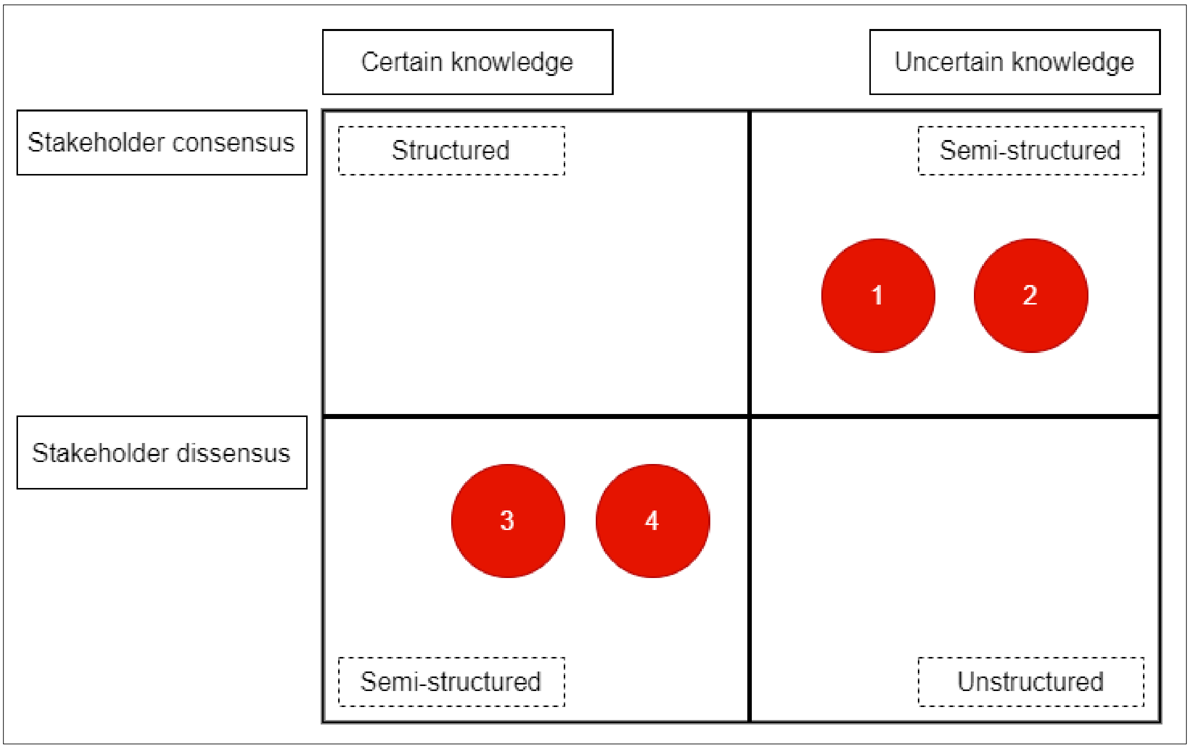


Figure 1-3: Categorization of the wickedness based on stakeholders and knowledge.

1: RTCs are identified as a public health problem but are still persistent
2: Fewer studies between road parameters and RTCs as factors that influence each other
3: Optimism bias in road users
4: Policy shortcomings/ ineffectiveness

Figure 1-3 shows that the wickedness in the problem arises either due to stakeholder dissensus or uncertain knowledge. Stakeholders' dissensus occurs when the involved people disagree with an approach to solve a problem. For example, it is common knowledge that speeding may cause crashes. However, road users neglect to follow this information, thus increasing their probability of collision (relation to points 3 and 4 in the diagram). Uncertain knowledge arises when there is not a known solution to a problem. For example, road accidents cannot be mitigated entirely with the available knowledge, even if the stakeholders agree on the information (relation to points 1 and 2 in the diagram). Figure 1-4 shows the primary and secondary stakeholders of this research. As defined in Clarkson (1995), as cited in Benn et al. (2016), primary stakeholders are the groups of people directly influenced by changes in decisions. In the case of this research, that group includes road users. Secondary stakeholders are people who control or affect but are not engaged directly (Benn et al., 2016). In this research, that group of people consists of the road safety authorities, organizations, experts, and policy makers.

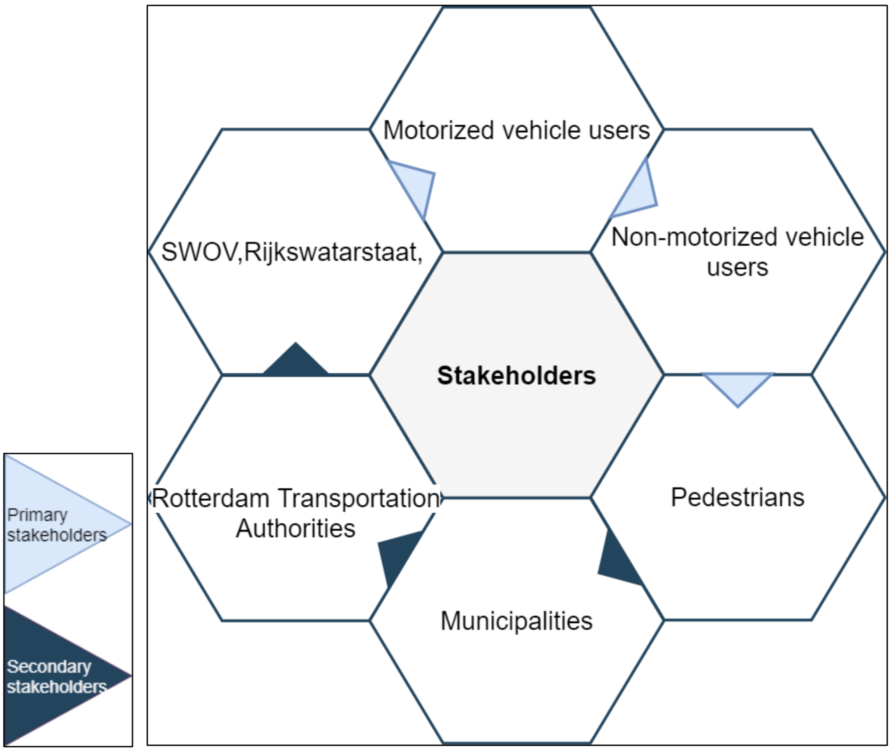


Figure 1-4: Primary and secondary stakeholders involved in this research

Based on the previous sections' problem identification, research objectives and questions are elaborated in the next section.

1.3 Research identification

In the European region, RTCs are considered to be a significant public health problem as it takes approximately 127 thousand lives per year, and around 2% of Gross Domestic Product (GDP) is lost due to transport-related crashes (about 180 Billion Euros per year) (Racioppi et al., 2004). The global plan of action for the decade is set to reduce the number of deaths due to RTCs by 50% (WHO, 2021).

This research performs a spatial analysis of RTCs that occurred in a road network and investigates the effect of road network parameters (non-operational) on the occurrence and severity of RTCs. The road parameters were selected based on site conditions and the literature review. A literature review was performed to identify the best tool in GIS for spatial analysis. As discussed in the previous sections, according to WHO (2004), human error is a significant factor in RTCs (around 90%). The logical process of reducing accidents is to adjust human behavior toward an “error-free” state. Thus, consideration of psychology is a backbone of RTC prevention. According to Kirley (2017), the following points relating to human psychology are to be considered when aiming to reduce RTCs: humans are not solely logical, rational beings, so they are prone to make mistakes, and the road environment plays a significant role in human behavior and perception of risk.

Experience shows that human beings make decisions impulsively more than deliberatively in case of a road situation that requires them to act in a short time (Kirley, 2017). It is advised that to reduce RTCs, the sole use of information-based approaches is not very effective unless the road environment is also changed. The knowledge of human risk perception and behavior is essential to policymakers since decisions are based on how the public perceives risks (Andersson, 2011). Thus, this research also uses road user perceptions to identify measures for road safety improvement.

The novelty of this research is the combined use of spatial data of RTCs and road users' risk perception of RTCs, road parameters, and attitudes towards policies. Combining these two different approaches can aid policy makers in better understanding the area and provide more effective and socially accepted interventions.

1.4 Research Objective and questions

Based on the problem analysis in section 1.2, the main objective of the research is to perform a spatial analysis of road traffic crashes and assess road safety issues from the road users' perspective.

Specific objectives and respective research questions are:

1. To identify spatial patterns of the occurrence of RTCs.
   a. Which locations in the road network are more susceptible to RTC?

2. To determine the relationship between certain road parameters and the occurrence and severity of RTCs.
   a. Which road parameters affect the occurrence and severity of RTCs?
   b. Is there a relationship between road parameters and the severity of RTC? If yes, to what extent?

3. To assess road safety issues from the road users' perspective
   a. What is a road user's understanding of the specific road parameters and their relation with RTCs?
   b. How does a road user perceive the personal risk of being involved in RTCs?

4. To explore the effectiveness of prevailing road safety policies
   a. Are the current policies successfully reducing RTCs in the study area?
   b. How do the road users perceive the road safety policies?

5. Based on the findings, to recommend measures for improving road safety.
   a. What are the potential areas of improvement in the current road safety scenario?

1.5 Research hypothesis

This research is based on the hypothesis that the occurrence and severity of RTCs depend on road network parameters and users' perceptions. Also, previous studies suggest that human errors are responsible for a significant fraction of RTCs. Therefore, only improving the physical infrastructure of the road will not be adequate in reducing RTCs. By identifying the risk-prone road parameters and analyzing road users' perception of the RTC, measures can be given to improve existing road policies. Additionally, policies are revisited when there is an increase or decrease in RTCs.

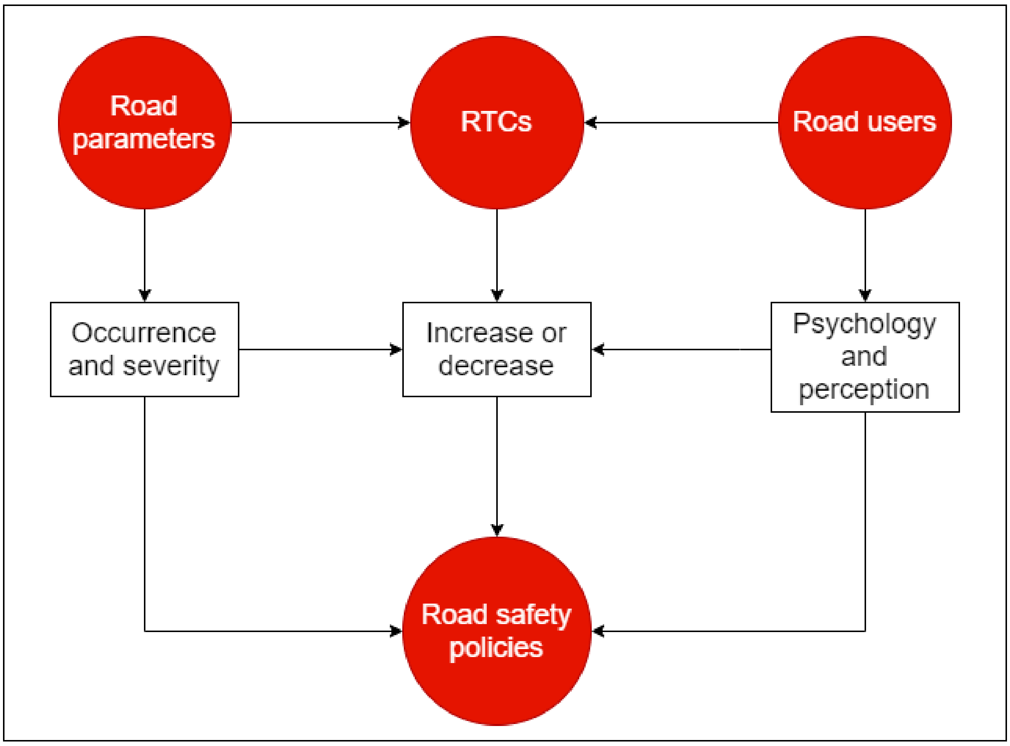


Figure 1-5: The research hypothesis shows the link between road parameters, road users, RTCs, and road safety policies.

Figure 1-5 shows the research hypothesis in a diagram. The red circles are the areas on which this research focuses, and the arrows represent the hypothesis on which factors in rectangle boxes affect or are affected by the focus areas. To summarize, the relation between RTCs, road parameters, and road users' perception affects the occurrence (increase or decrease) and severity of RTCs. This relation influences how road policies are formulated and revisited.

1.6 Thesis structure

This thesis consists of 8 chapters. Their contents are described in short in Table 1-1.

Table 1-1: Thesis structure

Chapter	Content
1: Introduction	Background on RTCs, societal problems caused due to RTC, the wickedness of the problem, research identification, question, objectives, and hypothesis.
2: Literature review	RTC trend in the European region, description of methods for spatial analysis and statistical analyses of risk perception, selection of road parameters and methods of risk perception analysis, and explanation of road safety policies.
3: Research design	Selection and justification of study area, data sources, and analysis software
4: Methodology	Selection and justification of methods, steps performed for spatial analysis, and road users' perception survey
5: Results and discussion	Results obtained from spatial analysis and road users' perception survey, followed by discussion

Chapter	Content
6: Conclusion	Reduction in wickedness, limitations, and recommendations
List of references	List of literature used in this research
Appendices	Additional maps/ question outlines of the key-informant interview
Annexes	Likert-scale responses of survey, questionnaire in English

2 LITERATURE REVIEW

This chapter includes a description of RTC trend in Europe, specifically the Netherlands, and the steps taken to reduce the number of casualties. Various methods of spatial analysis of RTCs based on previous studies and research and road users' perceptions in the context of RTCs are explored. Furthermore, existing literature specific to research questions is discussed in this chapter.

2.1 RTC trend over the years

The European Commission targeted reducing road deaths in Europe by 50% between 2010 and 2020. However, figures indicate only a 36% decline in deaths per million (European Commission, 2021). As a result of the Corona Virus Disease (COVID-19) traffic restrictions, a sudden decrease of 17% in road deaths was observed in the European Union (EU), which indicates that COVID-19 had a significant role in reducing deaths (Adminaité-Fodor et al., 2021). Nevertheless, this also implies that these figures resulted from the pandemic, not because of newly adopted policies or strategies.

Figure 2-1 shows the average road deaths per billion vehicle kilometers for 21 countries from 2018 to 2020 in the EU participating in the European Transport Safety Council's (ETSC) Road Safety Performance Index (PIN) program. It can be seen that Norway had the least and Poland had the highest number of deaths per billion vehicle kilometers in the past three years. However, it is worth noting that even if a country falls below the average EU value, there may not have been a noteworthy improvement in road safety during the period, for example, in the Netherlands (Adminaité-Fodor et al., 2021). The trend of RTC in the Netherlands is explored in the following sections and chapter 3.

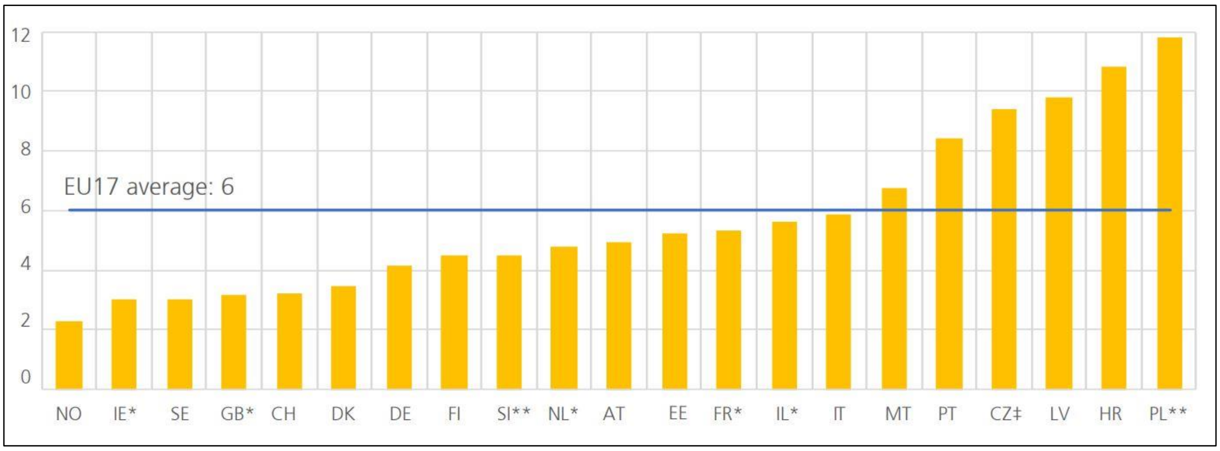


Figure 2-1: Average road deaths per billion vehicle km in different EU countries, 2018-2020

(Adminaité-Fodor et al., 2021)

In the case of the Netherlands, as shown in Figure 2-2, there were slightly more than 100000 road crashes in 2020. Out of 100000 road crashes, 19700 resulted in serious injuries. This exceeded the national target set for 2020, which was 10600 (Aarts et al., 2021). There were 610 deaths in 2020, not much different from the last decade's numbers (shown in Appendix 1). As a result, the national target of 500 deaths in 2020 was not achieved (SWOV, 2021a). The numbers for injuries and deaths were lower than in previous years but not the lowest value, which meant that despite the lockdown caused by COVID-19, there was not much effect on the accident fatalities trend (SWOV, 2021b).

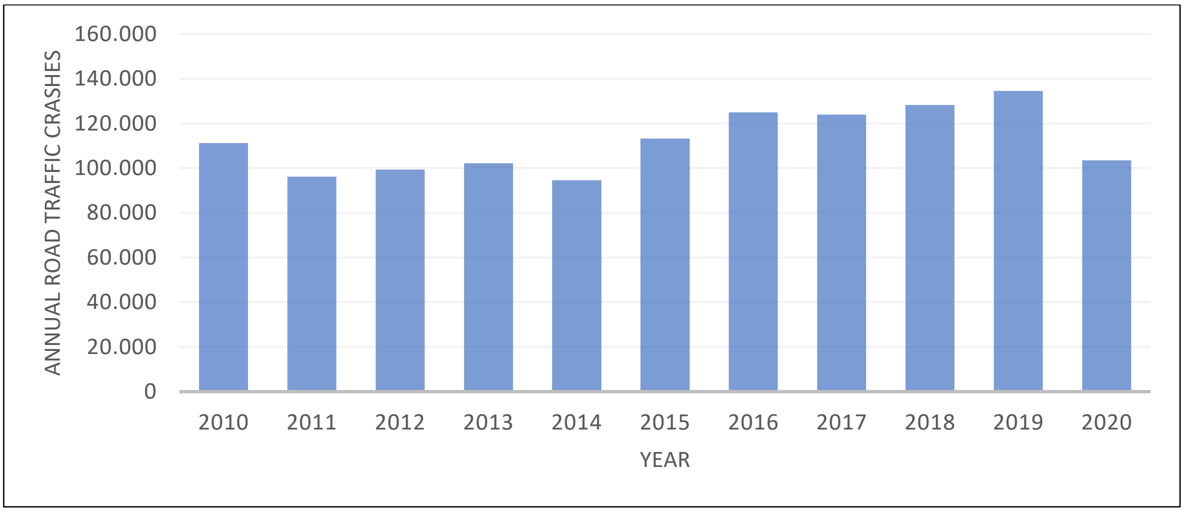


Figure 2-2: Annual road traffic crashes in the Netherlands, 2010-2020

("National road crash registration," 2021)

2.2 Levels of RTC severity

RTCs can result in different levels of severity (Mao et al., 1997). Severity is the intensity or level of destruction to a property or an injury (Soltani and Askari, 2017). According to Al-Ghamdi (2002), accident location plays a vital role in the severity of the outcome of an RTC. For example, the odds presented in the research showed that the probability of being involved in a fatal crash in a non-intersection area if the driver is going the wrong way is more than other violations. Other factors that affect the severity of crashes are driver's age, gender, time of the day, type of crash (frontal/flank/ rear collision), weather, and type of vehicle (Eboli et al., 2020).

The Abbreviated Injury Scale (AIS) is an index ranging from one (minor injury) to six (maximal injury) developed by the Association for the Advancement of Automotive Medicine (AAAM) for describing the physical injuries sustained as a result of traumatic events (Association for the Advancement of Automotive Medicine, n.d.). In the EU, an injury ranking three or higher on the AIS scale is classified as severe injury, also called the Maximum Abbreviated Injury Scale (MAIS 3+) (Aarts et al., 2016). According to the International Transport Forum (ITF), the actual number of serious injuries is not recorded according to the police report but according to the MAIS score (ITF, 2020). As a result, possible miscoding, underreporting, or bias of injury severity is prevented. Based on the combination of data from Bestand geRegistreerde Ongevallen in Nederland (BRON), or Database Registered Crashes in the Netherlands (translated to English) and Landelijke Basisregistratie Ziekenhuiszorg (LBZ), or National Basic Register Hospital Care (translated to English) if an injury has a severity of more than MAIS2 and the injured has not died within 30 days after the accident is defined as severe in the Netherlands (Bos et al., 2020). Since the EU definition does not consider the MAIS2 a severe injury, it is expected that the Netherlands will change its definition soon to adopt uniformity (SWOV, 2020a). As discussed in section 1.2.1, a uniform scale must be used to compare RTC severity to analyze the current level of road safety across different places/ countries.

2.3 Spatial analysis of RTCs

Many approaches can be applied to analyze the spatial distribution of crashes (Bíl et al., 2019). RTC data of minimum past three years are recommended for spatial analyses to achieve statistically dependable results (Benedek et al., 2016; Steenberghen et al., 2010). The hotspot analysis by Kernel Density Estimation (KDE) is the most commonly used technique for spatial analysis. This method enables the visualization of the clustering patterns of crashes along with the road network (Bíl et al., 2019). According to Anderson (2007), KDE is the most effective method since it allows for continuous modeling of collisions and also integrates datasets related to road users and the environment. The KDE is an example of density-based analysis (Bassani et al., 2020). There are two types of KDE. First is the Planar KDE (PKDE), which considers Euclidean distances between crash locations. However, it leads to unreliable results as crashes do not occur in a 2D manner. The second type is the Network KDE (NKDE) which considers the network linearly and gives a more fitting modeling of the crashes (Benedek et al., 2016). It has been proved by a study done by Tang et al. (2013) that network KDE yields a higher rate of accuracy for identifying hotspots in intersections and particular road segments in a time-efficient manner. The differences between Euclidean (2D) and network distance (1D) are further explained later in Figure 4-1 in section 4.2.

In a study by Soltani and Askari (2017), spatial autocorrelation of traffic crashes based on severity was conducted. Spatial autocorrelation is done to see the dependency of a variable in a point with other variables nearby that point (Rogerson, 2015). Global and Local Moran's I is one of the oldest and most commonly used methods to visualize the clustering of RTC hotspots in space (Abdulhafedh, 2017; Choudhary et al., 2015). Global Moran's I is used to analyze the entire dataset to find if the points are clustered in space or not. Local Moran's I analysis involves the analysis of zones within a large area to find where the potential hot spots or cold spots are clustered (Aldstadt J., 2010, as cited in Soltani and Askari, 2017). In other words, global clustering is an average of local clustering values (Anselin, 2010).

Analyses like Global and Local Moran's I require a threshold distance to set a distance limit for analysis. The optimal threshold distance signifies the distance in which the spatial processes are most active or when significant clusters start to form (Blazquez and Fuentes, 2019; ESRI, 2021a). Some research that involves finding spatial relation between RTCs first determined a threshold distance using Incremental Spatial Autocorrelation (ISA) (Hazaymeh et al., 2022; Le et al., 2020). There are many ways to conceptualize spatial relationships of the distances between features in GIS. Some examples are inverse distance, inverse distance squared, and fixed distance band (ESRI, 2021b). Some research uses a network Spatial Weight Matrix (SWM) file to conceptualize the spatial relationship of features lying on a network (Ermagun and Levinson, 2018; Zhang et al., 2020). The workflow of these methods is explained in the methodology section specific to the used tools. The justification for choosing a particular method depends on the dataset to be analyzed (ESRI, 2021b). Table 2-1 shows an outline of different methods used in research involving spatial analysis of RTCs and studies that analyze the relation between RTCs and road parameters.

Table 2-1: Overview of different methods and description for spatial analysis of RTCs

Analysis	Methods	Description	Relevant literature
Spatial Autocorrelation of RTCs	Global Moran's I	Used to get a single value that indicates a local crash pattern.	(Anselin, 2010; Soltani and Askari, 2017)
	Local Moran's I	Used to analyze zones within a large area to find potential hot spots (high values) or cold spots (low values) are clustered.	(Erdogan, 2009; Aldstadt J., 2010, as cited in Soltani and Askari, 2017)
Spatial analysis of RTC	Planar Kernel Density Estimation (PKDE)	Used to produce a smooth density of crashes over a 2D space.	(Anderson, 2007; Steenberghen et al., 2004; Tang et al., 2013)
	Network Kernel Density Estimation (NKDE)	Improvement of PKDE, analysis of crashes in 1D linear space for more fitting modeling of the crashes.	(Anderson, 2007; Benedek et al., 2016; Okabe et al., 2006; Shafabakhsh et al., 2017; Xie and Yan, 2013)

2.4 Effect of road parameters on the occurrence and severity of RTCs

As discussed in section 1.1, some previous studies have studied the relation between road parameters on the occurrence and severity of RTC. Table 2-2 shows other literature which discusses road parameters affecting the occurrence of RTCs.

Table 2-2: Road parameters and their effect on RTCs

Parameters	Description	Relevant literature
Width of carriageway	Crash rate was found to increase with increasing width of the carriageway	(Othman et al., 2009)
Direction of curves	Right curves were found to be more dangerous than left curves during lane changing or overtaking maneuvers	(Othman et al., 2009)
Median dividers	Roads containing medians near intersections have less severe crashes	(Anowar et al., 2014)
Intersections	Controlled intersections have minor severity and occurrences of crashes	(Anowar et al., 2014)
Presence of crossings	Locations with adequate crossings are less likely to have crashes compared to road sections with no crossings	(Ozturk, 2018)
Type of road stretch	Roads with intersections are likely to have more crashes than straight segments	(Eboli et al., 2020)
Safety structures	The presence of guard rails and safety barriers prevents severe crashes	(Klinjun et al., 2021)

Only those road parameters linked to RTCs' georeferenced data were considered for this study. This way, the number of crashes on each parameter could be known. They are straight ways, intersections, bends, and roundabouts. In the case of the Netherlands, approximately one-third of RTCs that result in deaths occur at intersections (SWOV, 2022). Roundabouts are the safest type of intersection since there are fewer conflict zones and smaller impact angles than other intersections (SWOV, 2022).

2.5 Human behavior in RTC causation

As mentioned in the previous section, it is essential to analyze the RTCs and understand human behavior on how they perceive the traffic environment to improve road safety. Human behavior is broadly divided into deliberative and intuitive systems based on how a decision is made. The deliberative system considers a rational line of thought when deciding by weighing the available information, and the intuitive system is an unconscious process used to create an instantaneous decision (Kirley, 2017). These systems are explained with the help of examples in Kirley (2017). An example of a deliberative system is when a driver avoids specific routes because it is congested at certain times of the day. Here, the driver utilizes what information is available to them and decides based on some logic. An example of an intuitive system is when a driver decides to speed up and cross the road or wait when the traffic light turns yellow. Here, the driver took an instantaneous decision without awareness of the process. The driving environment should be modified to target the intuitive decision-making system, such as building a pedestrian bridge or fence to prevent a crossing at dangerous locations (Kirley, 2017). Similarly, information-based measures like campaign programs are suggested to improve the deliberative decision-making system. Mistakes caused by road users result from intuitive and deliberative factors; thus, both should be targeted in road safety approaches (Kirley, 2017).

According to Bucsuházy et al. (2020), there is always more than one factor in the causation of traffic accidents. A traffic accident results from many interlinked factors Bucsuházy et al. (2020). Examples of those factors are human factors like inattention, misinterpretation of traffic conditions, panic reaction, and inexperience. Petridou and Moustaki (2000) also categorized human behavior that leads to RTCs based on capability reduction on a long-term and short-term basis and the factors that encourage risk-taking behavior with long-term impacts. It was found that the three mentioned factors were responsible for 95% of total road traffic crashes. By classifying human behavior into the three categories, it will be possible to prioritize behavior modification efforts realistically and eventually reduce the number of road injuries.

Bucsuházy et al. (2020) categorized human characteristics into two parts: factors that reduce the capability and factors that modulate risk-taking behavior. These aspects have been further divided into long-term and short-term factors. Some examples of long-term factors are inexperience or diminishing cognitive power of an individual (reduces the capability of driver) and speeding or conscious violation of traffic rules (risk-taking behavior) (Bucsuházy et al., 2020). These factors are or have been present in nature of the driver and are comparatively permanent. Some short-term factors explained in the paper were: reaction to panic or glare from a vehicle in the opposite direction (reduction in capability), overtaking, and suicide (risk-taking behavior). From the papers discussed above, it becomes clear that only improving the physical infrastructure of roads is not enough to guarantee the safety of road users. The focus should be on understanding and reducing risky behaviors, both short and long-term.

Furthermore, these risky behaviors can also lead to annoyance among road users. Research conducted by Zhang and Chan (2016) concluded a positive correlation between driving anger and aggressive driving, risky driving, and driving errors. Many studies indicate risky behaviors resulting from annoyed drivers (Wang and Chen, 2020; Zhang et al., 2019). This implies that it is essential to find the cause of risky behaviors. It is also necessary to determine which factors annoy the road users to improve road safety. Some anger triggers are congestion, noise due to honking, incorrect parking, overtaking from the wrong side, speeding, environment temperature, long travel distances, important meetings or deadlines, bad road conditions, and mixed traffic conditions (Sagar et al., 2013). These behaviors can be reduced with psychological approaches such as driving education and public campaigns (Sagar et al., 2013). Road users should learn how to cope with stressful situations that may arise so as not to cause inconvenience to people around them. Likewise, roads should be designed, keeping in mind the human characteristics of a road user and how it is perceived by other road users (Cunningham et al., 2017). An example of such design is a self-explaining road, which means road users can immediately perceive how to use (drive) on such roads (Cunningham et al., 2017). This can be achieved by changing the visual environment so that the road users perceive the risks and change their behavior accordingly, for example, reductions in speed (Charlton et al., 2010, as cited in Walker et al., 2013).

2.6 Risk perception towards road parameters and RTCs

Risk perception is a subjective assessment of the probability of incidence of a specific accident and the level of concern about risk consequences among the involved people (Sjöberg et al., 2004). Perception means the steps involved in using the senses to recognize, observe and discriminate between different objects, relations, and actions (APA Dictionary of Psychology, n.d.). The response to these stimuli enables organisms to respond in a particular manner.

There is a positive correlation between risk perception by road users and road safety (Ram and Chand, 2016). Therefore, it is essential to recognize how humans perceive RTCs on the roads they use daily. Many factors influence the risk perception of individuals. Human behavior is one of the factors, as it is responsible for a large number of accidents (Bucsuházy et al., 2020). Risk perception also depends on past experiences of the road users (Ram and Chand, 2016). According to a study by Andersson (2011), road users who use a comparatively safer means of transport such as a car are likely to perceive the risk of RTC to a lesser degree than those who use other means of transportation. Therefore, it is essential to recognize how humans perceive RTCs on the roads they use daily. Table 2-3 shows an overview of different approaches to quantifying risk perception.

Table 2-3: Overview of risk perception measures

Approach	Data typology	Relevant literature
Psychometric paradigm with a seven-point scale and the use of multivariate statistical methods	Compilation of nine dimensions from literature about risks. (voluntary vs. non-voluntary risk, immediacy of effect, chronic vs. catastrophic risk, common vs. dread risk, severity of consequences, known vs. unknown risk and levels associated, level of control, novelty of risk).	(Fischhoff et al., 1978, as cited in Sjöberg et al.(2004))
A questionnaire with independent variables. Analysis of Variance (ANOVA) was performed to find the degree of correlation.	Occupation, driving experience, fatalistic beliefs, and accident history.	(Kouabenan, 2002)
A questionnaire with a four-point scale, use of descriptive statistical methods to find correlated factors	Perceived risk of road travel in different scenarios	(Ngueutsa and Kouabenan, 2017)
A t-test for determining if accident involvement affects risk perception and safe behavior	Accident involvement history	(Ngueutsa and Kouabenan, 2017)
Mean and Standard Deviation (SD) relation between demographics and risk-taking behavior	Age, education, experience, accident involvements, and witnessed, perceived causes of accidents.	(Peltzer and Renner, 2003)

The knowledge of human risk perception and behavior is essential to policymakers since decisions are based on how the public perceives risks. This way, risk policies can be implemented easily and remain cost-effective simultaneously (Andersson, 2011). Traffic safety can be improved with the help of perceptual and objective data from respondents about the risk of prevalence of factors (Guerrero et al., 2020).

2.7 Measurement of risk perception

As discussed in the above section, risk perception toward road safety issues can be analyzed through surveying techniques. The survey can collect qualitative or quantitative responses specific to the research goals and objectives. Qualitative research provides in-depth knowledge about human behavior, attitudes, understanding, and objectives for the collected quantitative responses. Purposive sampling and ground theory analysis are methods for qualitative research (Ahmad et al., 2019).

Purposive sampling is widely used to collect data and produce significant results for qualitative research. Purposive, or judgment sampling, is the process in which the researcher obtains a representative sample by using their judgment, which will be helpful in cases where only a limited number of people can serve as a source of data to fulfill research goals (Black, 2010). The researcher collects and analyses the data simultaneously and decides to collect or not collect more data to develop a theory they are trying to prove

(Glaser and Strauss, 1999). The grounded theory analysis approach is an effective way to understand the interests of a group of people (Corbin, 2008, as cited in Sharifian et al., 2021). According to Mason (2010), qualitative research should consider data saturation. This means collecting and analyzing data till a point in which no "new" findings occur. In ground theory, hypotheses are developed by focusing on "discovery rather than verification of theory" (Javadi et al., 2017; Silva et al., 2020). After discovering a theory "grounded in the data," similar responses are grouped into categories then relationships between different categories are established (Holmes et al., 2019). When no new category is discovered or no new concept is added to an already established category, saturation is created (Glaser and Strauss, 1999; Sharifian et al., 2021).

2.8 Road safety approaches and policies

According to Racioppi et al. (2004), road safety policies should incorporate transport, environmental, and health plans for the community. For example, policies that enforce speed limits positively impact the environment by reducing air and noise pollution and road users' perception since they will be inclined to participate in walking and cycling, ultimately decreasing inactive lifestyles.

Generally, there are two approaches to developing a road safety policy: traditional and systemic (Safarpour et al., 2020). The conventional approach involves shifting road users' behavior and holding them accountable for possible crashes. However, the systemic approach focuses more on road design and aims to make the road system more "forgiving" towards human errors (Safarpour et al., 2020). The mentioned paper also discussed two approaches; the road-user approach, which is similar to the traditional approach, i.e., it is based on the fact that if road users are monitored and regulated, RTCs can be reduced. Another approach is the casual approach, in which RTC is said to be caused due to different events and factors (meaning road users and road design).

In the 1990s, the "sustainable safety approach" was first introduced in the Netherlands (Weijermars and Wegman, 2011). This approach is an improvement in the systemic approach, and it considered three factors: functionality of roads, homogeneity in mass, and predictability of traffic behavior (SWOV, 2018).

After the sustainable safety approach, the next step was the safe systemic approach, which began in Sweden and the Netherlands in the mid-1990s (Safarpour et al., 2020). This approach accepts that crashes will continue, no matter what infrastructures are used, because humans are prone to making mistakes. The main identified challenge was to reduce the number of severe injuries with the help of traffic, environmental, and infrastructure elements, given that road users follow the rules correctly (Larsson and Tingvall, 2013).

In 2010, the UN's General Assembly declared 2011-2020 as the decade of action for road safety to provide time to encourage improvement in politics and resourcefulness of road safety measures. The goal to reduce road deaths and injuries by half was set again for 2021-2030 by the UN General Assembly in 2020, after failing to achieve the same in the previous decade (WHO, 2021). The plan is developed on the safe system approach- to develop forgiving road infrastructures and not negotiate road users' safety for other factors such as cost or reduced travel times. Similarly, The European Commission formulated the EU Strategic Plan for Road Safety to halve road deaths in the coming decade (2021-2030) and halve the seriously injured casualties in the same time frame (European Commission, 2020).

In the Netherlands, the third edition of sustainable safety, SWOV (2018), focuses on the five approaches as a vision for 2018-2030, as shown in Table 2-4.

Table 2-4: Principles in the sustainable safety approach

Road Safety principles	Description
Functionality	Classifying roads based on functional structures (access, distributor, and through road)
(Bio)mechanics	Maximizing road user protection by minimizing differences in speed, direction, mass, and size of vehicles
Psychologies	Designing the road based on user competencies
Responsibility	Allocation of responsibilities to guarantee safety for users
Learning and innovating	Learning and motivating in a traffic system (learning from mistakes)

Additionally, through the joint approach of Dutch public authorities, civil society, and organizations, the Strategic road safety plan 2030 was devised. This vision was developed to view the problem of RTCs from the perspective of road users and on how to increase awareness regarding unsafe behavior. It focuses on a risk-based approach, where risks are identified, and measures to reduce them are suggested (Ministry of Infrastructure and Water Management et al., 2019).

There are three phases planned for the implementation of a risk-based approach. The first phase (2018-2020) was the implementation phase. Currently, the vision is in the second phase (2020-2025), focusing on three points- "experience, learn and evaluate." The third phase (2025-2030) is intended for adjusting and professionalizing (Ministry of Infrastructure and Water Management et al., 2019).

The implementation of these policies is dependent on various factors like the local tradition of the country, existing infrastructures, and costs for design, repair, and maintenance (Johansson, 2009). Many studies indicate that vision zero strategies effectively reduce RTCs (Haq and Whitelegg, 2006; Johansson, 2009; Mendoza et al., 2017). At this stage, it is essential to learn about the effectiveness of policies and measures to develop monitoring instruments and discover which actions will provide better results (Ministry of Infrastructure and Water Management et al., 2019).

2.9 Road safety in the Netherlands

In the Netherlands, over one-third of the societal costs of RTCs are attributed to severe injuries, and about 11% are attributed to RTCs resulting in deaths. The expenses include "hard costs" like medical bills and vehicle repair and compensation costs in case of loss of life. In 2018, the total societal costs were estimated at €17 billion, more than 2% of the GDP (SWOV, 2020b).

Rijkswaterstaat, also known as the Ministry of Infrastructure and the Environment in the Netherlands, works closely with various partners such as Veilig Verkeer Nederland (VVN), Regionaal Orgaan Verkeersveiligheid (ROV), Stichting Wetenschappelijk Onderzoek Verkeersveiligheid (SWOV), and Landelijk Parket Team Verkeer (LPTV) and TeamAlert to enforce road safety regulations, advise on road design and infrastructure on roads under their authority (Rijkswaterstaat, n.d.).

SWOV, or Institute for Road Safety Research (translated to English), is a national, non-profit organization in the Netherlands that aims to contribute to road safety through scientific research. SWOV collaborates with the central government, provinces, municipalities, and other bodies to perform research projects and prepare fact sheets and publications (SWOV, n.d.). The research done by SWOV covers infrastructure and traffic, behaviors in traffic, interaction with self-driving vehicles, and data and analysis for policy (SWOV, n.d.). As discussed in the above sections, SWOV has played a significant role in developing a sustainable safety vision in the Netherlands for 2018-2030. It is also known as a "safe system approach" internationally. It suggests that traffic systems be developed in a risk-based approach, where the fatal crashes will be investigated to identify and minimize existing factors (SWOV, 2018).

TeamAlert is an organization that carries out research, projects, and campaigns relating to road safety, focusing on youths in the Netherlands. The main themes of this organization are distraction in traffic, vulnerability of youths on roads, speed in traffic, driving under the influence, and inexperienced road users (TeamAlert, n.d.). In most places, awareness training in schools and festivals is carried out by this organization after the municipality approaches them (TeamAlert, personal communication, June 2, 2022).

The following sections describe road safety policies for the motorized and non-motorized forms of transport in the Netherlands.

2.10 Road safety policies for motorized transport

According to Mathijssen (2005), around 25% of severe RTCs in the Netherlands were drinking and driving, with young male drivers (18 to 24 years) being a risk group. Between 1970 and 2000, the Blood Alcohol Content (BAC) limit was 0.5% for all drivers. However, that was changed in recent years (since 2006) when novice drivers were given a 0.2% BAC limit (Vlakveld, 2004). Countries like Hungary, Slovakia, Romania, and the Czech Republic have a BAC limit of 0.0%, according to Adminaité-Fodor et al. (2021). Lowering the BAC limits is one of the effective policies to reduce serious RTCs. However, the effectiveness also depends on the target group's age, gender, and zone (Albalate, 2009).

Another policy or program initiated in the Netherlands is the Bob designated driver campaign. It is a positive enforcement technique. A person in a group is assigned as the Bob (known as Bewust Onbeschonken Bestuurder in Dutch), who is the designated driver for their friend's group and is not allowed to drink when going on drinking events (Mathijssen, 2005). However, a focus group survey conducted for a study in 2014 concluded that these campaigns tend to wear off the positive message unless they are adequately advertised and create awareness about their existence (Laing, 2014).

According to Goldenbeld et al. (2016), drivers apprehended for drinking and driving up to and including a BAC of 1.66% are punished by the Openbaar Ministerie (OM) or the Public Prosecution Office (translated to English) by issuing a fine and suspension of driving license. Offenders with BAC higher than 1.65% are brought to court; then, a criminal record is filed against them. In the administrative process, the offenders are made to attend Light Educational Measures Alcohol (LEMA) and Educational Measures Alcohol (EMA) or an exam to check if they are still fit to drive in the future. However, it was found in a study that EMA has comparatively more positive effects than LEMA for both general traffic offense recidivism and drink-driving recidivism (Blom et al., 2017). The effectiveness of these courses in the case of reducing reoffences is not appropriately quantified. For example, a speeding offense is registered with the vehicle's number plates, and there may be many cases where a driver may have speeded in a vehicle other than their own. In the Netherlands, most offenses are registered by road cameras, so the actual driver is unknown (Goldenbeld et al., 2011). This creates a bias in the data to count the exact number of committed reoffences (Blom et al., 2017).

The relationship between repeat offenses and risky behavior is shown in Dutch research by Goldenbeld et al. (2013). It is mentioned that vehicles with many fines have an increased risk of being in RTCs compared to vehicles with fewer traffic fines. Some road users with a very high number of penalties (11-20) fall under the 0.1% of total fines but are found to be involved in more than 4% of total crashes. Repeat offenders are road users who commit at least three serious traffic offenses within two years (SWOV, 2021c).

Studies suggest that progressive fine systems, in which sanctions increase as offenses repeat, will help adjust driver behavior (Hoekstra et al., 2017). Goldenbeld (2017) put forth an idea to set the progression of fines based on the time between the offenses. This would create a fair and positive system. Several progressive penalty systems are used in the Netherlands: for novice license holders, alcohol offenders, recidivism scheme for multiple offenders, and recidivism scheme for offenses like speeding, insufficient headway, driving without a license, maximum construction speed moped, driving against the traffic (Goldenbled, 2017)

These systems usually lead to either invalidation of a driver's license (in case of two offenses in the past five years) or suspension of a driver's license combined with a driving test. However, according to research by Castillo-Manzano and Castro-Nuño (2012), even though these systems have a positive effect on road safety (decrease in RTC and deaths by 15-20%), their effects are known to have a maximum time duration of 1.5 years only. After that time, the effect was diminished in European and non-European countries (Castillo-Manzano and Castro-Nuño, 2012).

Another policy this research considers is the speed limit on the Dutch motorways. The speed limit on motorways is 100 km/hr, which was reduced from 130 km/hr in March 2020 (SWOV, 2021d). Also, the minimum speed so that there is no hindrance on motorways is limited to 60 km/hr. Various studies have concluded that as mean speed decreases, the probability of crash occurrence and severity decreases (De Winne and De Winne, 2009). The speed limits should be based on the types of road users (either mixed or not) using the roads (SWOV, 2018).

2.11 Road safety measures for non-motorized transport

There are limited ways of influencing and monitoring the behavior of pedestrians and cyclists(Vermeulen, 2003). They are considered the most vulnerable road users due to lack of protection in the event of a collision with a motor vehicle (Rifaat et al., 2011; SWOV, 2018). Therefore, it becomes essential to make the road environment safe for them by implementing safety rules on other forms of transport. Infrastructural measures (example, having good markings and signages, setting a low-speed limit in crowded places, and vehicle technology like using side shields in trucks and in-vehicle radar systems), and behavioral measures (example, having appropriate driving tests and traffic education for road users) are some steps that can aid in improving road safety for non-motorized vehicles and pedestrians (SWOV, 2020c).

According to Houwing et al. (2015), the crash risk faced by a drunk cyclist with a BAC of more than 0.2% is sixty times more than a sober cyclist. In the Netherlands, the alcohol limit for cyclists is as same as for car drivers (SWOV, 2017a). The number of cyclists with BAC higher than the legal limit was found more in the weekend evenings (more than 80% of tested cyclists), as observed by Houwing et al. (2015). Since there is a high prevalence of drinking and cycling in the Netherlands, some suggestions can be to start night public transport services or to have more campaigns to reduce the numbers (de Waard et al., 2016).

Helmets are not compulsory for road users who use bicycles in the Netherlands. However, international research has shown that 60% of serious injuries can be prevented if the cyclist is wearing a helmet at the time of the crash (SWOV, 2019). Traffic regulations also state that cyclists must use lights on the front and rear of their bicycles in the dark (Ministry of Infrastructure and the Environment, 2013). Other measures to improve cyclist safety are constructing separate paths and using more roundabouts (SWOV, 2017b). Some measures already in place are reducing the speed limit in residential areas to 30 km/hr (previously 50 km/hr) and moving the moped path from the bicycle path (Schepers et al., 2017). This aids in the safety of both cyclists and pedestrians.

2.12 Intelligent Transport System for road safety

Intelligent Transport System (ITS) refers to technologies that can improve road users' perception of the road infrastructure, thus communicating the information related to possible risks (Vanderschuren and Mckune, 2011). Common ITS are traffic light controllers, navigation systems, parking guidance, distance warning, cruise control, and docking systems (Vanderschuren and Mckune, 2011). This research explores the use and social acceptance of some ITS in motorized vehicles. The focused ITS devices are: speed limiting devices, use of alcolock, black box installation, fatigue detection devices, and use of automated cars. The reason for selecting these options is to make sure these options are available in markets and accessible by most drivers.

Installation of night vision in cars and speed limiting devices can prevent speeding in speed-restricted areas if drivers fail to see road signs in time (Vlakveld and Twisk, 2012). Alcolock is an ITS in which drivers should blow into an alcohol meter, and the car starts only when BAC is below the legal limit. It has been proved that the alcolock program is more effective than the license suspension policy for repeat offenders, with a 60% reduction in drink-driving recidivism (Bjerre and Thorsson, 2008). Black boxes are devices used in vehicles that can record data like speed, throttle position, brake application, airbag deployment, steering angles, and other factors before and after a crash that can be used to understand injury mechanisms and evaluate the safety of drivers (European Commission, n.d.). Fatigue in drivers can be detected by eye movement monitoring systems, steering movements, heart rate, temperature, skin conductance monitoring, and other mechanisms. According to Hermens (2020), no single means mentioned above can be selected for fatigue detection, but a system comprising all the factors should be developed. Self-driving or automated cars with various levels of automation are currently being studied, and the transition toward self-driving vehicles is viewed positively by most stakeholders (van Nes and Duivenvoorden, 2017).

This research focuses not on how the ITS works but on how road users feel about using ITS. In the past, there were both positive and negative assumptions about the presence of automated vehicles on roads regarding traffic flow and safety (Calvert et al., 2017). Research conducted in Great Britain and Australia concluded that using such technology would increase the level of safety of vulnerable road users (Morris et al., 2021). Many types of research have proved the effectiveness of these strategies, but there is an equal need for society to accept them. Road authorities are also in favor of ITS, but there is a need for a profitable market and a safe financial risk margin to start production at an industrial level (Morsink et al., 2007). Critical stakeholders include road users, road authorities, and policymakers, and cooperation, communication, and coordination are essential for the success of the implementation of any ITS (Wilson et al., 2010).

3 RESEARCH DESIGN

3.1 Study area

The study area was chosen based on the number of RTCs that had taken place in the past. Among the provinces in the Netherlands, the highest number of accidents were recorded in the provinces of South and North Holland, respectively, in 2020, as shown in Figure 3-1.

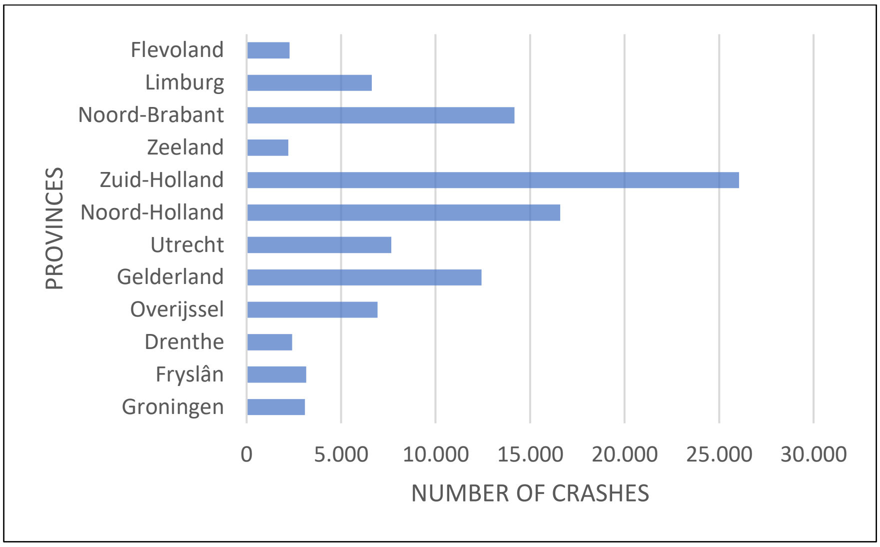


Figure 3-1: Road traffic crashes at a provincial level in the Netherlands in 2020

("National road crash registration," 2021)

South Holland is the sixth largest province in the Netherlands, with a total area of 3403 km^2 (CBS, 2018). Among the municipalities in South Holland province, this study focuses on Rotterdam. The population in Rotterdam was 651157 in 2020. The population growth rate per 1000 has been a positive of 0,7 (from 2019) and 10,2 (2018) (CBS, 2021a). Rotterdam had the highest RTCs (6280) among all the municipalities in South Holland Province in 2020 ("National road crash registration," 2021). As shown in Figure 3-2, the trend of road accidents in Rotterdam city has increased in the past decade. There was a drop in 2020 but lower traffic volumes during the implementation of COVID-19 containment measures. During that period, comparatively lesser RTCs resulted in injuries, but more deaths due to RTCs (approximately 13%) were reported compared to 2019 (ITF, 2020).

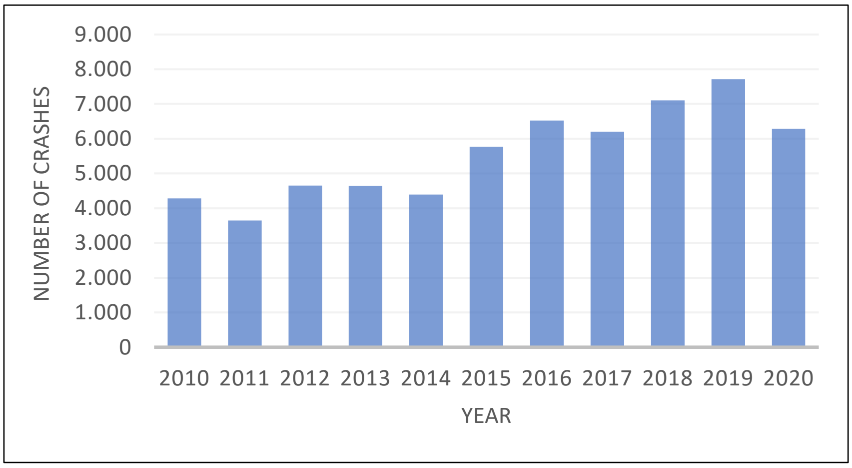


Figure 3-2: Road traffic crashes in Rotterdam, 2010-2020

("National road crash registration," 2021)

The study area is shown on a map in Figure 3-3. This research will consider the A4, A20, A16, and A15 motorways and the roads enclosed in their polygon. To study the spatial distribution of crashes, some extra extent of roadway should be considered. Many techniques have been explored in past studies to determine the extent that needs to be considered. Buffering technique is one of the widely used practices, keeping most of the radius within 100m (Kang et al., 2019; Ma et al., 2014; Pulugurtha and Sambhara, 2011; Quistberg et al., 2015). This is the reason for choosing the surrounding urban areas around Rotterdam. The spatial distribution of RTCs occurring on the roads extends beyond the polygon area bounded by A4, A20, A16, and A15 motorways can also be studied. In this case, a buffer of 1km radius outwards from the polygon formed by the motorways was shown in dark gray color. There were fewer crashes beyond this point; thus, the research was limited to this area.

The study area covers most of the Rotterdam city and Schiedam area. It also consists of some road networks in Ridderkerk, Barendrecht, and Albrandswaard. After locating the hotspots, the remaining analysis (relation between RTCs and road parameters, risk perception toward RTCs and roads) will be done only on the respective hotspots.

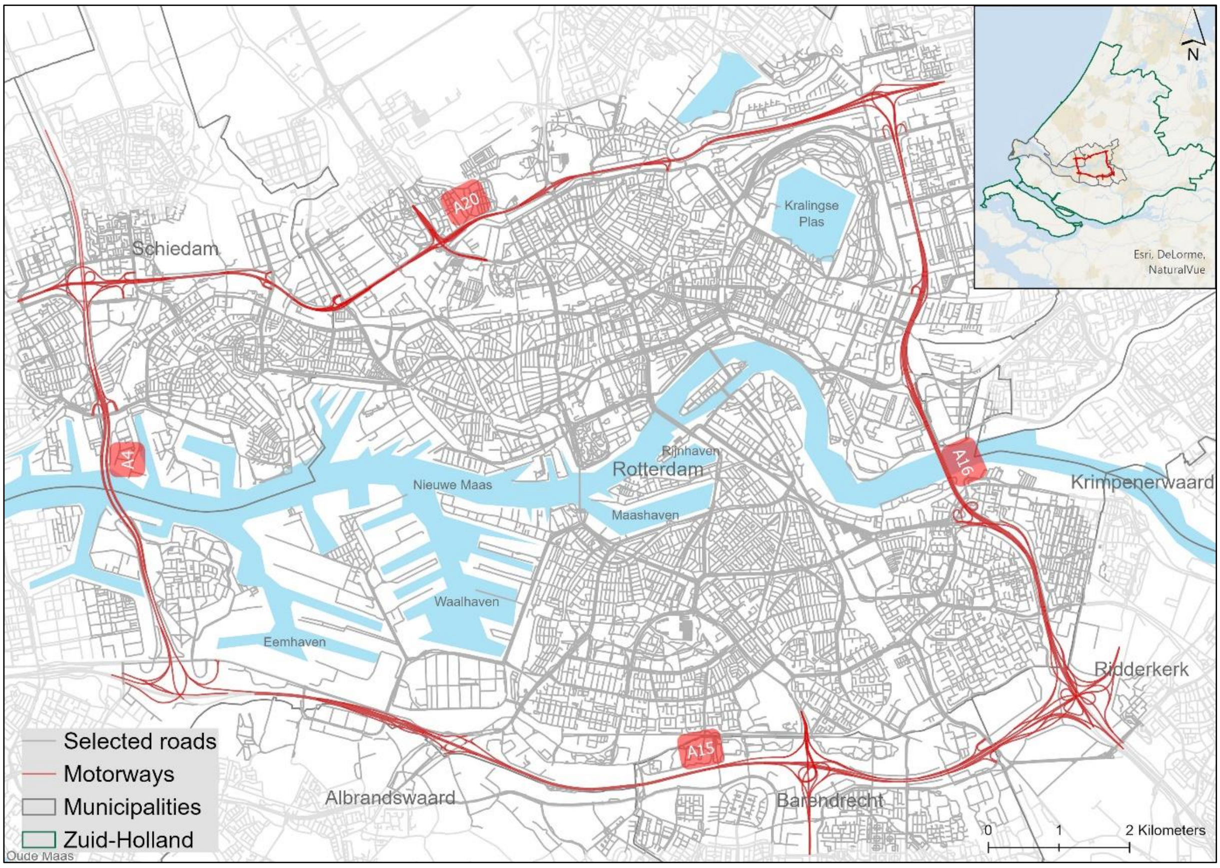


Figure 3-3: The study area map represents the selected roads in darker grey and the motorways in red. The inset map on the right shows the location of the study area with respect to Zuid-Holland province.

3.2 Data used

The shapefiles for municipal level boundaries of the Netherlands and road network shapefile were downloaded from various databases. RTC records collected by the police are included in the BRON database. SWOV supplements this data with data from LBZ to include information related to the severity of the crashes. The data from BRON is geographically referenced, ranging from 2003 to July 2021, by the ESRI Netherland. The data is available to freely download in either .csv or .shp or .kml format. A handbook created by Rijkswaterstaat explains the codes in the column headings of the crash data. It includes X and Y coordinate of the accident location, unique registration and identification code of the traffic incident, year of occurrence, the outcome of the crash (material damage, injury, or death), number of parties involved, road characteristics at the crash location (either straightway, bend, intersection or roundabout), time of the day (night or day), weather condition at the time and place of the crash and the maximum road speed of that road section. A crash location is linked only to either an intersection or road section. For each accident on a road section, the X and Y coordinate of the center of that road section is supplied for presentation purposes (Rijkswaterstaat, 2020). The accuracy of each crash location is also mentioned in the dataset. The crashes are linked to the exact point, street level, intersection, or municipal level (Rijkswaterstaat, 2020). This is the secondary data used in this research. The primary data includes responses collected from road users' perception surveys.

3.3 Research matrix

Table 3-1 gives an overview of data analysis and processing software to fulfill the research objectives.

Table 3-1: Research matrix showing used data, sources, and the types of analyses.

<table>
<tr><th>Used data</th><th>Data sources</th><th>Type of analysis</th><th>Software used</th></tr>
<tr><td colspan="4">Objective 1: To identify spatial patterns in the occurrence of RTCs.
Objective 2: To determine the relationship between certain road parameters and the occurrence and severity of RTCs.</td></tr>
<tr><td>District and neighborhood map of the Netherlands</td><td>Centraal Bureau voor de Statistiek (CBS)</td><td rowspan="3">Spatial analysis</td><td rowspan="3">Microsoft Excel, ArcGIS Pro, SANET</td></tr>
<tr><td>Road network shapefile</td><td>Geofabriek database</td></tr>
<tr><td>Crash data</td><td>National road crash register (BRON), file geodatabase from ESRI Netherlands</td></tr>
<tr><td colspan="4">Objective 3: To assess road safety issues from the road users' perspective.
Objective 4: To explore the effectiveness of prevailing road safety policies.</td></tr>
<tr><td>Questionnaire results with road users (primary data collection)</td><td>Road users</td><td>Statistical (qualitative and quantitative)</td><td>Kobo Toolbox, SPSS</td></tr>
<tr><td>Expert knowledge</td><td>Existing policy documents, SWOV publications, road safety vision documents</td><td>Literature review</td><td>-</td></tr>
<tr><td>Key-informant interview</td><td>Interview with road safety personnel</td><td>Descriptive analysis</td><td>-</td></tr>
<tr><td colspan="4">Objective 5: Based on the findings, recommend measures for improving road safety policies.</td></tr>
<tr><td>Expert knowledge</td><td>Results from spatial, statistical, and descriptive analyses</td><td>-</td><td>-</td></tr>
</table>

3.4 Ethical considerations and data management

Spatial analysis in this research was conducted with the help of freely available secondary data provided by BRON through ESRI Netherland. The usage and dissemination guidelines were followed when downloading the spatial data. The individual crashes were not linked nor could be linked to any person or organization. In the case of the road user questionnaire, the questions were formulated carefully to not offend or discriminate against anyone's personal opinions or beliefs. The survey forms were only distributed after receiving approval from the ethics committee of the ITC (International Institute for Geo-Information Science and Earth Observation). The participants were provided with an information leaflet, including a link to an online google document that explained their privacy rights. No personal information such as name and address was asked while conducting the questionnaire. The option to "rather not say" was provided in questions regarding opinions about a policy or demographical information if an interviewee did not want to express their opinion on a particular matter. The anonymity of the key informants is maintained in this research. Their names and position are not mentioned anywhere, and their organization's names are used to cite them.

The responses from the survey and the video recordings of the interviews remain only with the author herself. The author should be approached if those resources are required in the future.

4 METHODOLOGY

This chapter includes the methods followed in this research for the spatial analysis of RTCs, road user perception survey, and key-informant interviews. The different techniques applied for spatial analysis are explained and justified, followed by an explanation of survey data collection and analysis. A brief description of the selected key informants is provided at the end of this chapter.

4.1 Spatial Pattern of road traffic crashes

Spatial analysis of RTCs was performed to find dangerous locations in the study area. Crash records for 2018, 2019, and 2020 were downloaded from ESRI.nl (ESRI Nederland, n.d.). All the shapefiles were converted into a standard coordinate system for processing. The coordinate system used was Rijks-Driehoek New (RD new). The map and display units were set to meters.

The RTCs under the category of "linked to the Municipality" were removed for the analysis. Such filtration was necessary because the spatial accuracy of those points is very low since the exact road network location of those crashes is unknown (Rijkswaterstaat, 2020). Next, the road network shapefile was converted to a road network dataset using the "create network dataset" network analyst tool in ArcGIS Pro.

In the first step of the spatial analysis, the crash locations were plotted on a study area map based on their severity. However, some of the points did not fall precisely on the line features of the road. Therefore, all the crash points were first snapped to the nearest line features (roads) before starting the spatial analysis using the "snap to nearest feature" function in ArcGIS Pro.

The following sections describe different methods used for the spatial analysis of crashes and a justification for selecting those methods.

4.2 Global Moran's I

This method is one of the oldest analysis techniques for determining spatial autocorrelation for feature location or attribute values, whether clustered, dispersed, or random (Prasannakumar et al., 2011). This was done using the spatial analyst tool called "Spatial Autocorrelation (Global Moran's I)" embedded in ArcGIS Pro. Equation (1 below is the formula used to calculate Moran's I.

$$I = \frac{N \sum_i \sum_j W_{i.j} (X_i - \bar{X}).(X_j - \bar{X})}{(\sum_i \sum_j W_{i.j}) \sum_i (X_i - \bar{X}).(X_j - \bar{X})^2} \quad (1)$$

Where,
N= Number of crashes,
X_i= Crash at particular location i,
X_j= Crash at another location j,
$\bar{X}$= Mean of variables, in this case, mean of crashes,
W_{ij}= Weight applied to the comparison between crashes at locations i and j,

The values obtained from Global Moran's I indicate if the point locations form either high or low clustering and if it follows a specific or a random pattern. The values obtained vary from -1, indicating spatial spreading, to +1, which shows more clustering of similar values, and zero means a randomly spread pattern. Usually, the values are converted into Z score values. Positive Z values mean that there are similar values in the vicinity and negative Z score values indicate the opposite (Siddiqui et al., 2014; Soltani and Askari, 2017).

The null hypothesis in the spatial autocorrelation tool states that there is no significant spatial clustering of the values (Prasannakumar et al., 2011).

A threshold distance and the relation between point features should be set before running the Global Moran's I. Most options for conceptualizing spatial relationships use the Euclidean distance between the point features to find their influence on each other (ESRI, 2021b). Some options available in ArcGIS Pro are inverse band, fixed band, or inverse distance squared band. Euclidean distance (D) is calculated by ArcGIS Pro using the formula in Equation (2).

$$D = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \quad (2)$$

Where x_1 and x_2 is the coordinate of a particular point and y_1 and y_2 are the coordinates of another point in space (ESRI, 2021b).

However, Euclidean distance is not always the correct representation of the distance between two points in space because it represents the shortest distance between two points. This is explained in Figure 4-1. Consider "a" and "b" as two different RTC locations. In terms of Euclidean distances, the distance between them is only 4 kilometers. However, they are 9 kilometers (3+5+1) apart in terms of road network distance. This implies that a and b are quite far from each other and may not fall within the influence distance of each other.

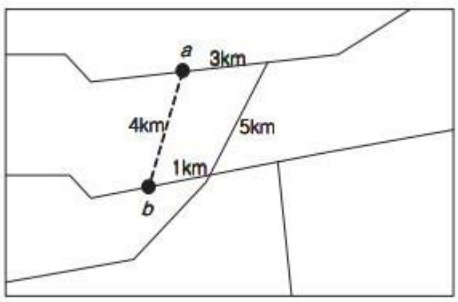


Fig. 1. Example of distances in road network space and Euclidean space

Figure 4-1: Road network vs. Euclidean distance

(Hwang et al., 2005)

Another option in the ArcGIS Pro environment for conceptualizing the spatial relationship to consider the network distance is using weights from a network spatial weight matrix file (.swm). The network weight matrices provide more accurate results because they use the nature of the road network dataset and RTCs to quantify their relationship (Ermagun and Levinson, 2018). A tool called "generate network spatial weight matrices" is embedded in ArcGIS Pro that performs this function. The required inputs are the road network dataset and the RTCs point features. The shape length of road features was used as an evaluator to develop the road network dataset. By doing this, the distance between RTCs was quantified in the matrix. The output files are in .swm format and include rows and columns for each feature and their weights (based on distance).

The impedance distance for SWM was set as 250 meters, following the recommended use between 50 to 300 meters as impedance distance (Steenberghen et al., 2010; Ulak et al., 2017; Xie and Yan, 2013). A fixed distance relationship was used when specifying the type of distance band when generating a spatial weight matrix. The fixed distance band works well with point data (ESRI, 2021b; Lee and Khattak, 2019). The neighboring features within the fixed distance around a specific feature receive a value of one, whereas the features outside that distance receive zero weight (Hazaymeh et al., 2022; Lee and Khattak, 2019). The .swm file obtained in such a way was used in Global Moran's I tool.

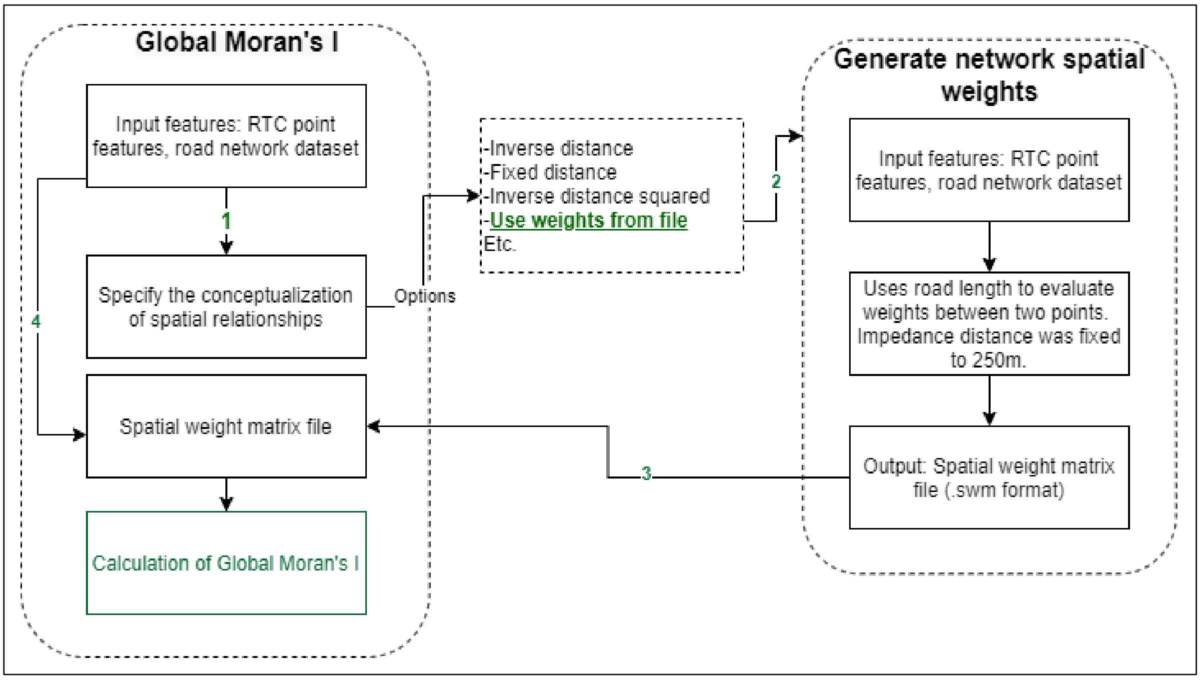


Figure 4-2: Diagrammatic representation of the calculation of Global Moran's I

Figure 4-2 shows how Global Moran's I was calculated using the conceptualization of the spatial relationship with the help of the network spatial weights matrix. After the Global Moran's I tool was run, a graph was obtained with z-score, p-values, and Moran's Index.

4.3 Local Moran's I

Local Moran's I was performed to see the locations where local clustering of RTCs occurred. This was done using a spatial analyst tool called "Cluster and Outlier Analysis (Anselin Local Moran's I)" embedded in ArcGIS Pro. With the help of local Moran's I, the four types of cluster zones were visualized in the Local Indicators of Spatial Autocorrelation (LISA) map: High-High (HH), High-Low (HL), Low-High (LH), and Low-Low (LL) (Erdogan, 2009). HH and LL indicate positive spatial autocorrelation, and HL and LH indicate negative spatial autocorrelation (Le et al., 2020). According to Anselin (2010) and Blazquez and Fuentes (2019), equation (3) below shows the formula used for calculating Local Moran's I.

$$I_i = \frac{X_i - \bar{X}}{S_i^2} \sum_{j=1, j \neq 1}^{N} W_{ij}(x_i - \bar{X}) \quad (3)$$

Where,

X_i= Crash at particular location i,
$\bar{X}$= Mean of variable, in this case, mean of crashes,
S_i = Sum of weights,
N= Number of crashes, W_{ij}= Weight applied to the comparison between crashes at locations i and j.

Local Moran's I tool in ArcGIS Pro requires input point features to have a specific count, rate, or measurement (ESRI, 2021c). Since this research considers all types of RTCs to be of the same ranking, the individual points have no specific rankings. Thus it was decided to aggregate the RTC counts per neighborhood level so there would be variation in input values. The aggregated map can be found in annex 1.

Similar to Global Moran's I, a certain threshold distance and the conceptualization of spatial relationships between the features have to be specified for Local Moran's I. Since local Moran's I does not deal with point features lying on a network in this particular research, it is not necessary to use spatial weight matrices to conceptualize the spatial relationship. The optimal threshold distance was calculated using a spatial statistic tool called "Incremental Spatial Autocorrelation" embedded in ArcGIS Pro. This tool calculates Global Moran's I at varying distances and the corresponding z-scores. The distance with the highest z-score is then used as the optimal threshold distance for further analysis (Blazquez and Fuentes, 2019; Hazaymeh et al., 2022; Le et al., 2020). ISA tool uses only aggregated features and not individual ones (Blazquez and Fuentes, 2019; ESRI, 2021d). The distance obtained in such a way is suggested to be used in the spatial autocorrelation analysis with a fixed distance band (ESRI, 2021a). This method was done by (Blazquez and Fuentes (2019) and Choudhary et al. (2015) to determine the spatial autocorrelation of RTCs. Thus, the fixed distance was used for conceptualizing the spatial relationship. Figure 4-3 shows the method followed to find the Local Moran's I in this research.

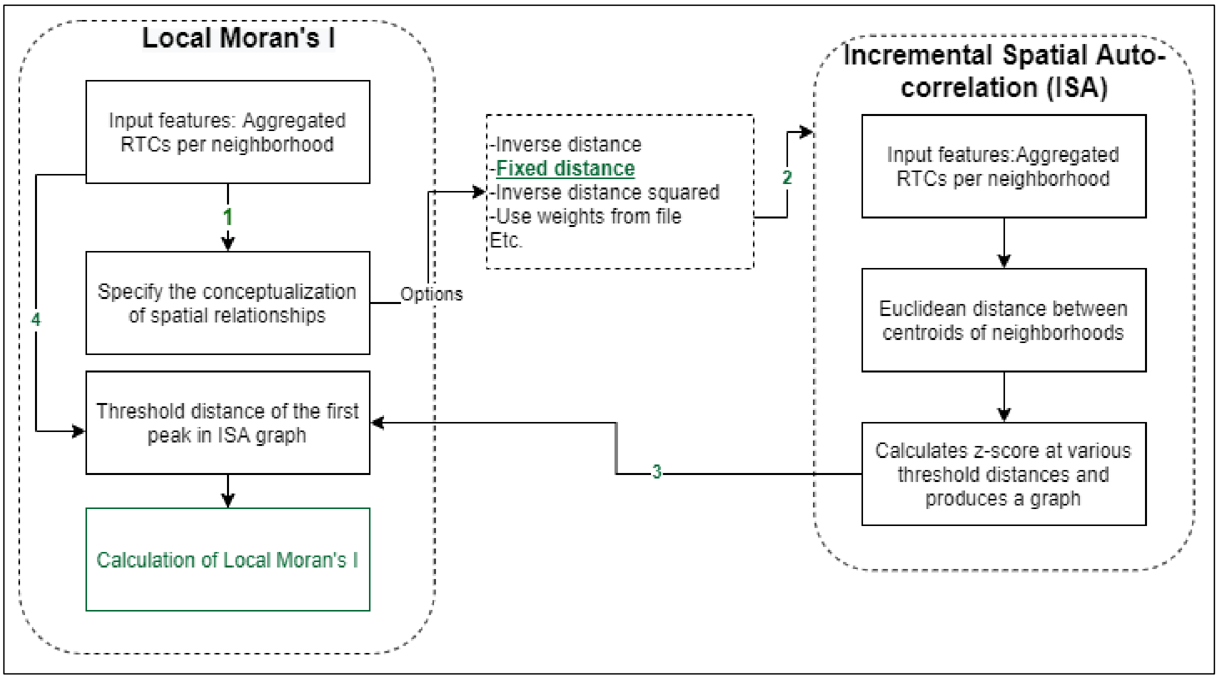


Figure 4-3: Diagrammatic representation of the calculation of Local Moran's I

4.4 Network Kernel Density Estimation

RTCs occur in 1D space (only along road length) and not 2D (Okabe and Sugihara, 2012, as cited in Abdulhafedh, 2017). Therefore, studies have attempted to convert the 2D version into 1D infinite space (Okabe and Yamada, 2001; as cited in Xie and Yan, 2008). Considering 1D space, NKDE was done to find hotspots in the study area. In this approach, the terminology of "lixel" (linear pixel) is used, which represents linear units of equal and regularly placed lengths in the network (Xie and Yan, 2008). Implementing this terminology improves the efficiency of calculating hotspots along with a road network. This approach is recommended if the research needs higher accuracy results in specific intersections or roadway segments.

However, computation time is comparatively more extended than the 2D approach (Tang et al., 2013). Equation (4) below computes the NKDE (K).

$$K(i)=\sum_{d<\tau}\frac{3}{\tau^2}\left(1-\frac{d^2}{\tau^2}\right)^2 \tag{4}$$

Where τ is the bandwidth, and d stands for distance from the crash location

To perform NKDE analysis, Spatial Analysis Along Network toolbox (SANET) is commonly used (Benedek et al., 2016). SANET is a toolbox with 13 tools currently, and researchers are still working on improving its functionality to expand the areas it can be used (Okabe et al., 2006). A license key is required from the University of Tokyo to use SANET (Tang et al., 2013). SANET can work with two network phenomena: one that is on a network and the other that is "almost" on a network, according to Okabe et al. (2006). Thus, it can be implied that SANET helps analyze crashes as point locations and check the density of clustering of RTCs in the study area road network. SANET uses equation (5) below to compute NKDE (Okabe et al., 2009, as cited in Satria, 2020).

$$K_y(x)=\begin{cases} k(x), & for -h \leq x2d-h \\ k(x)-\frac{n-2}{n}k(2d-x), & for\ 2d-h \leq x \leq d \\ \frac{2}{n}k(x), & for\ f \leq x \leq h \end{cases} \tag{5}$$

Where,
k(x)= basic kernel function for the crash locations,
y= center of the same kernel function,
x= point located on the network (crash location),
h= bandwidth in meters,
n= degree of the node in the road network which connects different links,
d=shortest distance from y to x (in meters)

Several free downloadable versions of SANET are available for different versions of ArcGIS. Since ArcGIS Pro was used in this research and no specific SANET version has been developed yet for ArcGIS Pro, the SANET 4.1 standalone version was used. The license key was obtained through Professor Okabe from the University of Tokyo. The shapefile of the entire road network of the study area was used as the input layer, and point features of crash data were uploaded as the kernel points. The bandwidth selection is subjective and depends on the extent of the study area (Srikanth et al., 2019). When selecting band size and cell size, narrow bandwidths lead to under-smoothed NKDE maps, whereas larger bandwidths cause smoother maps (Benedek et al., 2016; Srikanth et al., 2019; Tang et al., 2013). The user manual for SANET recommends that small bandwidth and cell size be chosen initially. Then, the hit and trial method is recommended to find a combination that appropriately represents the data (Okabe, 2020). In urban areas, a bandwidth of 50m to 300m is recommended to be appropriate (Steenberghen et al., 2010; Ulak et al., 2017; Xie and Yan, 2013). Several values were used to perform NKDE- 50, 100, 150, 200, and 250 meters. It was decided that 250 meters was the most appropriate choice based on the spatial extent of the study area and the distribution of RTCs.

Additionally, cell width needs to be specified in SANET, which is approximately one-tenth of the bandwidth (Okabe and Sugihara, 2012, as cited in Ulak et al., 2017). In this analysis, 20 meters was the chosen cell size. The results are stored in the form of shapefiles in a pre-selected local directory, which was imported into ArcGIS Pro for visualization.

4.5 Road users' perception of road safety issues

Many hotspots of RTCs were identified from the spatial analysis. Four zones- two hot and two cold spots were selected to ask the road users about their perception of road safety and crashes. The reason for choosing only four zones was to keep the survey within the acceptable time limit. Another reason was to uncover perceptions in zones with higher and lower occurrence crashes so that various responses could be collected. A survey was performed to analyze road users' perceptions regarding road safety issues and risks in the study area. In addition to the specific zones, the road users were asked questions about the roads they used in their daily transport (inside Rotterdam only) and road safety policies.

The risk stimuli considered were RTCs, several road parameters, and road safety policies for road users. The term "risk" in the survey referred to the prevalence of specific (dangerous) behavior, like driving while drinking, being present in a hazardous condition, or speeding above the limit. The term "perception (of road users)" refers to the concern about the risk factors and attitudes toward road safety policies. The questionnaire is attached at the end of this document, in annex 10.

The survey was performed using an online toolbox known as the Kobo toolbox. An average of 15-17 minutes was required to complete the questionnaire. The interviewees expressed their opinions on a five-point psychometric response Likert scale. In this way, qualitative and quantitative data were collected. For this research, the main focus is concentrated on factsheets and publications put forward by SWOV regarding RTC data, risky behavior, and road safety policies. Table 4-1 shows the categories of questions and their respective purposes.

Table 4-1: Question categories in the questionnaire

Question heading	Objective(s)	Question Numbers	Respondents criteria
Transport related details	To classify road users based on their mode(s) of transport so that questions applicable to the specific mode(s) could be asked in later stages	1.1 to 1.6	-
Perception towards four zones	To get qualitative and quantitative data on the perceived traffic safety in the four zones	2.1 to 2.4	Based on **only** the most frequently used mode of the road users familiar with the zones. Road users were able to skip the questions about zones unfamiliar to them
Perception of road parameters	To understand if road users believe the time of day and specific road parameters are causes of RTCs	2.5 to 2.7	Based on **only** the most frequently used mode of a road user
Self-declaration of risky behavior	To analyze which risky behaviors are more prevalent	3.1 (car drivers), 4.1 (cyclists) and 5.1 (pedestrians)	Based on **all** the modes used by a road user
Existing policies/ rules	To understand road users' opinions on existing road safety approaches and whether they are assisting in improving the overall safety	3.2 (car drivers), and 4.2 (cyclists)	Based on **all** the modes used by a road user

Question heading	Objective(s)	Question Numbers	Respondents criteria
Perception of other road users	To understand the attitude towards other road users	3.3 (car drivers), 4.3 (cyclists) and 5.2 (pedestrians)	Based on **all** the modes used by a road user
Perception of routes used by the road users	To know if road users avoid some routes in the study area	3.4 (car drivers), 4.4 (cyclists) and 5.3 (pedestrians)	Based on **all** the modes used by a road user
Perception of possible recommendations and authorities	To analyze which recommendations can be more effective, from road users' (stakeholder's) point of view	3.5 (car drivers), 4.5 (cyclists)	Based on **all** the modes used by a road user
Demographics	To use as explanatory variables for establishing relations from collected results between the question as mentioned earlier	6.1 to 6.4	Based on **only** the most frequently used mode by a road user
Self- perception	To know about involvement in RTCs, optimism bias, and human factors responsible for RTCs	7.1 to 7.8	Based on **only** the most frequently used mode by a road user

4.6 Data collection

Data collection was performed from 08 February 2022 to 26 February 2022. The data was collected through face-to-face interviews (picture in annex 10) using Asus Zen tablets. The mobile application for KoboToolbox was installed on the tablets. Since the application can collect data offline, an internet connection was not required. The first field visit was on 8 February 2022 (Tuesday). This day was chosen because there is an "Open-market" in the central part of Rotterdam (zone 2) every Tuesday and Saturday. Road users were approached only inside and around the open market during the first fieldwork. The second fieldwork was on 26 February 2022 (Saturday). On this day, all the selected zones were visited. The questionnaire was conducted in stations, parks, shops, and parking lots.

The first question asked to the road users was if they had been living in Rotterdam for more than the past three years. In case of a positive answer, the questionnaire was carried out. This ensured that the respondents possessed the tacit knowledge of the roads to provide qualitative answers. The road users were asked for their consent to record their answers. They were also given an information leaflet. Then, they were given the option to do the questionnaire in English or Dutch.

All the interviewees were given a printed form of the questionnaire's Quick Response (QR) code. They were requested to distribute it to someone they knew. In that way, other people could also complete the questionnaire online. The QR-code could be scanned using a mobile phone, which would open the questionnaire in the default internet browser. Table 4-2 shows the number of participants in the survey.

Table 4-2: Number of respondents

Date	Face-to-face		Online	
	English	Dutch	English	Dutch
08-February 2022	31	0	6	2
26 February 2022	17	4	4	0

Two weeks was set as a waiting time after the first fieldwork to get more online responses. The QR code generator tool allows the questionnaire link to be valid for only two weeks; thus, the waiting was set to two weeks. This time was used to analyze the collected data. Finally, after the second fieldwork, sixty-four responses were collected.

4.7 Data saturation

The data from the first fieldwork was downloaded in Microsoft excel to observe the trends, and some issues were discovered. They were resolved in the second fieldwork. This was the benefit of using the grounded theory method in analysis, which enabled a preliminary analysis and found improvements for the second round of data collection. The solutions to those problems, implemented on the second day of fieldwork, are shown in Table 4-3.

Table 4-3: Improvements applied for the second fieldwork

Problem	**Cause**	**Solution**
There were very few car users in the participant responses. Due to this, it would be challenging to analyze the responses of car users	Many people may prefer to use other modes more frequently compared to cars.	The question "Which of the following is your most used mode of daily transport?" was changed into "Which of the following modes do you use?" In this way, road users could answer question categories meant for car users, even if it was not their most frequently used mode of transport.
Some participants were not familiar with two of the selected zones, thus leading to blanks in the data	Since those two zones are residential areas, some respondents have no reason to generate trips in those zones; thus, they do not know about safety.	Fieldwork was decided to be conducted in those zones; that way, the residents in those zones could answer the questions.

The responses from the first questionnaire had some inconsistencies in the data due to the two problems mentioned above; however, after the second fieldwork, those problems were solved. Therefore, the final results were not significantly impacted.

The responses from the first fieldwork were convergent; the answers pointed to the same road safety issue in the study area. For example, the road users were more concerned about their safety in hotspot zones and less concerned in cold spot zones. They considered crashes to occur more at intersections and night-time. The main problems specific to zones were also exact; zone 1 had the problem of mixed traffic conditions, zone 2 had high volumes of mixed traffic, and zone 3 and 4 had some issues with road infrastructures. These responses were compared with responses from the subsequent fieldwork to check if they overlapped or if a new category of responses could be developed.

After the second fieldwork, the responses were analyzed to see if the road users gave any new information or a new category of answers. The answers were mainly similar to the responses collected on the first fieldwork; thus, the third fieldwork was not planned further. According to ground theory, as mentioned in section 2.7, the data saturation state was reached. This state was determined when no new or interesting responses were recorded, and all the new reactions were similar to what other road users had already responded to.

4.8 Data processing

Firstly, the Dutch answers were translated into English. Both fieldwork and online responses were merged into a single excel file. Following that, the responses of similar headings were filtered out into separate sheets for ease of calculation. After separating the answers into the following headings, they were imported to Statistical Package for the Social Sciences software (SPSS) for visualization. The responses in the Likert scale were weighted by giving numeric values, as shown in Table 4-4.

Table 4-4: Assigning numeric values to Likert responses

Assigned values	**5**	**4**	**3**	**2**	**1**	**0**
Responses-type I	Always	Sometimes	Neutral	Rarely	Never	Rather not say
Responses- type II	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Rather not say/not applicable

The different categories of responses were then shown in a stacked bar chart and adequately labeled with different colors for different numeric values. The results and discussion section includes qualitative responses; the Likert-scale responses are in annexes.

4.9 Key-informant interview

After completing the analysis, three online key informant interviews were conducted. The interviews were semi-structured so the interviewee and the interviewer could bring up new ideas. The first interview was carried out with road safety personnel from SWOV on 22 March 2022. This document refers to the road safety personnel with their organization's name (SWOV). This key-informant interview was done to get insight into the workings of SWOV for road safety issues to provide recommendations for further research.

The second key informant interview was conducted with the road safety personnel from the Urban Development Department of the Municipality of Rotterdam. The main objective of this interview was to gain information on how the municipality of Rotterdam handles the problem of RTCs. This document refers to road safety personnel with their organization's name (Rotterdam Municipality). Due to the key informant's busy schedules, a list of questions was sent by email, and the answers were obtained in a written format on 12 May 2022.

The third key informant interview was conducted with a researcher from TeamAlert on 2 June 2022. In this document, the researcher will be referred to with their organization's name (TeamAlert). The main objective of this interview was to get information on how a specific group of road users can be targeted to improve their perceptions and behavior in traffic. The findings from all the interviews are incorporated into the results and discussion section under relevant headings. The outline of the topics addressed in the interviews can be found in appendix 2.

4.10 Summary of methodology

Broadly, two methods are followed in this research, as described in the sections above. They are spatial analysis and the road users' perception survey. The results can be found in the following chapter. Table 4-5 shows the steps performed to fulfill each research objective. Research objectives one and two are specific to spatial analysis, three and four are specific to the road user survey, and five include synthesizing the results.

Table 4-5: Various results correlating to respective research objectives and questions

Research objective	Research Question	Results based on
1. To identify spatial patterns of the occurrence of RTCs.	1. a. Which locations in the road network are more susceptible to RTC?	Spatial analysis
2. To determine the relationship between certain road parameters and the occurrence and severity of RTCs.	2. a. Which road parameters affect the occurrence and severity of RTCs?	Literature review, road users' perception of road parameters
	2. b. Is there a relationship between road parameters and the severity of RTC? If yes, to what extent?	Secondary data of RTCs vs. road parameters involved
3. To assess road safety issues from the road users' perspective	3. a. What is a road user's understanding of the specific road parameters and their relation with RTCs?	1. Likelihood of being involved in a crash on specific road parameters (also correlated with BRON data), 2. History of involvement in RTCs, 3. Presence of optimism bias, 4. Avoiding some routes, 5. Time of the day vs. RTCs (also correlated with BRON data).
	3. b. How does a road user perceive the personal risk of being involved in RTCs?	1. Level of perceived road safety in specific zones, 2. Level of satisfaction with markings and signages in a specific zone, 3. Level of perceived change in road safety in specific zones
4. To explore the effectiveness of prevailing road safety policies	4. a. Are the current policies successfully reducing RTCs in the study area?	1. Self-declaration of risky behavior, 2. Perception of possible recommendations, 3. Ranking of risky behavior that causes RTCs
	4. b. How do the road users perceive the road safety policies?	1. Perception of existing policies, 2. Level of annoyance towards other road users, 3. Perception of road safety authorities
5. Based on the findings, to recommend measures for improving road safety	5. a. What are the potential areas of improvement in the current road safety scenario?	1. Results from analyses and key-informant interview

5 RESULTS AND DISCUSSION

5.1 Spatial Pattern of road traffic crashes

The maps in Figure 5-1, Figure 5-2, and Figure 5-3 show RTCs in 2018, 2019, and 2020. It shows different levels of severity; the biggest circle in red represents deaths, the medium-sized darker green circle represents injuries, and the smallest light green colored circle represents property damages.

Figure 5-1: Spatial distribution of RTCs in 2018

Figure 5-2: Spatial distribution of RTCs in 2019

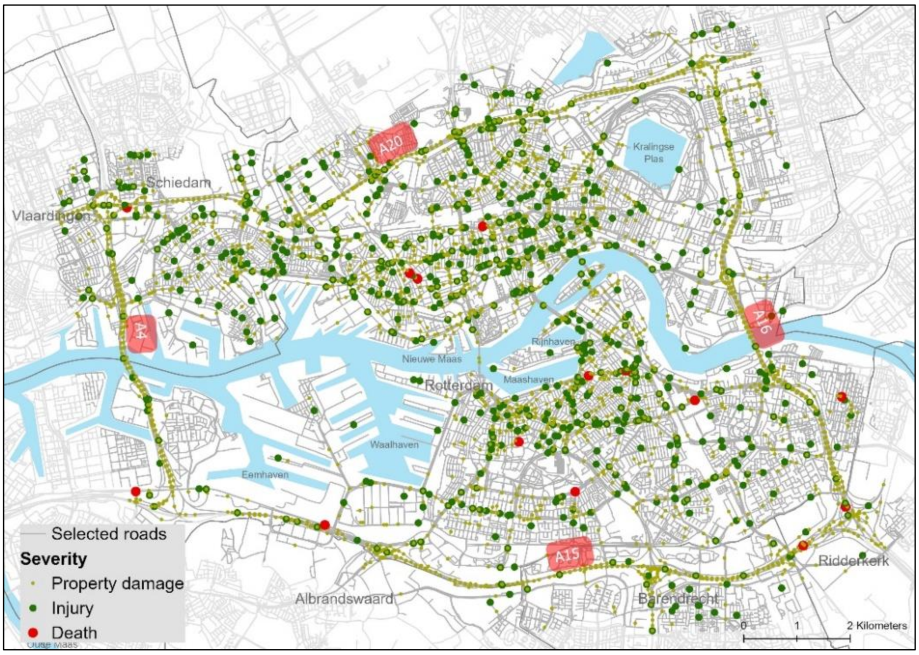


Figure 5-3: Spatial distribution of RTCs in 2020

Table 5-1 shows the numbers of RTCs resulting in property damages, injury, and death in 2018, 2019, and 2020.

Table 5-1: RTC counts 2018-2020 (% between brackets)

Year/Severity	Total	Property damage	Injury	Deaths
2018	6809	5780 (84,9)	1017 (14,9)	11 (0,16)
2019	7699	6666 (86,6)	1023 (13,3)	10 (0,13)
2020	6228	5319 (85,4)	895 (14,4)	14 (0,22)

The data from the past three years indicate that the crash counts increased in 2019, then reduced in 2020. In 2019, injuries and property damages due to RTCs had increased compared to 2018. The numbers for deaths increased by a small amount in 2020 but dropped for the remaining two levels of severity. The RTCs around motorways in Barendrecht and Ridderkerk have significantly reduced.

After visualization of crashes into maps, Global Moran's I was calculated.

The Global Moran' I was calculated using a network spatial weight matrices file, as explained in the methodology. The resulting matrix was obtained as a .swm file from the "generate network spatial weight matrices" toolbox. The .swm file was directly input into the Global Moran's I calculation. The column headings in the .swm file were interpreted with the help of Ermagun and Levinson (2018), ESRI (2021d), and Zhang et al. (2020). There were a total of 460455 rows of data for the 20736 RTCs.

The. swm file could be converted into an excel file format for visualization. Table 5-4 shows how the .swm file looks in excel format. The "SNO " field indicates the point features in the input field (RTC points). The field "NID" contains the neighbor features with which there is a relation (within 250m network distance) with features in the input field. For example, features 2,3, …, 10, 11, 12, and 13 falls within 250m of feature 1, so they have been assigned a weight of "1,0". However, in the second column, features 14-25 are not present adjacent to SNO 1. This means those features are beyond 250 meters of feature 1. In this way, each feature is evaluated against each other to check whether they are close in a network or not.

	A	B	C
1	SNO	NID	WEIGHT
2	1	2	1,0
3	1	3	1,0
10	1	10	1,0
11	1	11	1,0
12	1	12	1,0
13	1	13	1,0
14	1	26	1,0
15	1	27	1,0
25	2	1	1,0
26	2	3	1,0
27	2	4	1,0
34	2	11	1,0
35	2	12	1,0
36	2	13	1,0
37	2	26	1,0
38	2	27	1,0
39	2	28	1,0
40	2	29	1,0
41	2	30	1,0
42	2	31	1,0
43	2	32	1,0
44	2	54	1,0

Figure 5-4: Network Spatial Weight Matrix visualized in excel table, which shows the relationship between each RTC feature with respect to it's neighboring features

Figure 5-5 shows the report from Global Moran's I tool. It can be seen that Moran's I index is positive and very close to 1, which implies there is a clustering pattern in the occurrence of RTCs. The z-score means the standard deviation obtained after the value of each feature is subtracted from the mean value. The observed z-score is very high, which means that the input data (RTCs' incident features) are not distributed uniformly in the study area (more RTCs are seen in the map's motorways and center). Therefore, the difference between the feature value and the mean is likely to be of high values. A positive z-score and p-value very close to zero (zero in this case) represent that the null hypothesis can be rejected (Li et al., 2007; Ord, 1975). Thus, using spatial autocorrelation, the RTCs in the study area were found to be clustered.

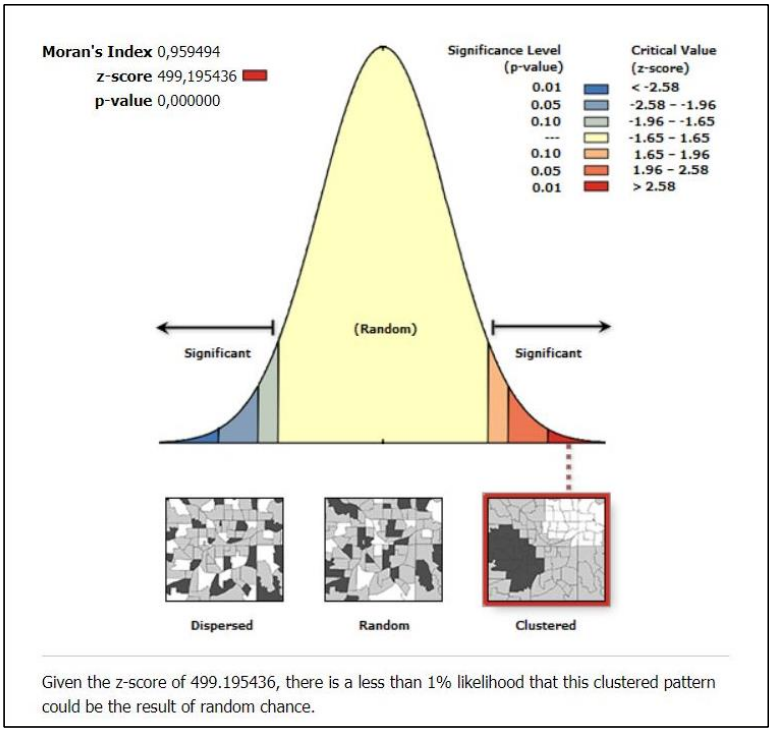


Figure 5-5: Spatial autocorrelation report shows a positive Moran's I and Z-score.

After the calculation of Global Moran's I, Local Moran's I was found. To find the threshold distance to be used in the calculation, ISA was performed. Figure 5-6 shows the ISA graph for the RTCs aggregated per neighborhood. The first z-score peak was observed at a distance of 1200 meters. The corresponding z-score was 7,03. There were also several peaks observed at different distances. The first or highest peak should be selected for optimal clustering because that is the distance from which spatially significant clusters begin to form (Choudhary et al., 2015; Lee and Khattak, 2019). Thus, a threshold distance of 1200 meters was used to perform Local Moran's I.

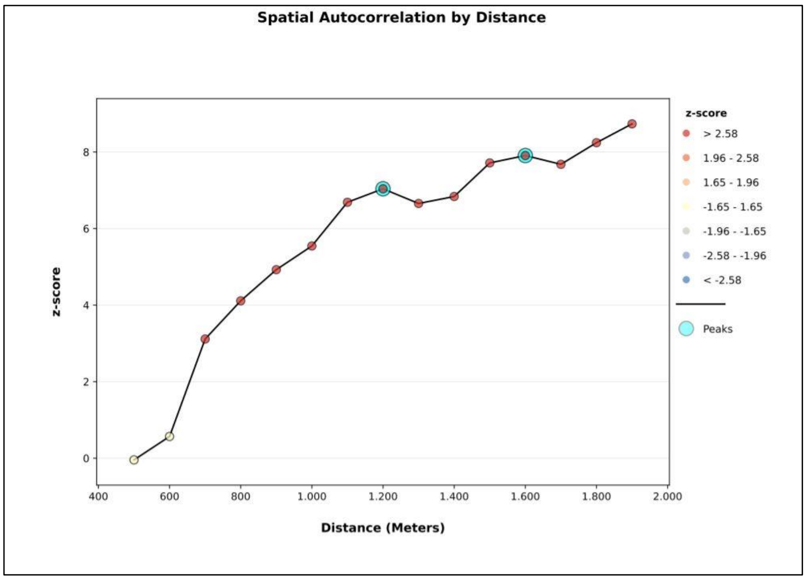


Figure 5-6: Incremental spatial autocorrelation showing multiple z-score peaks with varying distances.

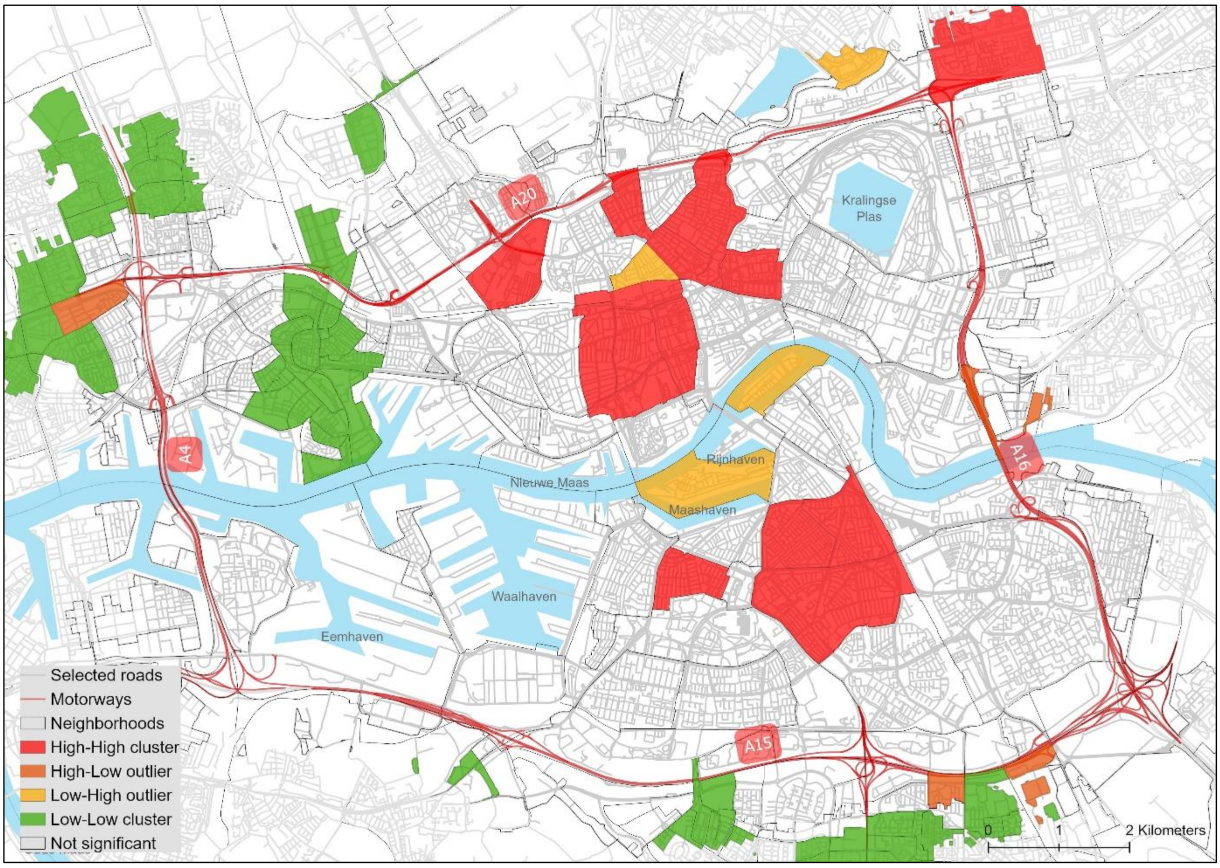


Figure 5-7: Local Moran's I of the aggregated RTCs per neighborhood.

Local Moran's I was used to find the patterns of RTC clusters, as shown in Figure 5-7. The locations in red represent high-high clustering, where a high number of RTCs is surrounded by similar occurrences of RTCs.

The orange color represents high-low outliers. This means there are clusters of a high number of RTCs surrounded by lesser RTCs, and vice-versa for yellow-colored locations. The green represents low-low clusters, which means there are clusters of low number of crashes in those neighborhoods. The neighborhoods without any color (transparent) represent places where there are no neighborhoods that have any of the clustering types mentioned above, i.e., they are not significant.

After Local Moran's I was completed, the combined dataset RTCs in three years was used to perform NKDE analysis. The reason for performing NKDE for the total dataset was to find locations where RTCs have been occurring more frequently over three years.

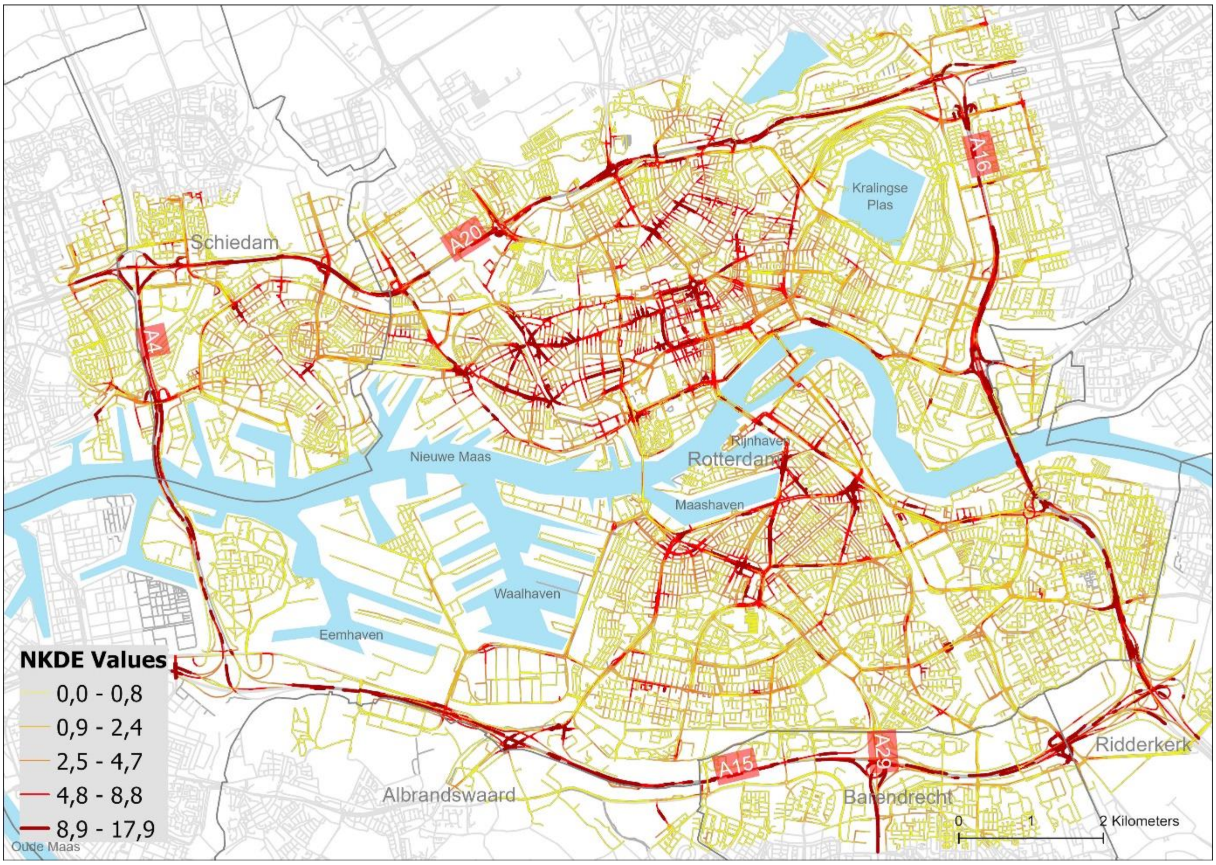


Figure 5-8: Network Kernel Density Estimation of RTCs in 2018-2020

The NKDE frequency of crashes is expressed in terms of average count per kilometer of road length, as shown in Figure 5-8. The legend contains five shades, with lighter colors meaning fewer and darker shades meaning a higher number of crashes. The maximum crash count value observed from the NKDE analysis was 8,9-17,9 per kilometer. The motorways seemed to have more crashes per kilometer of road length (more red lines along the motorways). Some areas inside the city also have a higher crash frequency.

Thus, using SANET, the NKDE of crashes along the road network in a 1D manner was completed. Based on the NKDE map for the combined dataset, four zones were selected for the survey on users' perceptions of road safety. Two areas with higher crash frequency and two regions with lower frequency were chosen. Furthermore, SANET was used to perform NKDE for individual years' RTCs. The respective maps can be found in appendix 3.

Zone 1 and 4: There has been a comparatively higher number of crashes than in the surrounding, as shown in Figure 5-9. The highway is open only to motor vehicles, and the cycling/ pedestrian path is below A20. Zone 4 is North of the study area, close to zone 1. This zone primarily consists of residential areas and lesser occurrence of RTCs. This zone was found to have no significant clustering from Local Moran's I.

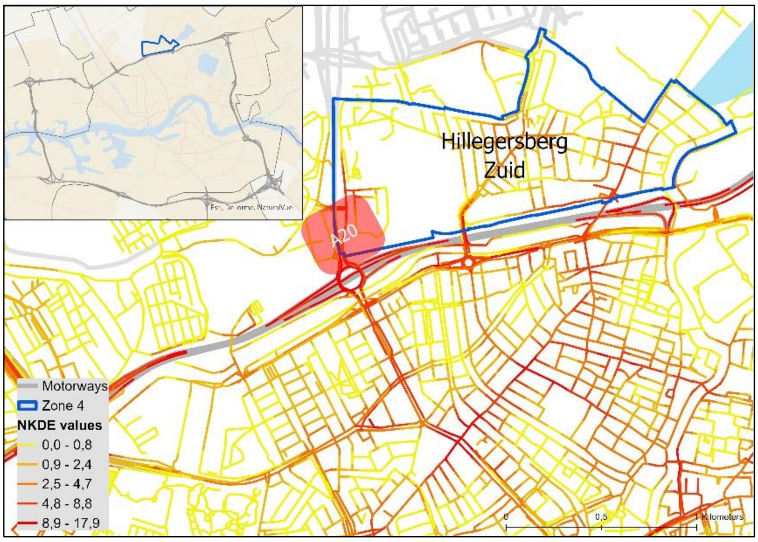


Figure 5-9: Zones 1 and 4. Zone 1 is the Northern road stretch near the intersection on the A20 motorway of the study area. Zone 4 is bounded by a blue line (Hillegersburg Zuid).

Zone 2: There have been many RTCs in this zone throughout the three years, as shown in Figure 5-10. The reason for selecting this zone was to understand how road users perceive the safety of a Central Business District (CBD), where there are high traffic volumes and mixed traffic conditions. This zone was found to have HH clustering from Local Moran's I.

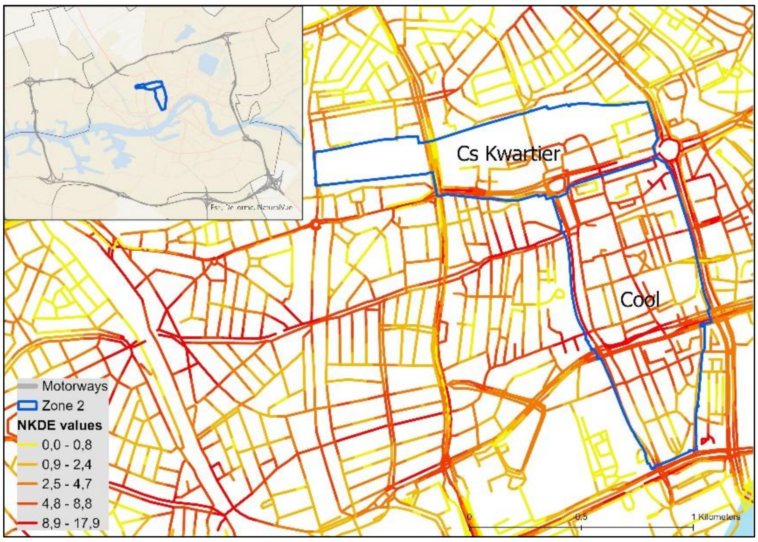


Figure 5-10: Zone 2. It is directly opposite the Rotterdam Central Station and includes two districts: Cs Kwartier and Cool.

Zone 3: Although the ring road has numerous intersections and is a "stadsweg," meaning a city road, there have been few occurrences of RTCs over the past three years, as shown in Figure 5-11. This zone was found to have no significant clustering from Local Moran's I.

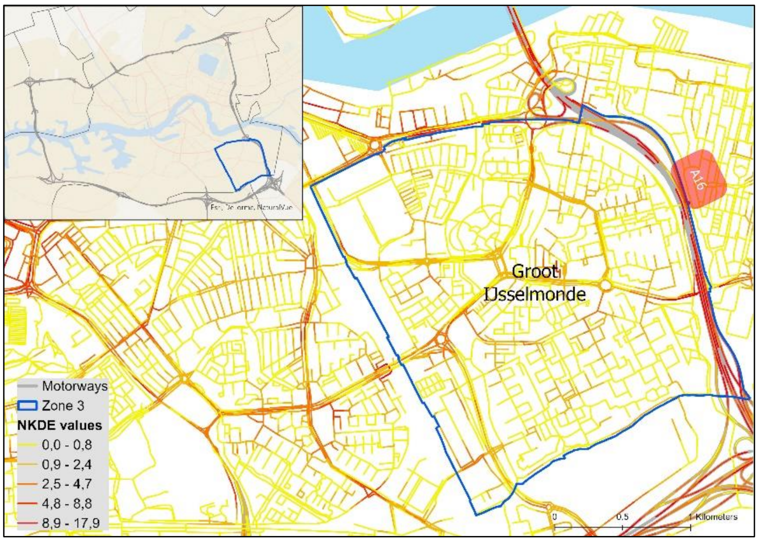


Figure 5-11: Zone 3. This zone is the ring road inside the Groot IJsselmondse area, close to the A16 motorway in the south of the study area.

The analyses of RTCs generated two insightful results. RTCs resulting in injuries and property damages reduced in 2020 when compared to the previous two years, but the RTCs resulting in deaths increased. The reduction in injuries and property damages due to RTCs in 2020 can also be attributed to a decline in trips due to the surge of the COVID-19 virus. According to the key informant from Rotterdam Municipality, "*The number of road injuries in Rotterdam during Corona was lower than before (due to less traffic). The number of fatal accidents* (deaths only) *remained at the same old level. Our assumptions and analyzes show that during the lockdown, people were bored and that certain groups used empty roads to hold street races. Some people also drove aimlessly around the city with friends in their cars because facilities were closed in the city. This resulted in several serious fatal accidents in Rotterdam due to reckless driving, according to the police reports"* (Personal communication, May 12, 2022). The key informant from SWOV mentioned that motorways in the study area have physical barriers (lane-separators), thus preventing conflicts with non-motorized transport. These barriers dramatically reduce the chances of a severe accident. This is a possible cause for deaths being less frequent on motorways. There were also RTCs in the central part of Rotterdam, which remained at the same level for three years.

According to the interviewed expert from Rotterdam Municipality, three criteria generally initiate a road safety project: i) the presence of black (or hot) spots (where six or more RTCs resulting in injuries have occurred in three consecutive years), ii) residents' perception, and iii) results obtained from risk models. The steps to develop a new road policy were discussed with the key informant from SWOV. In the past, road projects and policies were developed based solely on crash data. In recent years, SWOV has started working pro-actively by analyzing key performance indicators of road networks and checking guidelines (SWOV, personal communication, March 22, 2022). This is similar to the plan made by WHO (2021) for the decade plan 2021-2030 to perform risk-mapping in areas where the crash data is reliable and perform proactive safety assessments and road inspections per users' needs.

It was found out the scope of this research is within the two criteria to determine which road points in Rotterdam have to be improved to increase road safety, namely the presence of hot spots and residents' perception. The key informants from SWOV, Rotterdam Municipality, and TeamAlert responded that research like this, which first performs spatial analysis and then looks at road user perception, can be an excellent method to improve road safety (Personal communication, 22 March 2022; June 2, 2022; May 12, 2022).

5.2 Road users' perception survey

The following sections include the responses collected from the road users' perception survey. In the first survey that was conducted only in zone 2, the road users were more familiar with zones 1 and 2 compared to zones 3 and 4 . In such cases, they were allowed to skip questions about the zones they were unaware of. Thus, the number of respondents for the questions relating to zones is varied. However, all the respondents could answer questions relating to policies, road parameters, and possible recommendations, irrespective of their familiarity with zones.

Figure 5-12 shows the percentage of respondents. As discussed in Table 4-1 and the paragraph above, the number of respondents is varied based on the question category. There were different numbers of respondents who were familiar with different zones. The proportion is shown in Figure 5-12. Type 1 indicates the proportion of responses for self-declaration of risky behavior, policies, attitudes towards other road users, avoiding routes, and possible recommendations. These are based on **all** the modes used by a road user. Type two indicates the responses for involvement in RTCs, optimism bias, specific road parameters, and attitudes towards government. These are based on **only** the most frequently used mode of a road user.

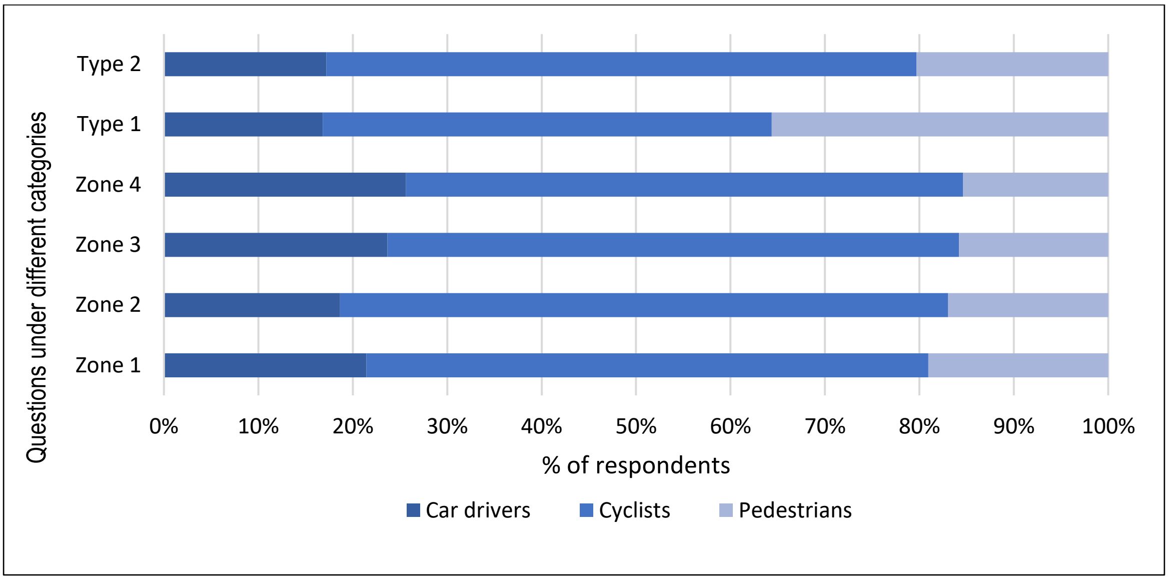


Figure 5-12: Percentage of responses who responded to questions under different categories, divided by their transport modes.

For example, if a road user uses their bicycle most frequently but drives their car less often, they were asked to answer the type 1 questions as cyclists and car drivers (all the modes they use) and type 2 and zone-specific questions only as cyclists (the main mode they use).

Section 5.3 deals with the self-perception of road users. Responses to questions regarding involvement in RTCs, self-declaration of risky behavior, and human factors causing RTCs are put into this section. Section 5.4 includes the perception of road safety in selected zones. Section 5.5 provides road users' perception of different road parameters and how they think the time of the day affects the occurrence and severity of RTCs. Finally, section 5.6 includes road users' perception of existing policies, possible recommendations, and the authorities. Each section follows the format where the result from the survey is explained first, followed by discussions backed up by insights from the key informant interviews and findings from the literature review.

5.3 Self-perception of road users

5.3.1 Involvement in RTC and optimism bias

Only ten out of sixty-four respondents were found to have been in a crash involving another road user/ vehicle in the past three years. They reported being in a crash due to one of these reasons: *"parking nuisances," "falling on tram tracks while cycling," "while turning a cycle/car crashed into me," "vehicles coming from other directions on intersections," "in a straight road while being overtaken by electric bike."* Many cyclists admitted that they fell into tram tracks and that *"it is quite unavoidable in Rotterdam because there are tram tracks everywhere."* The history of involvement in crashes was asked to relate to optimism bias. All the road users were asked whether they agreed or disagreed with having optimism bias, i.e., whether they felt less likely to be involved in RTC compared to other road users.

An interesting finding was that although car drivers felt less likely to be involved in crashes (45% of car users strongly agreed), most were involved in crashes in the past (36% of car drivers). The stacked bar chart can be found in annex 2. More than half of each transport-mode user had responded that they either strongly agreed/ agreed that they felt less likely to be involved in a RTC than people around them. A comparison of involvement in RTCs with optimism bias trait was made among all the road users, irrespective of transport mode. This led to the finding that the same proportion (60% agreed) of road users had the feeling of optimism bias irrespective of being involved in RTCs. The bar chart can be found in annex 2.

Many researchers have proved that humans tend to have optimism bias traits in their risk perception process (as discussed in 1.1). This finding was discussed with the key informant from TeamAlert, who stated, "*Optimism bias is one of the focuses in our projects. Especially youths overestimate their capacities a lot. We first talk about the facts, such as the statistics about road deaths, and then hope they will lower their overestimation after knowing about the risks."* (Personal communication, June 2, 2022). Thus, it is important to develop initiatives based on facts to target this long-term risk-taking behavior reduction with measures such as awareness and training campaigns, as discussed above by TeamAlert.

Finally, road users were asked if they considered themselves to be safe road users in general. All car users considered themselves to be safe road users. However, some cyclists and pedestrians consider themselves "unsafe road users" because they have a common habit of crossing illegally. The stacked bar charts showing the percentage of responses for this category can be found in annex 2. The perception of safety experienced by car drivers may be because they are not vulnerable road users, i.e., they are protected by their cars and not exposed to the traffic like pedestrians and cyclists (as discussed in section 2.11).

5.3.2 Self-declaration of risky behavior

This section reports the responses from different categories of road users regarding both short and long-term risky behavior. Influence of alcohol (short-term risky behavior) and long-term risky behaviors which involve a conscious violation of traffic rules such as passing through a red light, not giving way to pedestrians, using hand-held devices, following the preceding vehicle too closely, using the wrong lane was asked in the survey.

The stacked bar charts showing the percentage of responses for this question category can be found in annex 3. Car users, cyclists, and pedestrians were asked six, five, and three questions, respectively, under this heading.

None of the car users responded that they ever drive through a red light. The most prevalent risky behavior was following the preceding vehicle too closely. It was found that many car users do not keep a safe distance between their vehicle and the preceding vehicle most of the time, which leads to the rear-ended collision because the car may not have enough time for negative acceleration when the preceding cars stop suddenly or decrease their speed. Other common risky behaviors were using a handheld device while driving and driving on the wrong side of the road. There were mixed responses for not giving way to pedestrians. Some responded that they sometimes do not give way to pedestrians but did not explain why. A small portion of drivers (12,5%) also admitted to sometimes driving under the influence of alcohol.

More than half of cyclists responded to cycling through a red light, either "always" or "sometimes." Following that, using the wrong side of the road was the second most prevalent risky behavior. The prevalence of this behavior was followed by cycling under the influence of alcohol and using handheld devices while cycling. However, fewer cyclists were found to not give way to pedestrians at crossings.

The same portion of pedestrians responded that they had frequently committed the two risky behaviors-crossing at the red light and walking on the cycle path/ carriageway. They answered, "*I cross at a red light when there is no one on the roads, for example, at night,*" "*when there is no footpath, I walk on the street but keep very close to the road's edge.*" The responses for walking under the influence of alcohol were similar to the cyclists' responses stating that "an*other transport mode is expensive, so I do not use them when walking home while being drunk.*"

The results indicated that cyclists as the most risk-taking group, which was discussed in both key-informant interviews. *"Education programs in schools and awareness campaigns teach older people to respond to traffic conditions on time. Still, there have not been any programs targeting cyclists' behavior change. Awareness programs should be taken only as a supplement, as it is impossible to entirely change cyclists' behavior on roads just with the help of such soft measures"* (SWOV, personal communication, March 22, 2022). Their response can be taken as an addition to the measures mentioned in section 2.5, where many studies had recommended improving the visual environment of roads to reduce users' annoyance.

Road users' behavior can be improved with positive rather than negative reinforcement policies. For instance, awareness programs can be initiated to target a specific group of road users. This was supported by the key informant from Rotterdam Municipality, who added, *"Yes, great idea, and that is exactly what we do. We have a cycling behavior program. For example, we are organizing an urban cycling festival on May 22 (Rotterdam Rides 2022 | Fietsfestival | 22 mei 2022). You can cycle in groups from all parts of the city, and at the end of the day, we will gather at a central location in the city. A kind of festival spot. We use this moment to discuss road safety"* (Personal communication, May 12, 2022). According to the key informant from TeamAlert, *"our projects involve making young people aware of risky behavior. We go to schools, festivals, and parties and talk to the youth. We hope they will become more aware of their risk in traffic and adjust their behavior in the end"* (Personal communication, June 2, 2022). Their responses are similar to what was discussed in the literature review section 2.5, that deliberative and intuitive systems need to be targeted to improve road user safety.

5.3.3 Human factors responsible for RTC

The road users were asked to rank six risk factors on the scale of most likely to most unlikely cause RTCs. Among the sixty-four respondents, the top-ranked risk factor was alcohol. That was followed by using devices that distract the driver (e.g., mobile phones), fatigue, inexperience (young drivers), speeding, and drugs. Some other factors mentioned by the road users were *"I think elderly people are slow to react sometimes and they get into accidents," "arguing with driver or small children in the car," "people speeding in electric scooters," "lack of sleep," "not following the rules," "neglecting traffic rules," and "talking while driving."*

The abovementioned results correlate to the literature review findings. According to existing research, drunk-driving was the leading cause of RTCs, and around two-thirds of severe crashes involve alcohol use (ITF, 2020). Drunk driving was ranked as the human behavior most responsible for causing RTCs by the respondents in the survey. This finding was discussed with the key informant from TeamAlert. They stated that they have projects where the team goes to different locations and then talks to road users to spread awareness of the risk posed by drunk driving or using alternative transport sources when they are under the influence of alcohol or to adopt the Bob system (TeamAlert, personal communication, June 2, 2022).

The second-ranked factor (use of devices that distract the driver) was also one of the most common causes in the Netherlands (ITF, 2020). There are no recent studies in the Dutch context for RTC due to distraction (SWOV, 2020d). There has also not been a current measurement of drug use on Dutch roads (ITF, 2020). All these factors can be linked to risky behaviors discussed in section 2.5

The respondents were also asked which group of road users annoyed them most frequently on roads, either by not following rules or by partaking in risky behaviors. The findings are shown in Table 5-2.

Table 5-2: Causes of road users's annoyance

Road users	Most annoyed with	The reason for annoyance
Car drivers	Cyclists, followed by other car drivers	Some cyclists do not use bicycle lights in the dark
Cyclists	Motorcyclists, followed by car drivers	Some motorbikes (electric type) are silent, so road users cannot hear them approach, and some car drives tend to speed
Pedestrians	Cyclists followed by motorcyclists	Some cyclists use footpaths to cycle

The reason for this annoyance was derived from the results of other questions. In general, all road users were the least annoyed by pedestrians and most annoyed by cyclists. The stacked bar charts showing the percentage responses for this category can be found in annex 4.

To summarise this section, the literature indicated that risky behavior is one of the causes of annoyance for road users (section 2.6). The results from the survey are in line with this, as cyclists were found to be most guilty of several risky behaviors and caused the most level of annoyance to other groups of road users. The key informant from Rotterdam Municipality added, "*Behavior remains the key to change. Road layout can positively change behavior. For example, in a multicultural city like Rotterdam, many residents like to drive a nice fast car. It is a status symbol and shows that they are successful. These drivers prefer to show themselves by displaying fast and noisy driving behavior. They create many dangerous situations. Therefore, improving road safety is not only about adjusting to the road and offering education. In a large city like Rotterdam, we also have to respond to specific population groups"* (Personal communication, May 12, 2022).

5.4 Perception of road users towards selected zones

The following two sub-sections include road users' perceptions of the current road safety situation and changes in road safety in the selected zones. The stacked bar charts showing the percentages of road users grouped into different response categories per zone can be found in annex 5 for hotspot and annex 6 for coldspot zones.

5.4.1 Perception in RTC hotspot zones

Zone 1 and 2 were the chosen RTC hotspots. In zone 1, many pedestrians and only a few car drivers expressed safety concerns. Zone 2, the central part of Rotterdam city, was where all the road users were concerned about their safety. In both the zones, a small portion of cyclists was not satisfied with the markings and signages because of pedestrians using the cycle path to walk and many intersections on the road network. Pedestrians, as well as cyclists, observed a significant improvement in roads in zone 1. However, most car drivers responded that the motorway had remained the same over the past years. In zone 2, pedestrians were the road users who experienced the most significant safety improvements. However, some cyclists and car drivers expressed that safety had worsened in zone 2.

Road users reported that zone 1 had experienced the most significant improvement over the past few years compared to other zones. Opinions expressed by car drivers were: *"I feel very safe when driving in this area because the lanes are separate," "Sometimes it is congested, that is when I do not feel confident," "They could extend the insertion lane since I find it quite short and gives me little time to decide," "I feel protected through the wall* (separating the motorway*)," "The insertion lanes could be modified because it is a small distance from the insertion lane to switch lanes," "The insertion lanes are too small, and I need more time to adjust," "Lights in zebra crossing would be good, so I can see people in the dark and stop in time," "The Schieplein intersection is very crowded* (this is an intersection on the motorway)." Opinions expressed by cyclists were: *"There is a road section in this zone, where the road is quite steep for cycling, and I do not like* *going that way," "There is a nice cycle path, but sometimes there are pedestrians there, and it gets messy," "I feel protected because the cars are separated."* The most common response was, *"I cycle here very often, so I am used to it and feel safe."* Another cyclist said that the pedestrians sometimes make the cycle path unsafe. The opinion of pedestrians was similar to cyclists' views and could be summarised in one of two ways: either they use the road frequently, so they are used to it, or sometimes due to crowding, crashes occur between cyclists and pedestrians.

Road users expressed their concern about road safety in zone 2 with responses such as*: "there are different types of traffic at the same time, that makes me feel unsafe," "It is a busy place with people walking everywhere," "The trams cross the road everywhere in front of the central train station," "Due to trams, there is no oversight* (referring to being able to look to the other side of the road while crossing)*," "Some people are rude on bikes and think they own the cycling route, this causes much chaos on the cycling road," "You have to be careful when cycling near trams, you may fall into the tracks. It has happened to me many times", "I cannot hear the electric scooters, and they speed all the time."* Some car drivers said they do not feel concerned because the lanes are separate, and pedestrians reported feeling pretty safe because they use the sidewalk and do not go near traffic. They also said that *"There are so many intersections, and I have to look in all directions before crossing," "Although there are traffic lights, some cyclists and scooters do not pay attention to it,"* and *"There are no clear markings or surveillance," "There are signs, but still there is chaos, I would like more traffic signs in the future."* The common reason behind this was *"There is a lot more walking space since the past few years, and traffic signs have been added in the most of the places," "There are separated paths now but a few years ago especially in front of central station, there used to be so much crowd," "It is much more spacious now," "The sidewalks are larger (wider) now."*

To summarise, car drivers were the least concerned about their safety in zone 1. This is because the motorway is separated from other forms of traffic and only has exit lanes at a few points. Thus they do not face interruption in their flow from pedestrians or cyclists. Most of them also responded that zone 1 had the same level of road safety over the past years. This finding was in line with the spatial analysis results of individual years' crash data (maps of individual years' NKDE in appendix 3). The hotspots remained constant in the motorway section and the surrounding area. Zone 2 was found to have performed poorly in road safety improvement for cyclists and car drivers. From NKDE maps of the individual years, it can be seen that RTCs increased in zone 2. This could also be observed from the road users' responses about the change in road safety situation in zone 2. The key informant from TeamAlert stated "local municipalities approach us when they discover a traffic problem in their surroundings , for example when they see that youth often use their phone while biking. The other way around, when TeamAlert approaches local municipalities, we talk about the traffic problems with the local municipalities we see in the Netherland and then discuss the problems they encounter in their city. We approach the citizens and they also approach us" (Personal communication, June 2, 2022). Analyses such as NKDE can be used as a decision-making tool for such discussions.

5.4.2 Perception in RTC coldspot zones

Zone 3 and 4 were the chosen RTC hotspots. None of the road users in zone 3 expressed extreme concern (very concerned) towards their safety in this zone. Some cyclists were concerned with their safety in zone 4, the reason for which is explained below. In both zones, only a small number of cyclists expressed dissatisfaction with the markings and signages. Overall, car drivers and pedestrians were satisfied with the markings and signages in zone 3 and 4.

Road users had the following opinions about zone 3, *"Sometimes cars speed here, and it is dangerous for cycling," "I know this area is safer than zone 2 because it is not so crowded", "When there is traffic on the roads, they speed and do not care for crossing cyclists and pedestrians."* Some road users said traffic lights were added a few years ago in some areas, improving safety.

Some responses specific to zone 4 were, *"The last time I went there, there were no cycle paths on the main road, and in some places, it was very narrow. I feel this is quite dangerous", "Cars do not always stop when you are crossing in zebra crossing," "There is a narrow road near the gas station and many intersections," "There is a bend in the road near the hospital, which has a mirror to show vehicles from the other side, but the mirror is very small and is useless. It can be made bigger". "It has improved somewhat but is still busy, and cars speed by sometimes."* Many responses were about a specific area around a hospital in the study area and how the roads could be improved for driving and cycling.

To summarise, there were no reported cases of worsened traffic situations in the cold spot zones. The spatial analysis did not show significant changes in the number of crashes in cold spot zones (appendix 3). Only a few road users were dissatisfied with the signage and markings in all the zones. Most of them were cyclists. Based on this, the need for additional proper traffic signs for cyclists can be suggested when providing recommendations(see section 6.3 for the list of recommendations).

5.5 Road users' understanding of the specific road parameters and their relation with RTCs

This section contains road users' perceptions regarding specific road parameters, routes, and times of the day.

The road users were asked which of the four road parameters (straightway, roundabout, intersection, and bends) were likely to get more crashes. The Likert-scale responses for this question can be found in annex 7. Most road users associate intersections as a "dangerous road parameter." The second "most dangerous" road parameter was road bends, followed by roundabouts. Straight roads were considered least likely to have RTCs among the four parameters. The responses from road users are in line with the crash data; the intersections have more RTCs than roundabouts.

In Table 5-3, the severity of each crash is tallied with the road parameter. The second column indicates the percentage of total RTCs on one of the four road parameters in the study area from 2018 to 2020. The third, fourth and fifth column shows the crashes associated with a particular road parameter resulting in property damage, an injury, or death.

Table 5-3: Road parameters vs. severity of RTCs from 2018-2020

Road parameters	Percentage of total crashes	Property damage (%)	Injuries (%)	Deaths (%)
Bends	7,8	**76,6**	23,0	0,4
Intersection	35,6	**70,7**	28,9	0,4
Roundabout	5,7	**72,6**	27,2	**0,2**
Straight way	**50,8**	**77,1**	22,6	0,4

It can be seen that straight ways had the most significant proportion of crashes (50,8%). However, since more area is covered in any road network by straight sections than by intersections, the crash frequency can be expected to be higher on straight ways. This implies that even though road users consider straight sections the safest road parameter, the likelihood of crashes is higher on straight ways. There were more property damages in all road parameters than the other two severity levels, and the same proportion of deaths, except in roundabouts. Among the RTCs that occurred in roundabouts, the lowest portion was that of deaths (0,2%).

This finding was discussed in the key-informant interview with SWOV. A study was done to see the relationship between different road parameters and the impact on road safety in another Dutch city (SWOV, personal communication, March 22, 2022). One of the findings in the report was that the crash rate increases with the increase in the number of intersections per road segment (Dijkstra et al., 2021). This is in line with the findings discussed above, where many road users believed intersections would likely have more crashes.

Next, road users were asked whether they avoid specific routes in the study area while making a trip. The reasons for avoiding the routes were also asked to understand potential issues that could be improved in the future. The Likert-scale responses for this question can be found in annex 7. From the responses, it was understood that most cyclists avoid some routes to ensure their safety. The cyclists responded by saying, *"I avoid some routes in the central part of the city* (zone 2) *when cycling because those areas are always busy and crowded", "In the center, roads are always being repaired, then I have to take another route," "I do not avoid but be extra careful when there are many pedestrians or cyclists on the road, especially in central* Rotterdam,*" "I try to avoid intersections that are too busy," "In Melanchtonweg* (zone 4)*, there is a bike road very close to the street, and if you make a mistake, you will be hit by a car. I mostly try to take another way rather than going that way".* In the case of car drivers, they avoid specific routes crowded with cyclists and pedestrians to ensure others' safety. A car driver responded that he does not drive in the central part of Rotterdam because it is always crowded, so he prefers to use his cycle instead. A pedestrian said, *"There are many cyclists in zone 2, and they take little account of pedestrians."*

The key informant from the Rotterdam Municipality said that the Mobility Policy Department is responsible for monitoring and improving the road quality, and they work with area-oriented experts who have expert knowledge of specific road networks (Personal communication, May 12, 2022). The perception of road users toward road parameters and reasons why a road user avoids particular routes can be a helpful decision-making tool for those stakeholders. By collecting data on which routes are avoided mainly by road users, roads can be improved, so road user behavior is changed. In response to the suggestion for collecting such data, the key informant from Rotterdam Municipality responded, *"In Rotterdam, we are working on a strategy to continuously explain the benefits of road safety/ mobility measures via all types of communication channels. Storytelling is essential; you must explain the benefits to residents and convince them that their quality of life will improve. Only then do they come out of their current thinking"* (Personal communication, May 12, 2022).

In the final question in this category, road users were also asked if they believed the time of day was responsible for crashes. The reason for asking this question was to see if road users' perceptions varied with time of the day. The majority responded that time of the day was positively correlated with crashes. The reactions were similar irrespective of transport modes. Many road users replied that RTCs increases in peak hours when people are going to or coming back from their work/education places. They also commented that they could observe drunk people on bicycles or walking on the streets at night, which increased the risk of RTC. Many car drivers said it was difficult to see cyclists on the roads at night if they had not switched their bicycle lights, even if the roads were lighted. Other road users responded that the visibility was less in the evening and that people were tired; thus, more crashes occurred at night. Some people who disagreed with the question gave reasons such as, *"time of the day is not responsible, I am careful all the time," and "it is up to yourself to be safe."* The Likert-scale responses for this question can be found in annex 7.

The secondary crash data collected by BRON was analyzed to observe a relationship between crashes and time of the day in the study area. The BRON dataset is divided into different times of day as dark, day, and dusk. The percentage of crashes in the past three years cross-tabulated with severity is shown in Table 5-4.

Table 5-4: Time of the day vs. crashes from 2018-2020

Time of day	Percentage of total crashes	Property damages	Injuries	Deaths
Dark	24,7	25,0	23,2	**31,4**
Day	**69,1**	68,8	**70,9**	56,9
Dusk	6,2	6,2	5,9	**11,8**

The second column in Table 5-4 indicates the percentage of total RTCs that occurred at different times of the day from 2018 to 2020. The third, fourth and fifth column shows the rate of crashes associated with a particular time resulting in property damage, an injury, or death. The data shows that more than half the crashes occurred in daylight (69,1%). Traffic volumes are lesser at night. Thus the probability of crashes also decreases. However, there have been more deaths than injuries or property damages in most crashes in the dark and dusk. The key informant from SWOV says that, in one of the studies done by SWOV, it was found that generally, there are more crashes per kilometer at night than during the day (Personal communication, March 22, 2022). This is a likely explanation for the results from the road users.

Furthermore, the key informant from Rotterdam Municipality added, *"I believe residents are right. At night people are less alert because there is hardly any traffic. Because it is also dark, every encounter between road users is more dangerous in people's perception than during the day. The most serious accidents between cyclists/ pedestrians and cars, with fatal consequences in Rotterdam, have also occurred in the dark The fact that we see more accidents during the day has definitely to do with a greater volume of traffic, so there is a greater chance of encounters and accidents" (*Personal communication, May 12, 2022).

5.6 Road users' perception of the prevailing road safety policies

This section includes the responses regarding prevailing road safety policies for different modes of transport. The stacked bar graph showing the Likert-scale responses can be found in annex 8.

It was observed that out of sixty-four respondents, sixteen drove a car in the study area. They were asked questions about their attitude towards existing policies (ten questions) and attitude towards possible recommendations (six questions). Forty-eight respondents used a cycle in the study area. Some used their bicycles to reach either tram, train, or metro station. They were asked questions about their attitude towards existing policies (five questions) and attitude towards possible recommendations (three questions). Thirty-six respondents are used to walking in the study area. Some pedestrians reported walking to a tram, train, or a metro station. Questions regarding existing policies and possible recommendations were not asked to this group of road users. As discussed in 2.11, there are minimal ways of improving pedestrian safety that does not involve imposing policies on other forms of transport (Vermeulen, 2003).

5.6.1 Attitudes towards existing policies

In the case of car drivers, it was observed that the most agreeable policy was license suspension, and the policy that many people disagreed with was the reduction in speed limit. There were many responses in which people expressed dissatisfaction with reducing the speed limit in motorways because they perceived other road users to be "*slow*," which would make them feel impatient on the road. Other penalties on which people had strong opinions were: increased penalty for drunk driving, the Bob campaign, and awareness courses for repeat offenders of drunk driving. Many road users were unaware of the increased penalty for drink driving policy. They had to be explained that the policy had been changed in 2021 and also that the fines were higher than the previous years for drunk driving offenses. A respondent gave their reason to disagree with the awareness courses as *"awareness courses are more like an obligation and bother my routine, so I do not like it."* Another respondent also commented that the awareness courses are *"inconvenient sometimes."* This can be a possible reason for measures like this to lose effectiveness over time, as discussed in 2.10. Many drivers were unsure of or not in favor of the Bob campaign. Two drivers responded, *"I have not used this campaign so far, so I do not know if I like it or not."* Many people needed to be explained this campaign because they did not know how it works or its advantages. In the case of a lower BAC limit for novice drivers, a road user responded, *"I think all road users should have the same limit for BAC. Experienced drivers can be limited to the same levels as novice drivers."* The same proportion of drivers responded negatively to the penalty for using handheld devices while driving, having no license, and driving on the wrong side of the road. One road user who disagreed with the penalty for driving on the wrong side of the road said, *"I may make a mistake on a street where I have never been before. I would not like to be fined for it."* The penalty for not using a seatbelt received the minority proportion of disagreements.

In the case of cyclists, the policy with the highest levels of disagreement was: the "penalty for blood alcohol levels above the limit" and the "penalty for cycling on the wrong side." The cyclists responded with replies for reasons they disagree with penalties for cycling in the wrong direction as: *"Sometimes you need to take a detour, so you cycle in the wrong direction to reach quickly," "It is easier to use wrong way while cycling," "Sometimes cyclists have to ride long distances to make a turn, so I cycle in the wrong direction," "Sometimes cycling in the wrong direction is faster because I can skip three traffic lights and a whole route. So you just go straight and save time", "Sometimes it is quite safe," "If there is no traffic, it is okay to cycle in the wrong direction."* Cyclists responded that it was *"Okay to cycle when you are a bit drunk if you are very attentive."* Another cyclist responded, *"The alcohol one I find hard. Rationally, you should not participate in traffic under the influence- but how else will you get home, not uber because it is too expensive & public transport does not go where you want."* The general cause for disagreement with the penalty for crossing at a red light was *"If there is no traffic, it is ok to cycle through a red light, for example, at night when there is no one on the road,"* or that *"I know exactly when the green light goes on, so I can start my cycle a bit earlier."* Most of the respondents agreed with the case of being penalized for using handheld devices while cycling and cycling without proper lights. The responses were mixed. For example, A cyclist replied, *"Punishments are good and should be used more to save lives,"* or "*Mobile phone distracts a lot.*" However, another cyclist responded, *"Everyone can make a mistake, but some people do not like the consequences."* Many cyclists admitted to sometimes not using lights in the dark but still agreed with the respective penalty saying, *"I know drivers cannot see cyclists in the dark, but I still do it sometimes," "Sometimes it is okay not to use lights because all the roads are well lit."* Another interesting find was that many cyclists knew about the penalties but did not know how much money was involved in the fines of those penalties.

When compared, it was found that many cyclists agree with the existing policies more than the car drivers who strongly oppose some policies. Car drivers expressed discontent with the reduced speed limit on motorways. This was discussed in the first key-informant interview. SWOV checks whether roads fulfill a set of key performance indicators, for example, design guidelines or the acceptable number of crashes per a specified section. If not, the guidelines are revised. Similar methods were used to study the effects and benefits of reducing the speed limit for motorways before implementing the policy (SWOV, personal communication, March 22, 2022). Thus, even if road users disagree with this particular policy, it will not likely be modified in the future. According to the key informant from Rotterdam Municipality, "*People in the Netherlands have their own will. They are not easily forced to do anything by the government. You should communicate the right message at the right time for it to work. The measure to drive 100 km/hr on national roads has to do with emissions. People find it unfair to adjust their own speed when there are sectors that cause more emissions and are barely affected by government policy"* (Personal communication, May 12, 2022). Regarding the behavior influencing campaigns such as Bob and the demerit point system, it is wise to offer participants a better alternative than what they are no longer allowed to do, such as providing cheap public transport on weekends (Rotterdam Municipality, personal communication, May 12, 2022). According to the key informant from TeamAlert, they talk to road users about the known facts first and then about the possible benefits of safety policies through their campaigns to shift the attitude towards a positive side (Personal communication, June 2, 2022).

5.6.2 Attitudes towards possible recommendations

To keep the questionnaire time under an acceptable limit, the car drivers were informed that semi/ fully automated cars (in the context of this questionnaire) would help in reducing the occurrence of three risky behaviors: driving through the red light, not giving way to pedestrians at crossings and following the preceding vehicle too closely. The attitude of car users towards semi/fully automated cars and speed limiting devices was mainly negative. Most of the respondents gave their reasoning for not being in favor of semi/fully automated cars as *"I do not trust the machine to make decisions for me" or "There is always something that* *can go wrong with a car like that; it is too much of a risk" or "I would rather be in control myself" or "I once had an accident in a similar car because the system stopped working," "I do not like the automatic system, and "I would rather be in control myself."* An equal proportion of drivers responded positively and negatively to using alcolock for previous offenders, installing the black box, and fatigue detection devices. Those three recommendations were found to have more people in support compared to the demerit point system. Since these methods are not in practice, some respondents had to be made aware of how they would work. A driver responded, *"A demerit or progressive penalty system is not helpful, "* but another road user said, *"A demerit point system is good, but people may not favor it."*

There were many neutral responses in the case of cyclists because the respondents could not precisely answer how they would perceive the recommendation if it became a policy in the future. Most cyclists did not understand the use of reflective materials in the dark because either they were using bicycle lights or the roads were well lit. Many cyclists replied, "*Helmets are quite unnecessary in my opinion for short distance travels,"* meaning they would not want to wear helmets because they are already familiar with cycling on usual roads. Others added to the same statement with replies such as "*Helmets make you think you are safe, but that is not true*," and "*It really is just a cultural thing- helmets are unnecessary for experienced cyclists, but everyone can make their choice though-I just do not want to wear one*." In the case of using rearview mirrors on their cycles, the primary concern of the majority of cyclists seemed to be, *"I might hurt myself if I fall, so I think it is a dangerous idea."* A typical response for all the three policies was, *"I do not know if other people will actually like them or follow it through."*

The possible recommendations for car drivers' safety were accepted higher than those for cyclists. Annex 9 contains the Likert-scale responses for car drivers and cyclists, respectively.

To summarise this section, car drivers were not in much agreement with using ITS in their vehicles in the future or with attending awareness classes as a form of penalty. This contradicts existing research, which demonstrates that ITS can help improve road user safety (section 2.12). This issue was discussed in the first key informant interview. The expert agreed, stating, *" Indeed, many road users strongly dislike using speed limiting devices and automated cars. There had been campaigns promoting ITS use in the past, and SWOV had analyzed the number of people in support but was unable to achieve the intended target*" (SWOV, personal communication, March 22, 2022). The key informant from Rotterdam Municipality stated that there are existing awareness programs to promote ITS use. The municipality of Rotterdam also uses social media to convince road users to use the information systems and organize their journey more smartly. They added, *"We have set up much communication about our ITS systems on behalf of the municipality. These systems provide information about travel time, road works, and road safety and travel alternatives" (*Personal communication, May 12, 2022).

The key informant from Rotterdam Municipality discussed the negative opinions of cyclists toward wearing a helmet. They say, *"I do not think we have to wear bicycle helmets by law. Stimulating voluntary use for vulnerable groups such as children and the elderly is a good idea. If we start mandating too many traffic regulations (beyond the ones we already have), I am afraid we will see the opposite effect. We already see an increasing resistance to government measures among citizens. In addition, we fear that bicycle use will decrease if helmet use is made compulsory. This has also been researched. In addition, we still have a lot to improve by making bicycle paths safer and offering more education. If that does not work, we can always reconsider a possible helmet requirement by 2030"* (Personal communication, May 12, 2022).

5.6.3 Attitudes towards the government/ authorities

At the end of the questionnaire, the respondents were asked if they feel the road safety authorities (local and country-level) are responsible for formulating the policies and developing infrastructures concerned with their safety. The majority of the respondents agreed or strongly agreed that the authorities are concerned for their well-being, but a small minority of cyclists disagreed with the statement. One elderly respondent commented, however, *"I have no way of knowing the new policies being implemented. How do I know if what I am doing is right or wrong? "*

More information was gathered from the key-informant interviews about stakeholder inclusion in their works. The key informant from SWOV was asked about stakeholders' involvement in the decision-making process for policy development by SWOV. It was found that the SWOV independently researches the feasibility, impacts, and costs of new policies on road safety and then suggests road authorities and, in some cases, municipalities with improvement measures. It is up to the other party to incorporate stakeholder concerns through discussions or focus groups to make necessary adjustments to the guidelines provided by the SWOV. The policy that set the speed limit of residential areas to 30 km/hr was used as an example. In the beginning, the SWOV researched the impacts of speed limit reduction. It was passed to the local level after discovering several benefits to road safety. Road users were allowed to use stickers to indicate the areas they thought were necessary to reduce the speed limit. This way, the policy was modified (SWOV, personal communication, 22 March 2022). From this, it becomes clear that primary stakeholders, as identified in section 1.2.2, are included in decision-making only in the final stages of the policy development process.

The key informant from the municipality of Rotterdam was asked about the involvement of local stakeholders in the decision-making process for road projects. *"Procedurally, we must always involve residents in projects of a certain size. If the project goes beyond the scope of the existing road layout, the process of an integrated plan will follow. Residents are then involved in all project phases"* (Rotterdam Municipality, personal communication, May 12, 2022). The key informant also discussed an ongoing policy approach involving a city-wide survey in which residents are asked about their perception of road networks. Based on the responses, the infrastructure improvement projects are initiated (Rotterdam Municipality, personal communication, May 12, 2022). The answer is in line with the Ministry of Infrastructure and Water Management et al. (2019), which states the success of measures depends on the local context, i.e., feasibility and appropriateness among road users. "*We sometimes test complex traffic measures in a temporary form first. We then evaluate with residents (interviews, surveys, etc.). If they do not like it, we will not continue the existent plans"* (Personal communication, May 12, 2022). They added that there are online platforms where road users can directly communicate with the municipality and interest parties like VVN, where they can report unsafe situations. "*The main issue is prioritizing the known spots"* (Personal communication, May 12, 2022).

Integration of road user perspective to reduce RTCs was discussed with the key informant from TeamAlert. They stated that they initially observe a societal problem, research the available data, and finally carry out campaigns involving residents (Personal communication, June 2, 2022). *"Mostly the projects have a knowledge part, followed by some kind of games to target youths and a part where people talk with each other about existing norms"* (TeamAlert, personal communication, June 2, 2022). Thus, in this way, the steps followed by the different secondary stakeholders to incorporate local stakeholders in their projects or research were found.

6 CONCLUSION

Figure 6-1 explains the workflow followed to synthesize the results from the spatial analysis, the risk perception analysis, and findings from the literature review. The box with dotted lines indicates individual research steps, with objectives in the gray box and questions in the box(es) below it. The three kinds of methods used in this research- spatial (red), survey (blue), literature review (brown), and key-informant interview (pink) and how they contributed to the completion of each research objective are indicated with respective colored arrows. Green parallelograms indicate the end product of each research objective. The green arrows joining them to the fifth research objective express how all the results were used to recommend improvements in road safety and policies.

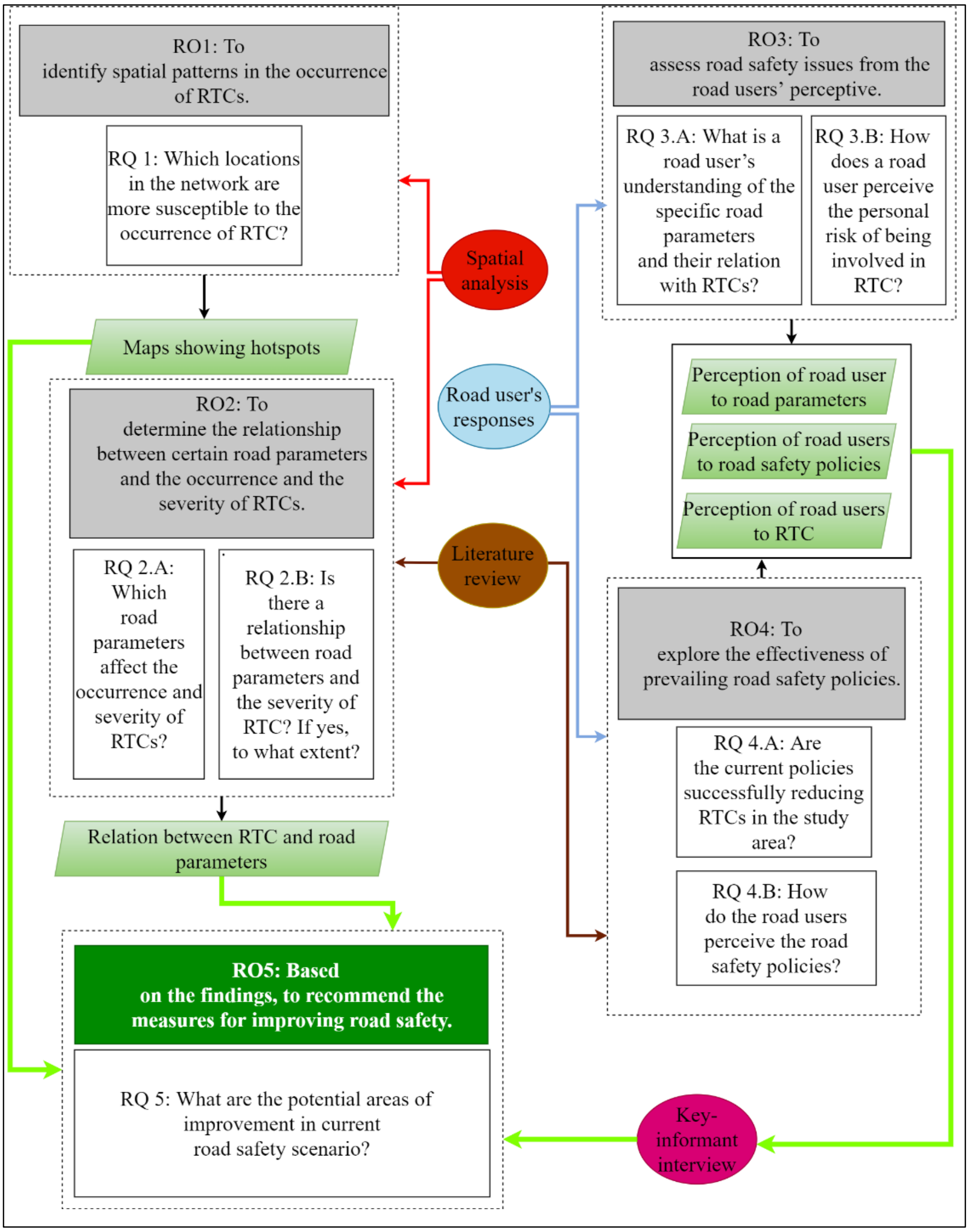


Figure 6-1: Synthesis of results

This research's main objective was to perform a spatial analysis of road traffic crashes and assess road safety issues from the perspective of road users. This study applied techniques for spatial analysis using different tools and ways to understand and evaluate road users' perceptions of RTC.

This research performed spatial analysis of RTCs in Rotterdam municipality and the surrounding urban conurbation using data from 2018 to 2020. The numbers of RTCs resulting in property damages, injuries, or deaths in individual years were visualized in maps. Following that, crash hotspots were determined using NKDE analysis. Two hotspots and two cold spots were chosen as a basis for developing a survey to collect road users' perceptions of road safety in these four areas. As understood from the literature review and the limitations of existing research, only knowing dangerous locations in the road network is not enough to improve road safety. Thus, this research dived further into why some areas are perceived as dangerous regarding road safety and how road parameters affect the users' perception. Road users were asked about risky behaviors, their perception of road safety policies, penalties, and possible recommendations for improving road safety in the study area.

Most road users considered intersections to be the road parameter most likely to have more RTCs, and roundabouts to be safer. They also believed that there were higher risks of crashes in the dark compared to day. Analysis of existing data and literature also suggested the same. When road users were asked about their perception of safety in the selected zones, it was found that they consider hot spots risky because of high traffic volumes, mixed traffic conditions, and speeding vehicles. Some road users had reported shortcomings of infrastructures in cold spot zones, such as an ineffective roadside convex mirror (as mentioned in 5.4.2) or a steep cycling path. Optimism bias was present in more than half of all the categories of road users. Other short-term risky behaviors such as following a preceding vehicle too closely, using handheld devices on roads, cycling through a red light, or being on the wrong side of the road, were most prevalent among the interviewed group. The road users were also asked about their perception of existing policies. Car drivers were found to have the strongest negative opinion on the decreased speed limit, and cyclists were not very agreeable towards penalty regarding BAC levels. Overall, the current road safety policies successfully reduce the RTCs in the study area, even though some are not viewed positively by road users. Following that, road users were asked their view on the list of possible recommendations. It was found that car drivers agreed more to a list of possible recommendations for the future than cyclists. To better understand the results of the spatial analysis and survey, they were discussed in the key-informant interviews.

The recommendations for potential areas of improvement that can be provided to the Municipality of Rotterdam are listed in section 6.3. The additional takeaway point that can be extracted from the results and interviews is that awareness in road users should be promoted regarding long-term and short-term risky behaviors by targeting both intuitive and deliberative systems. This can be achieved by non-physical interventions (as mentioned) and physical interventions, such as improving road infrastructures based on road user perception, similar to the methodology followed in this research.

6.1 Reduction in wickedness

This research has covered all the four wickedness areas as identified in the section 1.2.2:

1: RTCs are identified as a public health problem but are still persistent
The methodology used in this research has aided in determining RTC hotspots and their connection to road users' perceptions in Rotterdam. A method that combines spatial and individual data can help find significant points in a road network that can be improved to reduce the occurrence and severity of RTCs.

2: Fewer studies between road parameters and RTCs as factors that influence each other
A part of this research has analyzed the presence of four road parameters and the perception of road users towards them. Road users were also asked about which routes they avoid. The results can determine the potentially dangerous road parameters and locations that can be improved to reduce RTCs.
3: Optimism bias in road users

The results from the risk perception survey were in line with findings from the literature review, which indicated that most road users have optimism bias traits. The key-informant interviews concluded that there are existing awareness programs and training to reduce optimism bias. The specific group of road users who were found to take more risks (cyclists) can be targeted in the future.

4: Policy shortcomings/ ineffectiveness
Road users were asked about their attitudes towards existing policies and possible recommendations. Road users did not appreciate some policies. They were: the decrease in the speed limit on the motorways, Increased penalties, and awareness courses for drunk driving and cycling on the wrong side of the road. Those policies can be revised/modified by considering the local context and the opinions of the road and users.

As outlined in the points above, the research successfully moves the wickedness of the social problem of RTCs from a state of semi-structured and stakeholder dissensus to a state of a structured and stakeholder consensus.

6.2 Limitations

There are some limitations to this research. They can be divided into data or method-related limitations.

A data-related limitation is the under-reporting of RTCs by BRON. Between 2011 and 2020, BRON's crash records were around 16% less than that of CBS Netherlands. This was because BRON does not report crashes that involve non-motorized transport exclusively or when there is confusion about the type of crash (SWOV, 2021b). Another limitation is that the recorded crashes are put under one of the three headings- death, injury, or property damage by the police authority which registers the crash. According to the key informant from SWOV, if a road user has to be admitted to a hospital for a crash injury, the hospital stores data on the types of injuries. However, the type of injury is not linked to the X and Y coordinates of the crash location (Personal communication, March 22, 2022). Data like that is also not easily accessible due to privacy issues. However, a more detailed classification of injury types would provide more information for analysis.

A methods-related limitation is that traffic volume is not considered in this analysis because that would lead to temporal analysis, which is not the objective of this research. Secondly, the risk perception survey considered only four road parameters because only those parameters could be linked to the spatial RTC data. Thirdly, there might have been biases in the risk perception survey. For example, suppose the minority of cyclists had responded to cycling through a red light. But, it might be the case that this is not the actual representative of the existing population. More detail of the same group is needed to perform accurate analysis to form new policies. The road users were approached based on ground theory, assuming that no new category of answers could be expected from third fieldwork. Thus the sample of 64 residents of Rotterdam may not be an actual representation of the entire city. Some questionnaire results relied on Likert scale data; this type of data has some limitations because the scale is not continuous.

6.3 Recommendations for the Municipality of Rotterdam

Based on the findings of this research, the following recommendations can be listed for the municipality of Rotterdam to improve road safety:

- The hotspots (Zone 1 and 2) were reported to have mixed traffic, which caused inconvenience for road users. Especially pedestrians and cyclists responded that they felt less safe. It is unavoidable to prevent the high traffic volume in a city such as Rotterdam. Still, road safety projects, similar to what was done in the Cool district (Bicycle Dutch, 2021), where the cycling path was widened and the road was made safer for walking, can be carried out in other districts depending on the need.

- The main issue with Zone 3 and 4 (cold spots) was that motor vehicles tend to speed, taking advantage of lesser traffic volume. More signages can be put up in such areas to make road users aware, and traffic calming measures such as humps can be integrated into the existing infrastructure.
- Additionally, in zone 4, there were problems regarding a narrow cycling path and a dangerous bend. These physical infrastructures can be modified.
- Warning signs can be placed in the hotspots determined in this study. Furthermore, data can be incorporated into those warning signs; for example, a warning sign can say, "17,9 RTCs occurred within a kilometer of this road." This way, the road users remain alert to their surroundings when using those roads.
- From all the key-informant interviews, it was found that there are numerous campaigns to increase the awareness of road users towards optimism bias. It was found that road users who were involved in RTCs in the past had more traits of optimism bias. In this field, a recommendation can be made to target those groups of road users and share facts through existing platforms.
- Although research proves those measures to be beneficial, possible recommendations such as using ITS or reflective tape were not well received. Facts and statistics should back up the awareness campaigns to ensure maximum impact among road users.

6.4 Recommendations for further studies

Some recommendations that can be made as a continuation of this research are as follows:

- The same analysis can be conducted with a newer dataset for 2021 (which will be made available later in 2022). The change in RTCs before and after COVID-19 can provide a valuable comparison for finding how lockdown influences the occurrence of RTCs,
- From 2018 to 2020, several road renovation projects were carried out in Rotterdam. One of them was the improvements in Coolsingel, which falls in the central part of Rotterdam. The project started in 2018 and was opened to the public in 2021. Changes were made to provide more space for non-motorized traffic and were separated from motorized traffic in the street. (Bicycle Dutch, 2021). The same analysis with newer data can help in the determination of the effectiveness of that project in zone 2,
- The same study can be done for other major cities in the Netherlands, and a comparison can be made for the perception of policies and road safety between cities to understand how road users' perception varies with changes in the road environment.

LIST OF REFERENCES

Aarts, L., Wijlhuizen, G.J., Gebhard, S., Goldenbeld, C., Decae, R., Bos, N., Bijleveld, F., Mons, C., Hoekstra, T., 2021. De Staat van de Verkeersveiligheid 2021; Doelstellingen voor 2020 definitief niet gehaald – hoe nu verder?, SWOV. The Hague.

Aarts, L.T., Commandeur, J.J.F., Welsh, R., Niesen, S., Lerner, M., Thomas, P., Bos, N., Davidse, R.J., 2016. Study on Serious Road Traffic Injuries in the EU, European Commission, Directorate-General for Mobility and Transport. Brussels.

Abdulhafedh, A., 2017. Identifying Vehicular Crash High Risk Locations along Highways via Spatial Autocorrelation Indices and Kernel Density Estimation. World J. Eng. Technol. 05, 198–215. https://doi.org/10.4236/wjet.2017.52016

Adminaité-Fodor, D., Carson, J., Jost, G., 2021. Ranking EU Progress on Road Safety; 12th Road Safety Performance Index Report, European Transport Safety Council. Brussels.

Ahmad, S., Wasim, S., Irfan, S., Gogoi, S., Srivastava, A., Farheen, Z., 2019. Qualitative v/s. Quantitative Research- A Summarized Review. J. Evid. Based Med. Healthc. 6, 2828–2832. https://doi.org/10.18410/jebmh/2019/587

Al-Ghamdi, A.S., 2002. Using logistic regression to estimate the influence of accident factors on accident severity. Accid. Anal. Prev. 34, 729–741. https://doi.org/10.1016/S0001-4575(01)00073-2

Albalate, D., 2009. Lowering Blood Alcohol Content Levels to Save Lives: The European Experience, in: Pirog, M.A. (Ed.), Social Experimentation, Program Evaluation, and Public Policy. Blackwell Publishing Ltd., Oxford, UK, pp. 205–224. https://doi.org/10.1002/9781444307399.ch13

Anderson, T., 2007. Comparison of spatial methods for measuring road accident "hotspots": A case study of London. J. Maps 3, 55–63. https://doi.org/10.1080/jom.2007.9710827

Andersson, H., 2011. Perception of Own Death Risk: An Assessment of Road-Traffic Mortality Risk. Risk Anal. 31, 1069–1082. https://doi.org/10.1111/j.1539-6924.2011.01583.x

Anowar, S., Yasmin, S., Tay, R., 2014. Factors influencing the severity of intersection crashes in Bangladesh. Asian Transp. Stud. 3, 143–154. https://doi.org/10.11175/eastsats.3.143

Anselin, L., 2010. Local Indicators of Spatial Association-LISA. Geogr. Anal. 27, 93–115. https://doi.org/10.1111/j.1538-4632.1995.tb00338.x

APA Dictionary of Psychology, n.d. Perception [WWW Document]. URL https://dictionary.apa.org/perception (accessed 12.6.21).

Association for the Advancement of Automotive Medicine, n.d. Abbreviated Injury Scale (AIS) - [WWW Document]. URL https://www.aaam.org/abbreviated-injury-scale-ais/ (accessed 2.3.22).

Bassani, M., Rossetti, L., Catani, L., 2020. Spatial analysis of road crashes involving vulnerable road users in support of road safety management strategies. Transp. Res. Procedia 45, 394–401. https://doi.org/10.1016/j.trpro.2020.03.031

Benedek, J., Ciobanu, S.M., Man, T.C., 2016. Hotspots and social background of urban traffic crashes: A case study in Cluj-Napoca (Romania). Accid. Anal. Prev. 87, 117–126. https://doi.org/10.1016/j.aap.2015.11.026

Benn, S., Abratt, R., O'Leary, B., 2016. Defining and identifying stakeholders: Views from management and stakeholders. South African J. Bus. Manag. 47, 1–11. https://doi.org/10.4102/sajbm.v47i2.55

Bicycle Dutch, 2021. Rotterdam takes an important step towards becoming a cycle friendly city [WWW Document]. URL https://bicycledutch.wordpress.com/2021/05/19/rotterdam-takes-an-important-step-towards-becoming-a-cycle-friendly-city/ (accessed 2.23.22).

Bíl, M., Andrášik, R., Sedoník, J., 2019. A detailed spatiotemporal analysis of traffic crash hotspots. Appl.

Geogr. 107, 82–90. https://doi.org/10.1016/j.apgeog.2019.04.008

Bjerre, B., Thorsson, U., 2008. Is an alcohol ignition interlock programme a useful tool for changing the alcohol and driving habits of drink-drivers? Accid. Anal. Prev. 40, 267–273. https://doi.org/10.1016/j.aap.2007.06.008

Black, K., 2010. Business statistics for contemporaty decision making, 6th ed. John Wiley & Sons, Inc., Houston.

Blazquez, C., Fuentes, M., 2019. Global and Local Spatial Autocorrelation of Motorcycle Crashes in Chile, in: Proceedings of the 5th International Conference on Vehicle Technology and Intelligent Transport Systems. SCITEPRESS - Science and Technology Publications, pp. 159–170. https://doi.org/10.5220/0007716701590170

Blom, M., Blokdijk, D., Weijters, G., 2017. Recidive na een educatieve maatregel voor verkeersovertreders of tijdens een Alcoholslotprogramma, Wetenschappelijk Onderzoek- en Documentatiecentrum. The Hague.

Bos, N.M., Bijleveld, F.D., Decae, R.J., Aarts, L.T., 2020. Ernstig verkeersgewonden 2020 Ongevallen voorkomen Letsel beperken Levens redden; Schatting van het aantal ernstig verkeersgewonden in 2020, SWOV. The Hague.

Briz-Redón, Á., Martínez-Ruiz, F., Montes, F., 2019. Spatial analysis of traffic accidents near and between road intersections in a directed linear network. Accid. Anal. Prev. 132, 105252. https://doi.org/10.1016/j.aap.2019.07.028

Bucsuházy, K., Matuchová, E., Zůvala, R., Moravcová, P., Kostíková, M., Mikulec, R., 2020. Human factors contributing to the road traffic accident occurrence. Transp. Res. Procedia 45, 555–561. https://doi.org/10.1016/j.trpro.2020.03.057

Cabrera-Arnau, C., Prieto Curiel, R., Bishop, S.R., 2020. Uncovering the behaviour of road accidents in urban areas. R. Soc. Open Sci. 7, 191739. https://doi.org/10.1098/rsos.191739

Calvert, S.C., Schakel, W.J., van Lint, J.W.C., 2017. Will Automated Vehicles Negatively Impact Traffic Flow? J. Adv. Transp. 2017, 1–17. https://doi.org/10.1155/2017/3082781

Castillo-Manzano, J.I., Castro-Nuño, M., 2012. Driving licenses based on points systems: Efficient road safety strategy or latest fashion in global transport policy? A worldwide meta-analysis. Transp. Policy 21, 191–201. https://doi.org/10.1016/j.tranpol.2012.02.003

CBS, 2021a. Population dynamics; birth, death and migration by region [WWW Document]. StatLine. URL https://opendata.cbs.nl/#/CBS/en/dataset/37259eng/table?ts=1654167527417 (accessed 6.2.22).

CBS, 2021b. 610 traffic deaths in 2020 [WWW Document]. CBS. URL https://www.cbs.nl/en-gb/news/2021/15/610-traffic-deaths-in-2020 (accessed 3.11.22).

CBS, 2018. Country use; all categories, municipalities [WWW Document]. StatLine. URL https://opendata.cbs.nl/statline/#/CBS/en/dataset/70262ENG/table?ts=1651734592939 (accessed 5.5.22).

Choudhary, J., Ohri, A., Kumar, B., 2015. Spatial and statistical analysis of road accidents hot spots using GIS Spatial and statistical analysis of road accidents hot spots using GIS, in: 3rd Conference of Transportation Research Group of India (3rd CTRG). Kolkata.

Cunningham, M.L., Regan, M.A., Cairney, P., 2017. Human Factors in Traffic Engineering, in: Delbosc, A., Young, W. (Eds.), Traffic Engineering and Management: Melbourne, pp. 23–62.

de Waard, D., Houwing, S., Lewis-Evans, B., Twisk, D., Brookhuis, K., 2016. Bicycling under the influence of alcohol. Transp. Res. Part F Traffic Psychol. Behav. 41, 302–308. https://doi.org/10.1016/j.trf.2015.03.003

De Winne, P., De Winne, E., 2009. The influence of higher speed limits on motorways on road safety and truck accidents, in: WIT Transactions on the Built Environment. pp. 553–564. https://doi.org/10.2495/SAFE090511

DeJoy, D.M., 1989. The optimism bias and traffic accident risk perception. Accid. Anal. Prev. 21, 333–340. https://doi.org/10.1016/0001-4575(89)90024-9

Dijkstra, A., Schermers, G., Petegem, J.H. van, 2021. Verkeersveiligheid van stedelijke verkeersinfrastructuur, Veiligheid van wegen en straten in Amsterdam in relatie tot wegkenmerken, SWOV. The Hague.

Eboli, L., Forciniti, C., Mazzulla, G., 2020. Factors influencing accident severity: an analysis by road accident type. Transp. Res. Procedia 47, 449–456. https://doi.org/10.1016/j.trpro.2020.03.120

Erdogan, S., 2009. Explorative spatial analysis of traffic accident statistics and road mortality among the provinces of Turkey. J. Safety Res. 40, 341–351. https://doi.org/10.1016/j.jsr.2009.07.006

Ermagun, A., Levinson, D., 2018. An Introduction to the Network Weight Matrix. Geogr. Anal. 50, 76–96. https://doi.org/10.1111/gean.12134

ESRI, 2021a. Best practices for selecting a fixed distance band value—ArcGIS Pro | Documentation [WWW Document]. URL https://pro.arcgis.com/en/pro-app/2.8/tool-reference/spatial-statistics/choosingdistanceband.htm (accessed 6.1.22).

ESRI, 2021b. Modeling spatial relationships—ArcGIS Pro | Documentation [WWW Document]. URL https://pro.arcgis.com/en/pro-app/2.8/tool-reference/spatial-statistics/modeling-spatial-relationships.htm (accessed 5.19.22).

ESRI, 2021c. How Cluster and Outlier Analysis (Anselin Local Moran's I) works—ArcGIS Pro | Documentation [WWW Document]. URL https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-statistics/h-how-cluster-and-outlier-analysis-anselin-local-m.htm (accessed 5.20.21).

ESRI, 2021d. Incremental Spatial Autocorrelation (Spatial Statistics)—ArcGIS Pro | Documentation [WWW Document]. URL https://pro.arcgis.com/en/pro-app/2.8/tool-reference/spatial-statistics/incremental-spatial-autocorrelation.htm (accessed 6.1.22).

ESRI Nederland, n.d. Verkeersongevallen [WWW Document]. URL https://hub.arcgis.com/datasets/esrinl-content::verkeersongevallen/explore?location=52.232823%2C4.930473%2C14.81 (accessed 5.16.22).

ETSC, 2007. Social and Economic Consequences of Road Traffic Injury in Europe. Brussels.

European Commission, 2021. Road safety: 4,000 fewer people lost their lives on EU roads in 2020 as death rate falls to all-time low [WWW Document]. Eur. Comm. URL https://ec.europa.eu/commission/presscorner/detail/en/IP_21_1767

European Commission, 2020. Next steps towards ' Vision Zero ': EU road safety policy framework 2021-2030. Luxembourg. https://doi.org/10.2832/391271

European Commission, n.d. Black boxes/ in-vehicle data recorders [WWW Document]. URL https://ec.europa.eu/transport/road_safety/statistics-and-analysis/statistics-and-analysis-archive/esafety/black-boxes-vehicle-data-recorders_en (accessed 2.22.22).

Glaser, B.G., Strauss, A.L., 1999. The Discovery of Grounded Theory, 1st ed. Routledge, New York. https://doi.org/10.4324/9780203793206

Goldenbeld, C., 2017. Progressive penalty systems in traffic. SWOV Fact sheet.

Goldenbeld, C., Blom, M., Houwing, S., 2016. Zware alcoholovertreders in het verkeer, SWOV. The Hague.

Goldenbeld, C., Reurings, M., Van Norden, Y., Stipdonk, H., 2013. Crash Involvement of Motor Vehicles in Relationship to the Number and Severity of Traffic Offenses. An Exploratory Analysis of Dutch Traffic Offenses and Crash Data. Traffic Inj. Prev. 14, 584–591.

https://doi.org/10.1080/15389588.2012.743125

Goldenbeld, C., Reurings, M.C.B., van Norden, Y., Stipdonk, H.L., 2011. Relatie tussen verkeersovertredingen en verkeersongevallen; Verkennend onderzoek op basis van CJIB (Central Fine Collection Agency)-gegevens, SWOV. Leidschendam.

Goldenbled, C., 2017. Progressive penalty systems in traffic, SWOV. The Hague.

Guerrero, T.E., de Dios Ortuzar, J., Raveau, S., 2020. Traffic accident risk perception among drivers: a latent variable approach. Transp. Plan. Technol. 43, 313–324. https://doi.org/10.1080/03081060.2020.1735763

Haq, G., Whitelegg, J., 2006. Vision Zero : Adopting a Target of Zero for Road Traffic Fatalities and Serious Injuries; The Stockholm Environment Institute. Stockholm.

Hazaymeh, K., Almagbile, A., Alomari, A.H., 2022. Spatiotemporal Analysis of Traffic Accidents Hotspots Based on Geospatial Techniques. Int. J. Geo-Information 11, 260. https://doi.org/10.3390/ijgi11040260

Hermens, F., 2020. Fatigue and distraction detection; A review of commercially available devices to detect fatigue and distraction in drivers, SWOV. The Hague.

Hoekstra, A.T.G., Eenink, R.G., Goldenbeld, C., 2017. Progressief boetestelsel en verkeersveiligheid; Geschatte veiligheidseffecten van hogere boetes bij herhaalde snelheidsovertredingen, SWOV. The Hague.

Holmes, B.D., Haglund, K., Beyer, K.M.M., Cassidy, L.D., 2019. Qualitative methods of road traffic crash research in low- and middle-income countries: a review. Int. J. Inj. Contr. Saf. Promot. 26, 194–199. https://doi.org/10.1080/17457300.2018.1535512

Houwing, S., Twisk, D., De Waard, D., 2015. Alcoholgebruik van jongeren in het verkeer op stapavonden, SWOV. The Hague.

Hwang, J.R., Kang, H.Y., Li, K.J., 2005. Spatio-temporal similarity analysis between trajectories on road networks, in: Akoka, J., Liddle, S.W., Song, I.-Y., Bertolotto, M., Comyn-Wattiau, I., Heuvel, W.-J., Klop, M., Klop, C., Mayr, H.C. (Eds.), Perspectives in Conceptual Modeling. Klagenfurt, pp. 280–289. https://doi.org/10.1007/11568346_30

ITF, 2020. Road Safety Annual Report 2020, Road Safety Annual Report. OECD, Paris. https://doi.org/10.1787/f3e48023-en

Jadaan, K., Al-Braizat, E., Al-Rafayah, S., Gammoh, H., Abukahlil, Y., 2018. Traffic Safety in Developed and Developing Countries: A Comparative Analysis. J. Traffic Logist. Eng. 1–5. https://doi.org/10.18178/jtle.6.1.1-5

Javadi, S.-M.-H., Tahmasebi, S., Azari-Arghun, T., Arshi, M., 2017. The Youth and Experience of Traffic Accidents (Grounded Theory). Heal. Emergencies Disasters Q. 2, 79–88. https://doi.org/10.18869/nrip.hdq.2.2.79

Johansson, R., 2009. Vision Zero – Implementing a policy for traffic safety. Saf. Sci. 47, 826–831. https://doi.org/10.1016/j.ssci.2008.10.023

Kang, M., Moudon, A.V., Kim, H., Boyle, L.N., 2019. Intersections and non-intersections: A protocol for identifying pedestrian crash risk locations in GIS. Int. J. Environ. Res. Public Health 16. https://doi.org/10.3390/ijerph16193565

Kirley, B., 2017. Human Behavior and Road Safety, in: Carter, D. (Ed.), Road Safety Fundamentals. North Carolina, pp. 44–61.

Klinjun, N., Kelly, M., Praditsathaporn, C., Petsirasan, R., 2021. Identification of Factors Affecting Road Traffic Injuries Incidence and Severity in Southern Thailand Based on Accident Investigation Reports. Sustainability 13, 12467. https://doi.org/10.3390/su132212467

Kouabenan, D.R., 2002. Occupation, driving experience, and risk and accident perception. J. Risk Res. 5, 49–68. https://doi.org/10.1080/13669870110036577

Kumar, S., Toshniwal, D., 2016. A novel framework to analyze road accident time series data. J. Big Data 3. https://doi.org/10.1186/s40537-016-0044-5

Laing, V., 2014. Bob-campaigns in order to have a positive impact on the attitudes and behaviour of dutch licenced drivers between the age of 18-34 (Master's thesis). Utrecht University Of Applied Sciences, the Netherlands.

Larsson, P., Tingvall, C., 2013. A Road Safety Strategy Based on Human Factors Principles, in: Harris, D. (Ed.), Engineering Psychology and Cognitive Ergonomics. Las Vegas, pp. 19–28. https://doi.org/10.1007/978-3-642-39354-9

Law, J., Martin, E.A., 2009. A Dictionary of Law, A Dictionary of Law. Oxford University Press. https://doi.org/10.1093/acref/9780199551248.001.0001

Le, K.G., Liu, P., Lin, L., 2020. Determining the road traffic accident hotspots using GIS-based temporal-spatial statistical analytic techniques in Hanoi, Vietnam. Geo-spatial Inf. Sci. 23, 153–164. https://doi.org/10.1080/10095020.2019.1683437

Lee, M., Khattak, A.J., 2019. Case Study of Crash Severity Spatial Pattern Identification in Hot Spot Analysis. Transp. Res. Rec. 2673, 684–695. https://doi.org/10.1177/0361198119845367

Li, H., Calder, C.A., Cressie, N., 2007. Beyond Moran's I: Testing for Spatial Dependence Based on the Spatial Autoregressive Model. Geogr. Anal. 39, 357–375. https://doi.org/10.1111/j.1538-4632.2007.00708.x

Lund, I.O., Rundmo, T., 2009. Cross-cultural comparisons of traffic safety, risk perception, attitudes and behaviour. Saf. Sci. 47, 547–553. https://doi.org/10.1016/j.ssci.2008.07.008

Ma, L., Yan, X., Qiao, W., 2014. A Quasi-Poisson Approach on Modeling Accident Hazard Index for Urban Road Segments. Discret. Dyn. Nat. Soc. 2014, 1–8. https://doi.org/10.1155/2014/489052

Mao, Y., Zhang, J., Robbins, G., Clarke, K., Lam, M., Pickett, W., 1997. Factors affecting the severity of motor vehicle traffic crashes involving young drivers in Ontario. Inj. Prev. 3, 183–189. https://doi.org/10.1136/ip.3.3.183

Mason, M., 2010. Sample size and saturation in PhD studies using qualitative interviews. Forum Qual. Sozialforsch. 11, Art. 8. https://doi.org/doi.org/10.17169/fqs-11.3.1428

Mathijssen, M.P.M., 2005. Drink driving policy and road safety in the Netherlands: a retrospective analysis. Transp. Res. Part E Logist. Transp. Rev. 41, 395–408. https://doi.org/10.1016/j.tre.2005.03.001

Mendoza, A.E., Wybourn, C.A., Mendoza, M.A., Cruz, M.J., Juillard, C.J., Dicker, R.A., 2017. The Worldwide Approach to Vision Zero: Implementing Road Safety Strategies to Eliminate Traffic-Related Fatalities. Curr. Trauma Reports 3, 104–110. https://doi.org/10.1007/s40719-017-0085-z

Ministry of Infrastructure and the Environment, 2013. Road Traffic Signs and Regulations in the Netherlands. The Hague.

Ministry of Infrastructure and Water Management, Ministry of Justice and Security, Association of Provincial Authorities, Association of Netherlands Municipalities, Amsterdam Transport Authority, Rotterdam- The Hague Metropolitan Area, 2019. Door to door safety Road Safety Strategic Plan 2030.

Morris, A.P., Haworth, N., Filtness, A., Nguatem, D.-P.A., Brown, L., Rakotonirainy, A., Glaser, S., 2021. Autonomous Vehicles and Vulnerable Road-Users—Important Considerations and Requirements Based on Crash Data from Two Countries. Behav. Sci. (Basel). 11, 101. https://doi.org/10.3390/bs11070101

Morsink, P., Goldenbeld, C., Dragutinovic, N., Marchau, V., Walta, L., Brookhuis, K., 2007. Speed Support Through the Intelligent Vehicle: Perspective, Estimated Effects and Implementation Aspects, SWOV.

Leidschendam.

Musselwhite, C., Avineri, E., Fulcher, E., Goodwin, P., Susilo, Y., 2010. Understanding public attitudes to road user safety. A review of the literature 2000-2009, in: 19th Behavioural Studies Seminar. Bristol.

National road crash registration [WWW Document], 2021. URL https://theseus.swov.nl/single/?appid=abe4ba46-bfa8-4d2b-88db-9b6afb0d0ab1&sheet=fd750336-ee63-4e97-ae88-9619d7b351d1&opt=currsel%2Cctxmenu (accessed 6.9.22).

Ngueutsa, R., Kouabenan, D.R., 2017. Accident history, risk perception and traffic safe behaviour. Ergonomics 60, 1273–1282. https://doi.org/10.1080/00140139.2016.1259508

Okabe, A., 2020. User Guide / Manual for SANET Standalone Beta. Tokyo.

Okabe, A., Okunuki, K.-I., Shiode, S., 2006. The SANET Toolbox: New Methods for Network Spatial Analysis. Trans. GIS 10, 535–550. https://doi.org/10.1111/j.1467-9671.2006.01011.x

Ord, K., 1975. Estimation Methods for Models of Spatial Interaction. J. Am. Stat. Assoc. 70, 120–126. https://doi.org/10.1080/01621459.1975.10480272

Othman, S., Thomson, R., Lannér, G., 2009. Identifying critical road geometry parameters affecting crash rate and crash type. Ann. Adv. Automot. Med. Assoc. Adv. Automot. Med. Annu. Sci. Conf. 53, 155–65.

Ozturk, Z.K., 2018. Importance of road parameters on traffic accidents, in: Transist 2018 Istanbul Transport Congress And Exhibition. Istanbul.

Peltzer, K., Renner, W., 2003. Superstition, risk-taking and risk perception of accidents among South African taxi drivers. Accid. Anal. Prev. 35, 619–623. https://doi.org/10.1016/S0001-4575(02)00035-0

Petridou, E., Moustaki, M., 2000. Human Factors in the Causation of Road Traffic Crashes 16, 819–826. https://doi.org/https://doi.org/10.1023/A:1007649804201

Prasannakumar, V., Vijith, H., Charutha, R., Geetha, N., 2011. Spatio-Temporal Clustering of Road Accidents: GIS Based Analysis and Assessment. Procedia - Soc. Behav. Sci. 21, 317–325. https://doi.org/10.1016/j.sbspro.2011.07.020

Pulugurtha, S.S., Sambhara, V.R., 2011. Pedestrian crash estimation models for signalized intersections. Accid. Anal. Prev. 43, 439–446. https://doi.org/10.1016/j.aap.2010.09.014

Quistberg, D.A., Howard, E.J., Ebel, B.E., Moudon, A. V., Saelens, B.E., Hurvitz, P.M., Curtin, J.E., Rivara, F.P., 2015. Multilevel models for evaluating the risk of pedestrian-motor vehicle collisions at intersections and mid-blocks. Accid. Anal. Prev. 84, 99–111. https://doi.org/10.1016/j.aap.2015.08.013

Racioppi, F., Eriksson, L., Tingvall, C., Villaveces, A., 2004. Preventing road traffic injury: a public health perspective for Europe, World Health Organization. Copenhagen.

Ram, T., Chand, K., 2016. Effect of drivers' risk perception and perception of driving tasks on road safety attitude. Transp. Res. Part F Traffic Psychol. Behav. 42, 162–176. https://doi.org/10.1016/j.trf.2016.07.012

Rifaat, S.M., Tay, R., de Barros, A., 2011. Effect of street pattern on the severity of crashes involving vulnerable road users. Accid. Anal. Prev. 43, 276–283. https://doi.org/10.1016/j.aap.2010.08.024

Rijkswaterstaat, 2020. Handleiding product Bestand geRegistreerde Ongevallen Nederland (BRON).

Rijkswaterstaat, n.d. Road safety | Mobility, public transport and road safety | Government.nl [WWW Document]. URL https://www.government.nl/topics/mobility-public-transport-and-road-safety/road-safety (accessed 1.26.22).

Rogerson, P.A., 2015. Maximum Getis-Ord Statistic Adjusted for Spatially Autocorrelated Data. Geogr. Anal. 47, 20–33. https://doi.org/10.1111/gean.12055

Safarpour, H., Khorasani-Zavareh, D., Mohammadi, R., 2020. The common road safety approaches: A scoping review and thematic analysis. Chinese J. Traumatol. 23, 113–121. https://doi.org/10.1016/j.cjtee.2020.02.005

Sagar, R., Mehta, M., Chugh, G., 2013. Road rage: An exploratory study on aggressive driving experience on Indian roads. Int. J. Soc. Psychiatry 59, 407–412. https://doi.org/10.1177/0020764011431547

Sajed, Y., Shafabakhsh, G., Bagheri, M., 2019. Hotspot location identification using accident data, traffic and geometric characteristics. Eng. J. 23, 191–207. https://doi.org/10.4186/ej.2019.23.6.191

Satria, R., 2020. Spatial Analysis of Traffic Accidents using GIS. The Case of Banda Aceh, Indonesia (Doctoral dissertation). Universidad Politécnica De Madrid, Madrid.

Schepers, P., Twisk, D., Fishman, E., Fyhri, A., Jensen, A., 2017. The Dutch road to a high level of cycling safety. Saf. Sci. 92, 264–273. https://doi.org/10.1016/j.ssci.2015.06.005

Shafabakhsh, G.A., Famili, A., Bahadori, M.S., 2017. GIS-based spatial analysis of urban traffic accidents: Case study in Mashhad, Iran. J. Traffic Transp. Eng. (English Ed. 4, 290–299. https://doi.org/10.1016/j.jtte.2017.05.005

Sharifian, S., R, K.J., Mh, V., Mohammadi, R., 2021. A model to explain road traffic data collection and registry in Iran: a grounded theory. J. Inj. Violence Res. 13. https://doi.org/10.5249/jivr.v13i2.1406

Siddiqui, C., Abdel-Aty, M., Choi, K., 2014. Implications of Pedestrian Safety Planning Factors in Areas with Minority and Low-Income Populations. Int. J. Sustain. Transp. 8, 360–381. https://doi.org/10.1080/15568318.2012.702853

Silva, C., Moeckel, R., Clifton, K., 2020. Proof of Concept for a Grounded Theory Approach to Understanding Interactions Occurring on Bicycle Facilities. Transp. Res. Rec. J. Transp. Res. Board 2674, 94–104. https://doi.org/10.1177/0361198120943588

Sjöberg, L., Moen, E., Rundmo, T., 2004. Explaining risk perception. An evaluation of the psychometric paradigm in risk perception research, Rotunde. Trondheim.

Soltani, A., Askari, S., 2017. Exploring spatial autocorrelation of traffic crashes based on severity. Injury 48, 637–647. https://doi.org/10.1016/j.injury.2017.01.032

Srikanth, D.L., Srikanth, I., Arockiasamy, D.M., 2019. Identification of Traffic Accident Hotspots using Geographical Information System (GIS). Int. J. Eng. Adv. Technol. 9, 4429–4438. https://doi.org/10.35940/ijeat.B3848.129219

Steenberghen, T., Aerts, K., Thomas, I., 2010. Spatial clustering of events on a network. J. Transp. Geogr. 18, 411–418. https://doi.org/10.1016/j.jtrangeo.2009.08.005

Steenberghen, T., Dufays, T., Thomas, I., Flahaut, B., 2004. Intra-urban location and clustering of road accidents using gis: A belgian example. Int. J. Geogr. Inf. Sci. 18, 169–181. https://doi.org/10.1080/13658810310001629619

SWOV, 2022. Roundabouts and other intersections, SWOV Fact sheet. The Hague.

SWOV, 2021a. Dutch road safety targets for 2020 out of reach [WWW Document]. SWOV. URL https://swov.nl/en/nieuws/dutch-road-safety-targets-2020-out-reach (accessed 6.14.22).

SWOV, 2021b. Road deaths in the Netherlands [WWW Document]. URL https://www.swov.nl/en/facts-figures/factsheet/road-deaths-netherlands (accessed 10.15.21).

SWOV, 2021c. Risky road user behaviour, aggression and repeat offenders, SWOV Fact sheet. The Hague.

SWOV, 2021d. Speed and speed management, SWOV Fact sheet. The Hague.

SWOV, 2020a. Serious road injuries in the Netherlands [WWW Document]. URL https://swov.nl/en/fact-sheet/serious-road-injuries-netherlands (accessed 3.22.22).

SWOV, 2020b. Road crash costs [WWW Document]. URL https://swov.nl/en/fact-sheet/road-crash-costs (accessed 3.23.22).

SWOV, 2020c. Pedestrians, SWOV Fact sheet. The Hague.

SWOV, 2020d. Distraction - How many casualties are caused by distraction in traffic? [WWW Document]. URL https://swov.nl/en/fact/distraction-how-many-casualties-are-caused-distraction-traffic (accessed 3.14.22).

SWOV, 2019. Bicycle helmets, SWOV Fact sheet. The Hague.

SWOV, 2018. Sustainable Safety 3rd edition – The advanced vision for 2018-2030; Principles for design and organization of a casualty-free road traffic system, SWOV. The Hague.

SWOV, 2017a. Cyclists - How dangerous is cycling under the influence of alcohol? [WWW Document]. URL https://swov.nl/en/fact/cyclists-how-dangerous-cycling-under-influence-alcohol (accessed 2.22.22).

SWOV, 2017b. Cyclists [WWW Document]. URL https://swov.nl/en/fact-sheet/cyclists (accessed 2.22.22).

SWOV, n.d. Organization [WWW Document]. URL https://swov.nl/en/organisation-0 (accessed 1.26.22).

Tang, Y., Knodler, M.A., Park, M., 2013. A Comparative Study of the Application of the Standard Kernel Density Estimation and Network Kernel Density, in: 16th International Conference Road Safety on Four Continents. Beijing.

TeamAlert, n.d. TeamAlert [WWW Document]. URL https://teamalert.nl/ (accessed 6.2.22).

Termeer, C.J.A.M., Dewulf, A., Biesbroek, R., 2019. A critical assessment of the wicked problem concept: relevance and usefulness for policy science and practice. Policy Soc. 38, 167–179. https://doi.org/10.1080/14494035.2019.1617971

Ulak, M.B., Ozguven, E.E., Spainhour, L., Vanli, O.A., 2017. Spatial investigation of aging-involved crashes: A GIS-based case study in Northwest Florida. J. Transp. Geogr. 58, 71–91. https://doi.org/10.1016/j.jtrangeo.2016.11.011

van Nes, N., Duivenvoorden, K., 2017. Safely towards self-driving vehicles, SWOV. The Hague.

Vanderschuren, M., Mckune, A., 2011. The sustainable transport and mobility handbook, in: van Wyk, L. (Ed.), The Sustainable Transport and Mobility Handbook, The Essential Guide - South Africa. Alive2Green, Cape Town, pp. 117–125.

Vermeulen, J.H.K.& W., 2003. Dutch long-term policies on non-motorised traffic Dutch long-term policies on non-motorised traffic, in: ICTCT Workshop on Non-Motorised Traffic. Vancouver.

Vlakveld, W., 2004. New policy proposals for novice drivers in the Netherlands, Behavioural Research in Road Safety. London.

Vlakveld, W., Twisk, D., 2012. Fietsen en verkeersonveiligheid in Nederland, Tijdschrift Vervoerswetenschap.

Walker, G.H., Stanton, N.A., Chowdhury, I., 2013. Self Explaining Roads and situation awareness. Saf. Sci. 56, 18–28. https://doi.org/10.1016/j.ssci.2012.06.018

Wang, M., Yi, J., Chen, X., Zhang, W., Qiang, T., 2021. Spatial and Temporal Distribution Analysis of Traffic Accidents Using GIS-Based Data in Harbin. J. Adv. Transp. 2021, 1–10. https://doi.org/10.1155/2021/9207500

Wang, Y., Chen, Q., 2020. Case study of road rage incidents resulting from the illegal use of high beams. Transp. Res. Interdiscip. Perspect. 7, 100184. https://doi.org/10.1016/j.trip.2020.100184

Weijermars, W., Wegman, F., 2011. Ten Years of Sustainable Safety in the Netherlands. Transp. Res. Rec.

J. Transp. Res. Board 2213, 1–8. https://doi.org/10.3141/2213-01

WHO, 2021. Decade of Action for Road Safety 2021-2030. Geneva.

WHO, 2018. Global Status Report on Road Safety. https://doi.org/http://dx.doi.org/10.1136/ip.2009.023697

WHO, 2004. World report on road traffic injury prevention, WHO. Geneva.

Wilson, E.J., Bunn, M.D., Savage, G.T., 2010. Anatomy of a social partnership: A stakeholder perspective. Ind. Mark. Manag. 39, 76–90. https://doi.org/10.1016/j.indmarman.2008.06.005

Xie, Z., Yan, J., 2013. Detecting traffic accident clusters with network kernel density estimation and local spatial statistics: An integrated approach. J. Transp. Geogr. 31, 64–71. https://doi.org/10.1016/j.jtrangeo.2013.05.009

Xie, Z., Yan, J., 2008. Kernel Density Estimation of traffic accidents in a network space. Comput. Environ. Urban Syst. 32, 396–406. https://doi.org/10.1016/j.compenvurbsys.2008.05.001

Zeng, J., Qian, Y., Wang, B., Wang, T., Wei, X., 2019. The Impact of Traffic Crashes on Urban Network Traffic Flow. Sustainability 11, 3956. https://doi.org/10.3390/su11143956

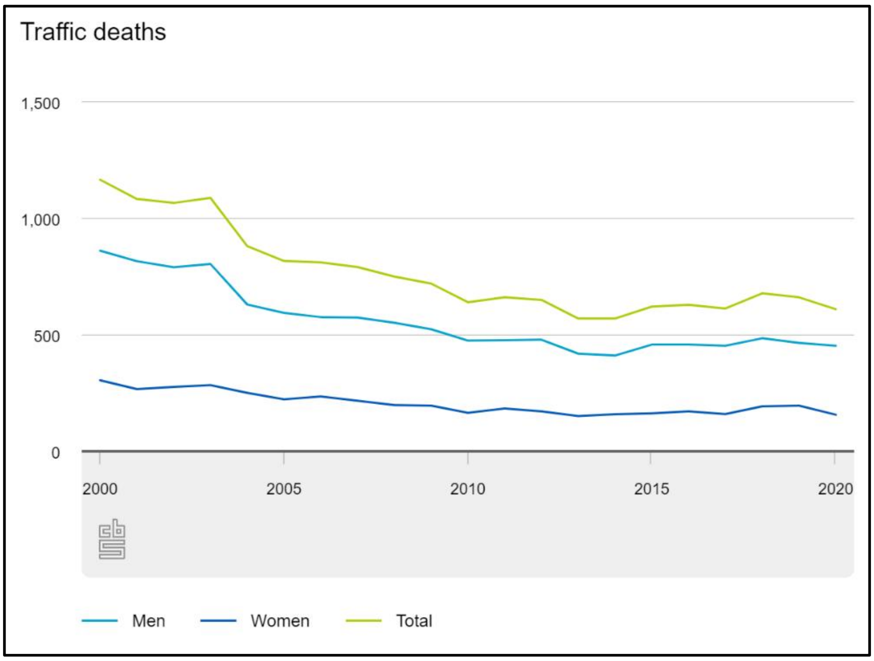
Zhang, T., Chan, A.H.S., 2016. The association between driving anger and driving outcomes: A meta-analysis of evidence from the past twenty years. Accid. Anal. Prev. 90, 50–62. https://doi.org/10.1016/j.aap.2016.02.009

Zhang, T., Chan, A.H.S., Xue, H., Zhang, X., Tao, D., 2019. Driving Anger, Aberrant Driving Behaviors, and Road Crash Risk: Testing of a Mediated Model. Int. J. Environ. Res. Public Health 16, 297. https://doi.org/10.3390/ijerph16030297

Zhang, Z., Ming, Y., Song, G., 2020. A New Approach to Identifying Crash Hotspot Intersections (CHIs) Using Spatial Weights Matrices. Appl. Sci. 10, 1625. https://doi.org/10.3390/app10051625

Appendices

Appendix 1: Road deaths in the Netherlands in the past decade



(CBS, 2021b)

Appendix 2: Topics discussed in the key-informant interview

Key-informant interview with SWOV on 22 March 2022

- Decision-making process for road safety projects related to infrastructure change/ improvement.
- Decision-making process for development/ implementation of road safety policies
- Incorporation of local stakeholders in the policy development/implementation phase
- Work done by other organizations to promote road safety
- Work done by other organizations to promote the use of ITS
- RTC data limitation of BRON
- Effect of COVID lockdown in RTCs

Key-informant interview with Rotterdam Municipality on 12 May 2022

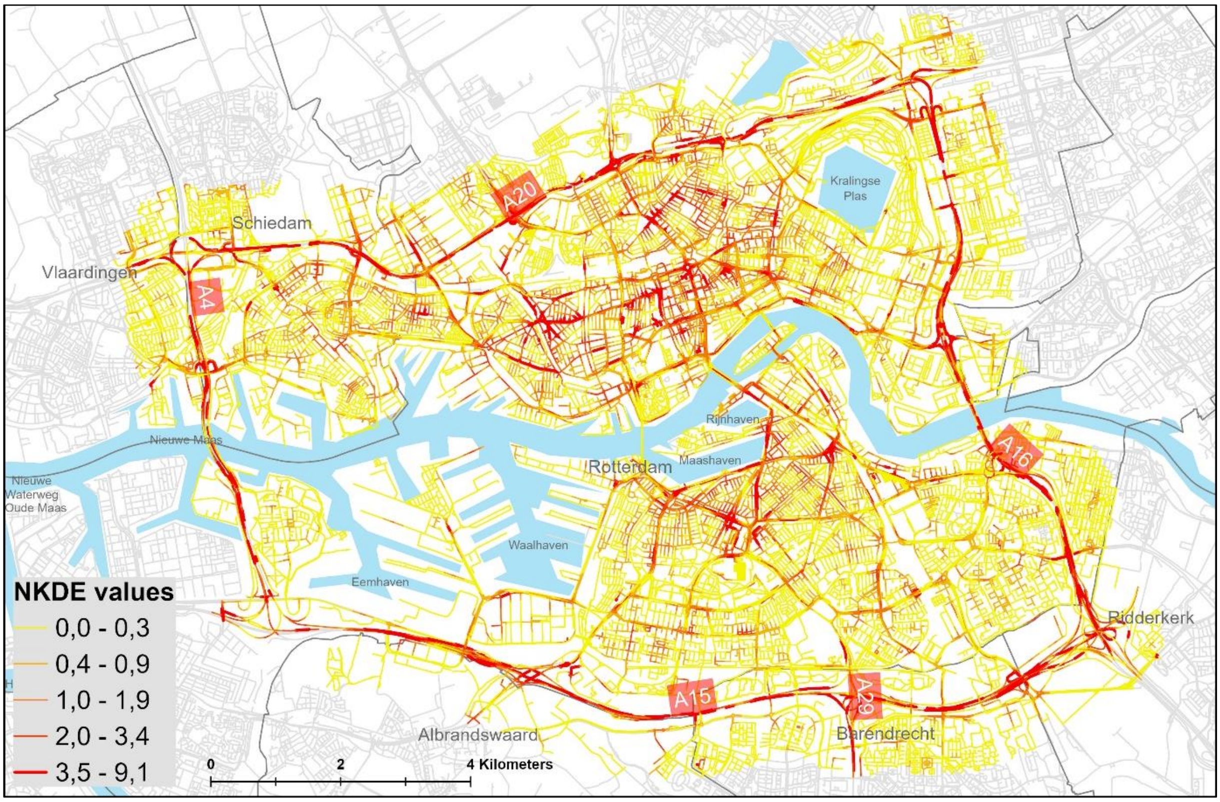
- Decision-making process for road safety projects related to infrastructure change/ improvement.
- Decision-making process for development/ implementation of road safety policies
- Incorporation of local stakeholders in the policy development/implementation phase
- Work done to encourage car users to use ITS,
- Reasons behind car users and cyclists not liking some recommendations such as the Bob system, wearing helmets
- Effect of time of day on RTCs
- Effect of COVID lockdown on RTCs

Key-informant interview with TeamAlert on 2 June 2022

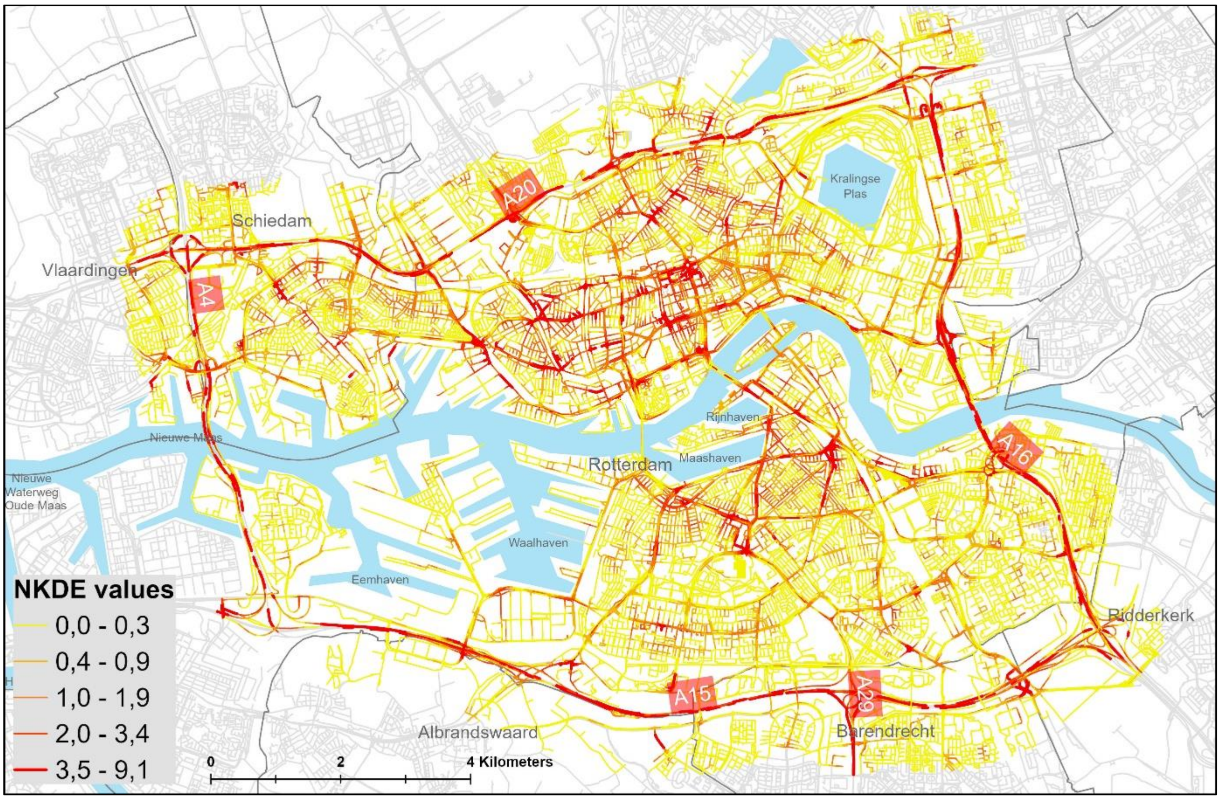
- Targeting specific road users

- Optimism bias
- Starting a campaign in a particular city
- Inclusion of stakeholders in campaigns

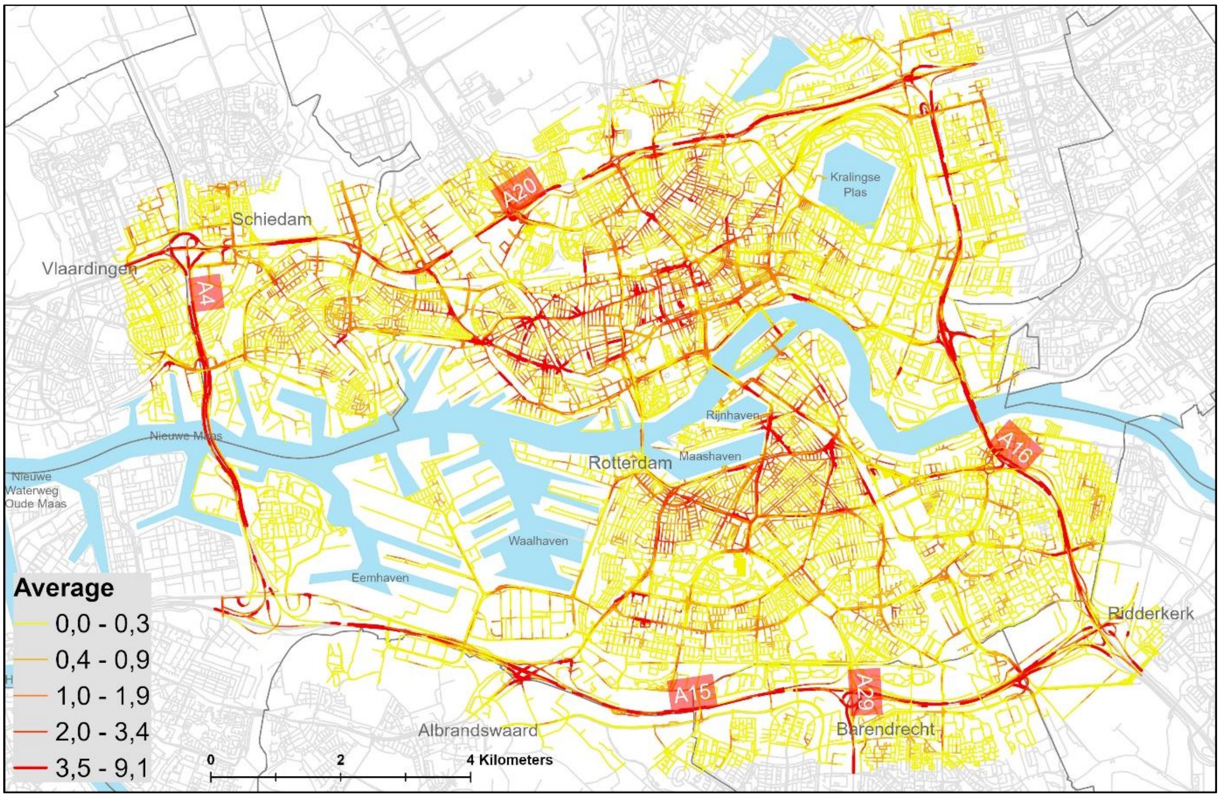
Appendix 3: NKDE of crashes in 2018, 2019 and 2020



NKDE of RTCs in 2018



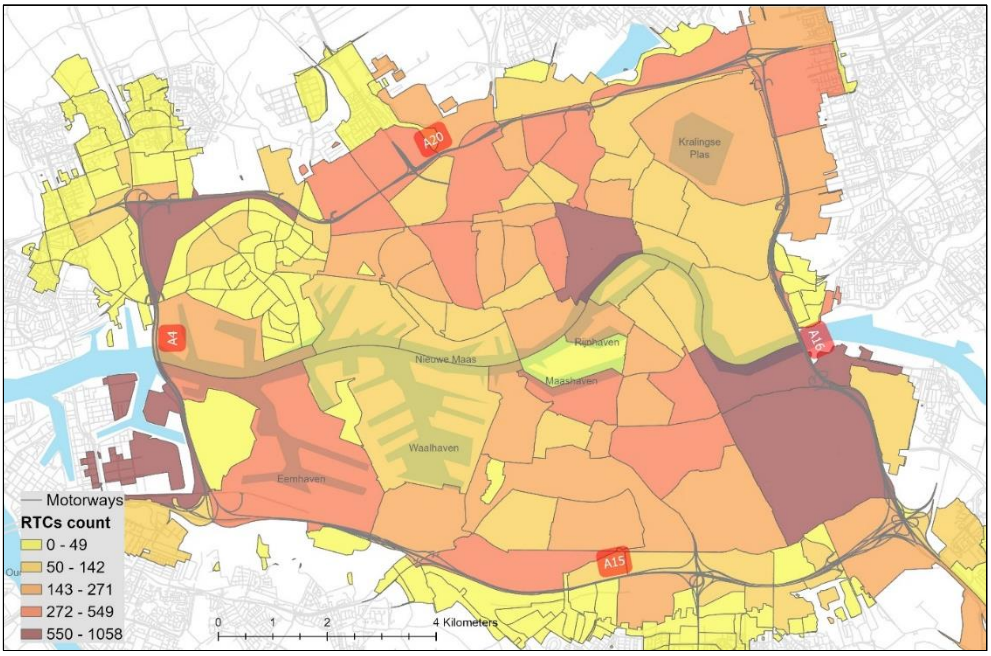
NKDE of RTCs in 2019



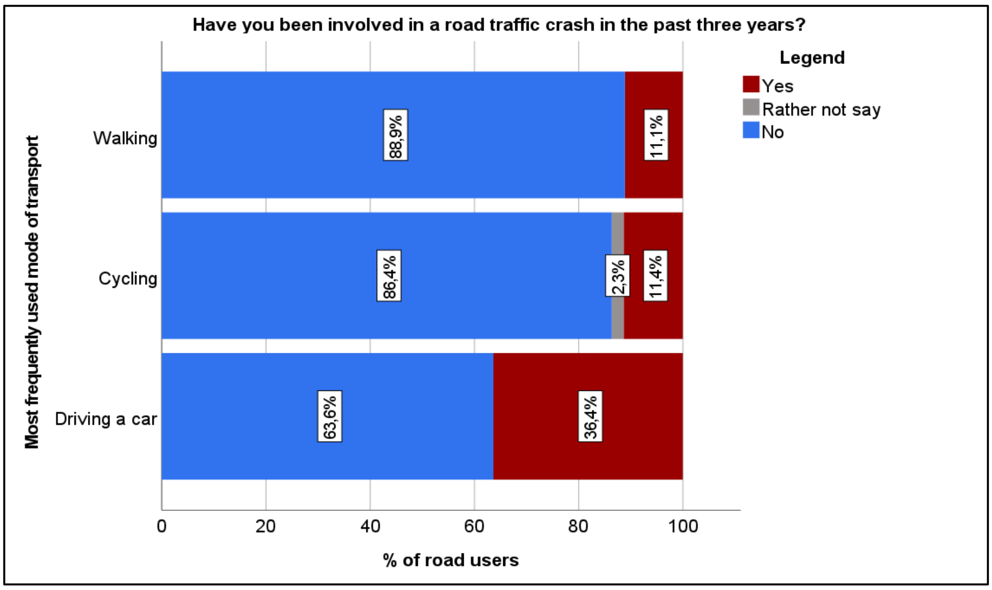
NKDE of RTCs in 2020

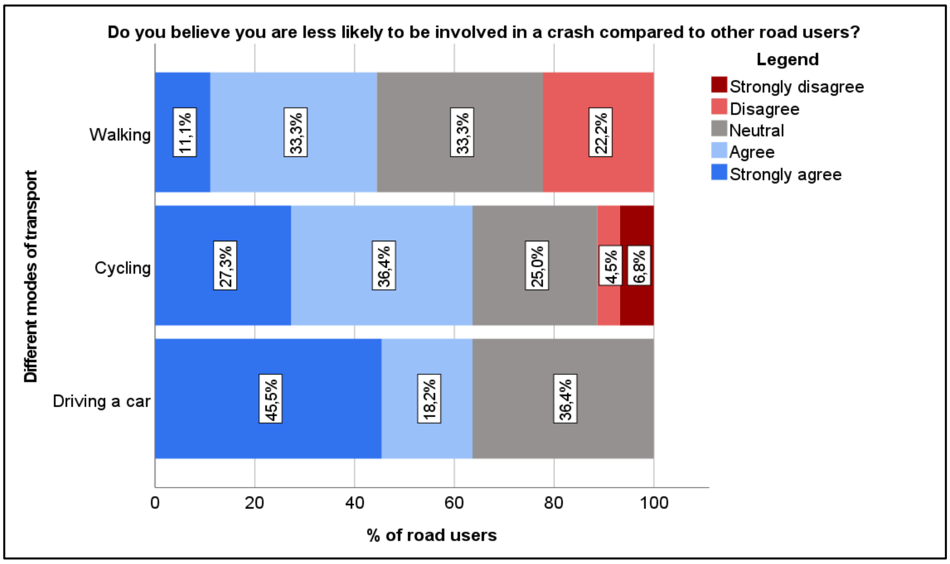
Annexes

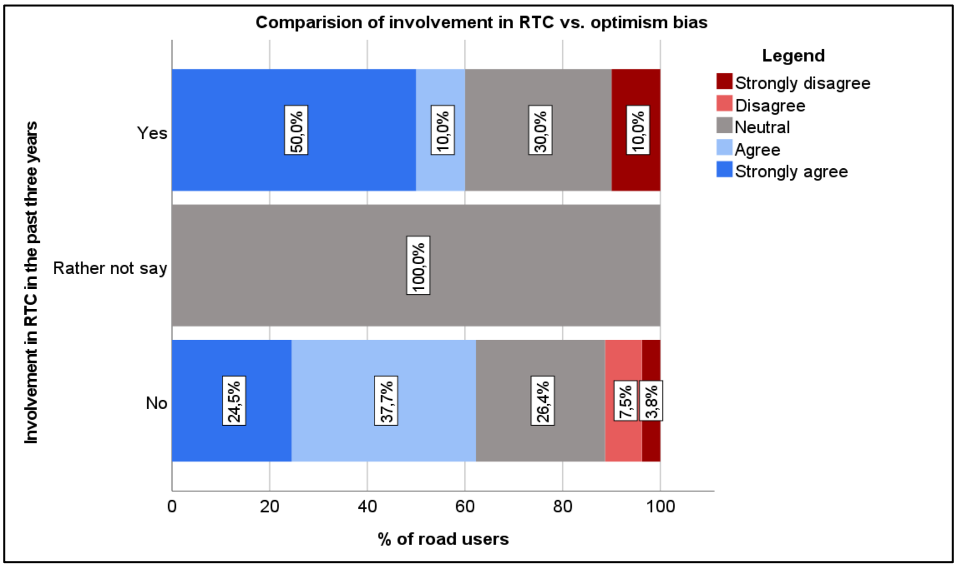
Annex 1: Aggregated counts of RTCs per neighborhood

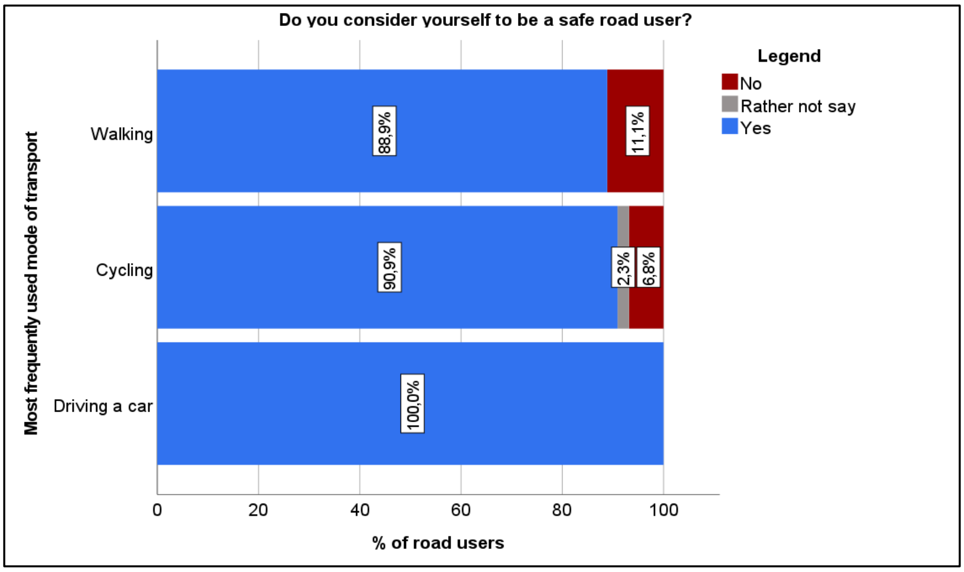


Annex 2: Involvement in RTC and optimism bias




Do you believe you are less likely to be involved in a crash compared to other road users?
Legend
Strongly disagree
Disagree
Neutral
Agree
Strongly agree
Different modes of transport
Walking
Cycling
Driving a car
11,1%
33,3%
33,3%
22,2%
27,3%
36,4%
25,0%
4,5%
6,8%
45,5%
18,2%
36,4%
0
20
40
60
80
100
% of road users

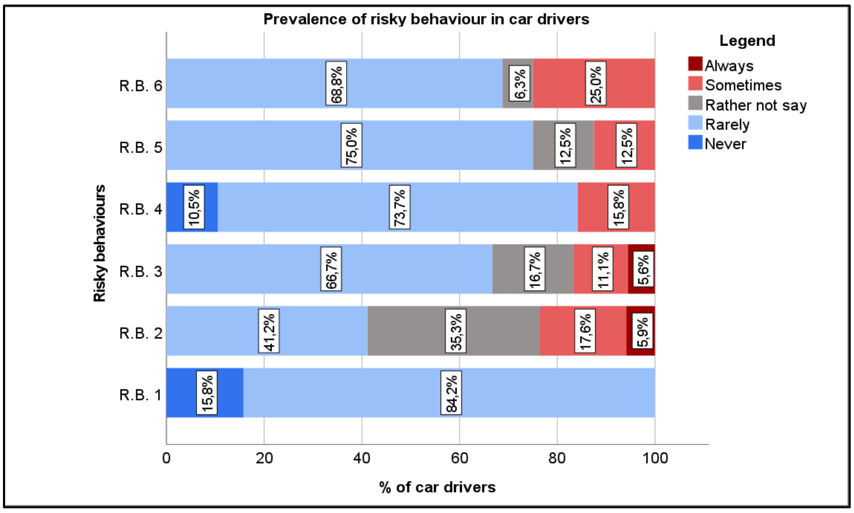

Comparision of involvement in RTC vs. optimism bias
Legend
Strongly disagree
Disagree
Neutral
Agree
Strongly agree
Involvement in RTC in the past three years
Yes
Rather not say
No
50,0%
10,0%
30,0%
10,0%
100,0%
24,5%
37,7%
26,4%
7,5%
3,8%
0
20
40
60
80
100
% of road users


Do you consider yourself to be a safe road user?
Legend
No
Rather not say
Yes
Most frequently used mode of transport
Walking
Cycling
Driving a car
88,9%
11,1%
90,9%
2,3%
6,8%
100,0%
0
20
40
60
80
100
% of road users

Annex 3: Self-declaration of risky behavior (R.B.)

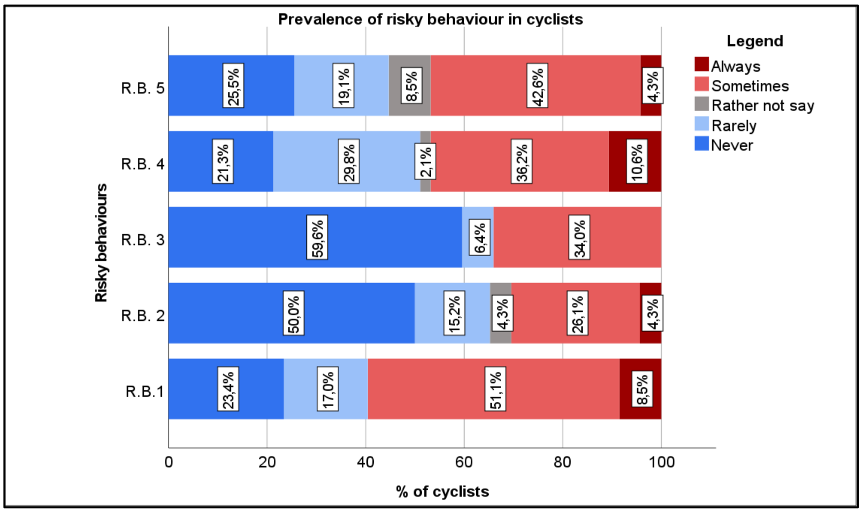
Each of the six bars represents each risky behavior for car drivers as listed below:

R.B.1: Drive through a red light
R.B. 2: Follow the vehicle in front of you too closely
R.B. 3: Make/answer a call with hand-held devices
R.B. 4: Not give way to pedestrians at crossings
R.B. 5: Drive under the influence of alcohol
R.B. 6: Use the wrong side of the road



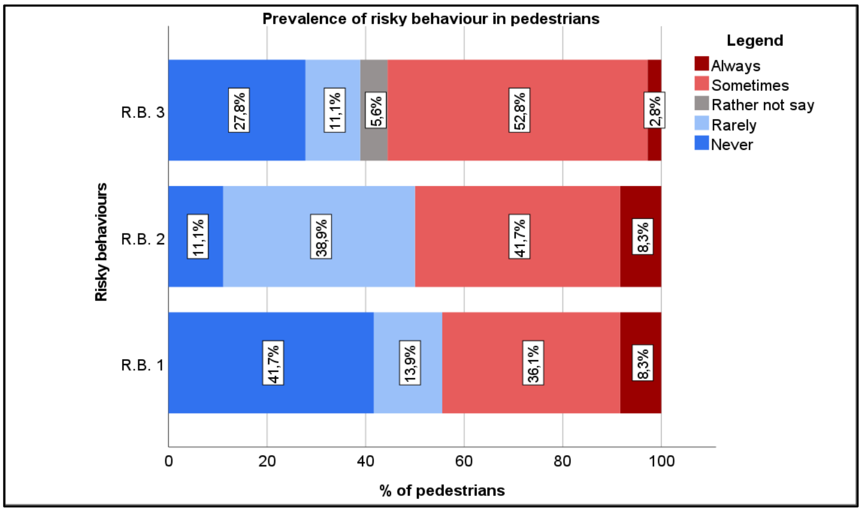
Each of the five bars represents each risky behavior for cyclists as listed below:

R.B.1: Cycle through the red light
R.B. 2: Make/answer a call with hand-held devices
R.B. 3: Not give way to pedestrians at crossings
R.B. 4: Use the wrong side of the road
R.B. 5: Cycle under the influence of alcohol.

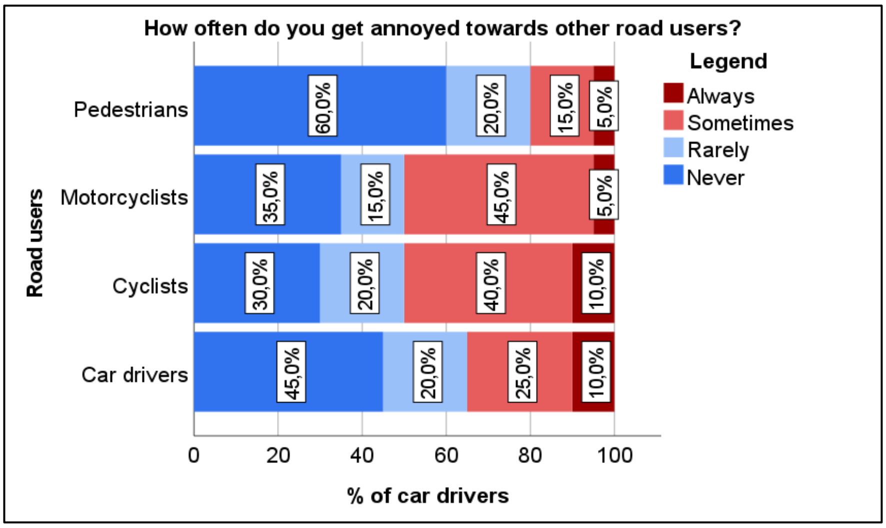


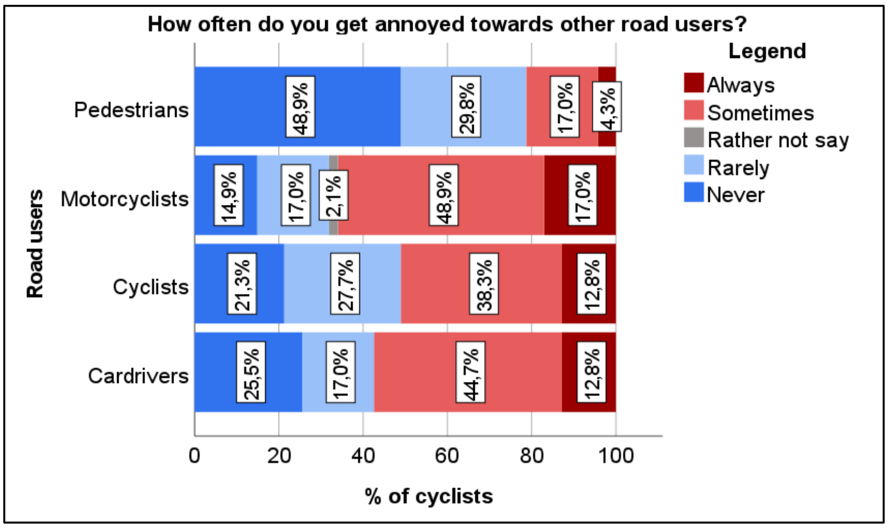
Each of the five bars represents each risky behavior for pedestrians as listed below:

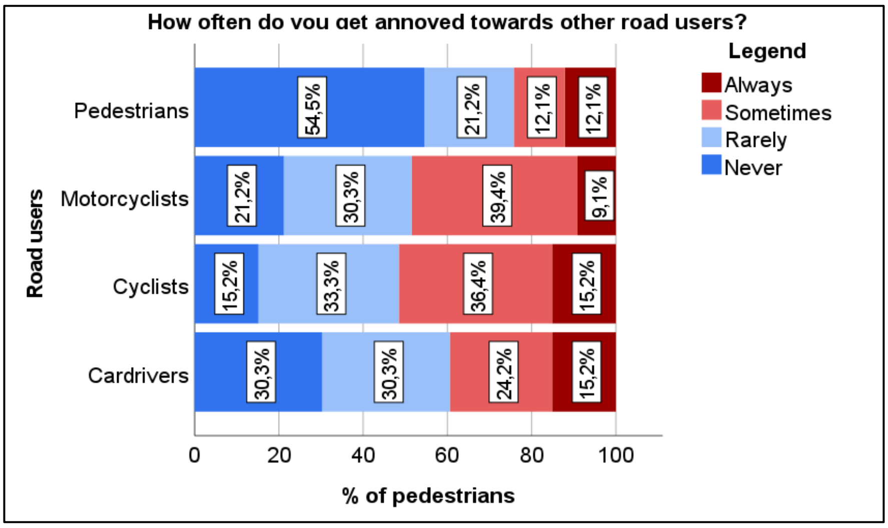
R.B.1: Cross when it is a red light for you
R.B. 2: Walk on the cycle path or carriageway
R.B. 3: Walk when you are under the influence of alcohol



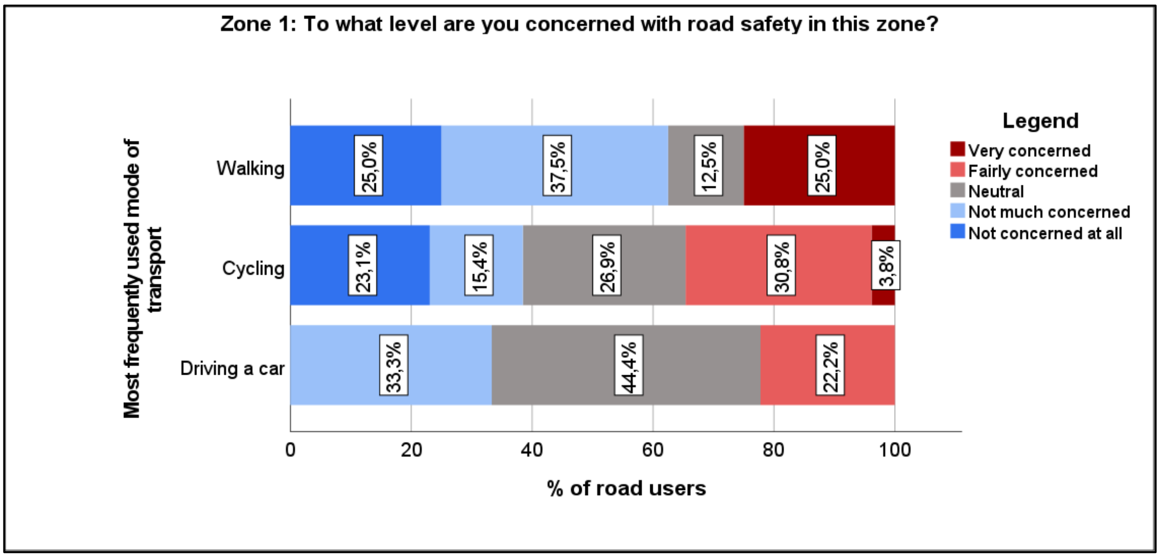
Annex 4: Annoyance towards other road users

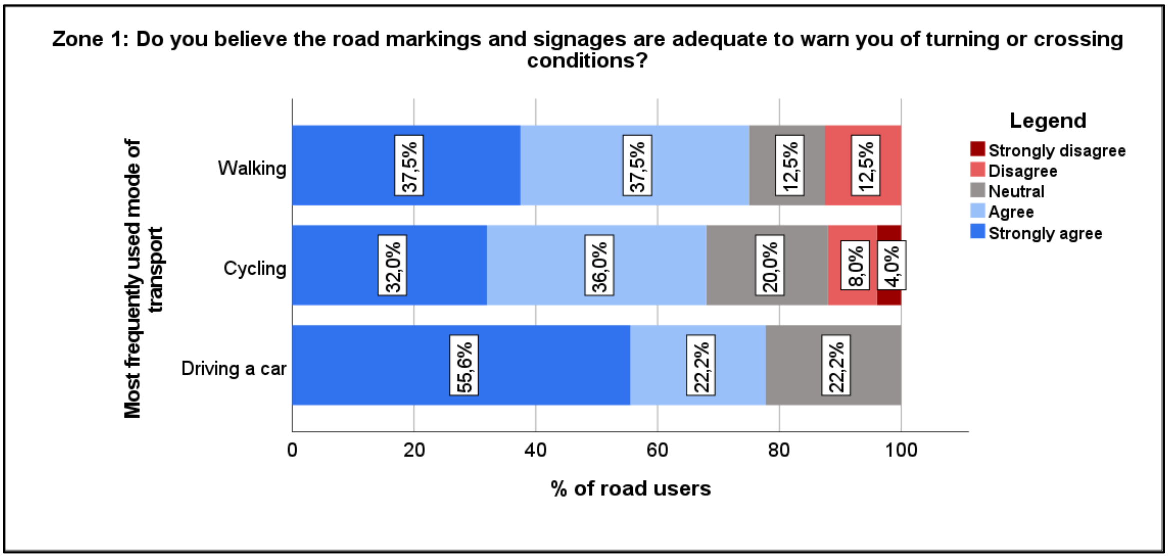


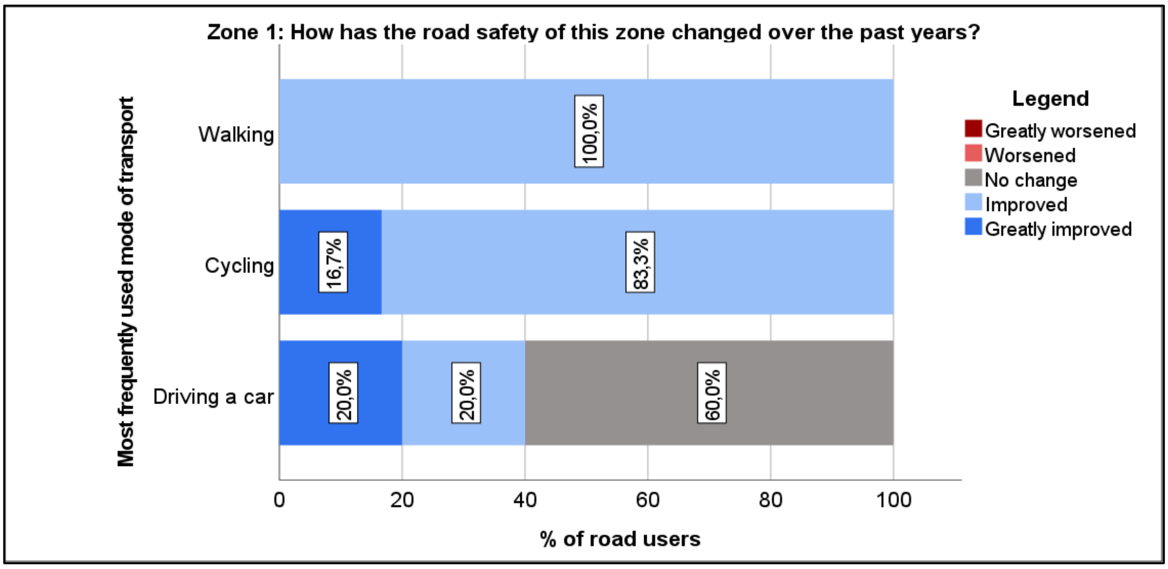


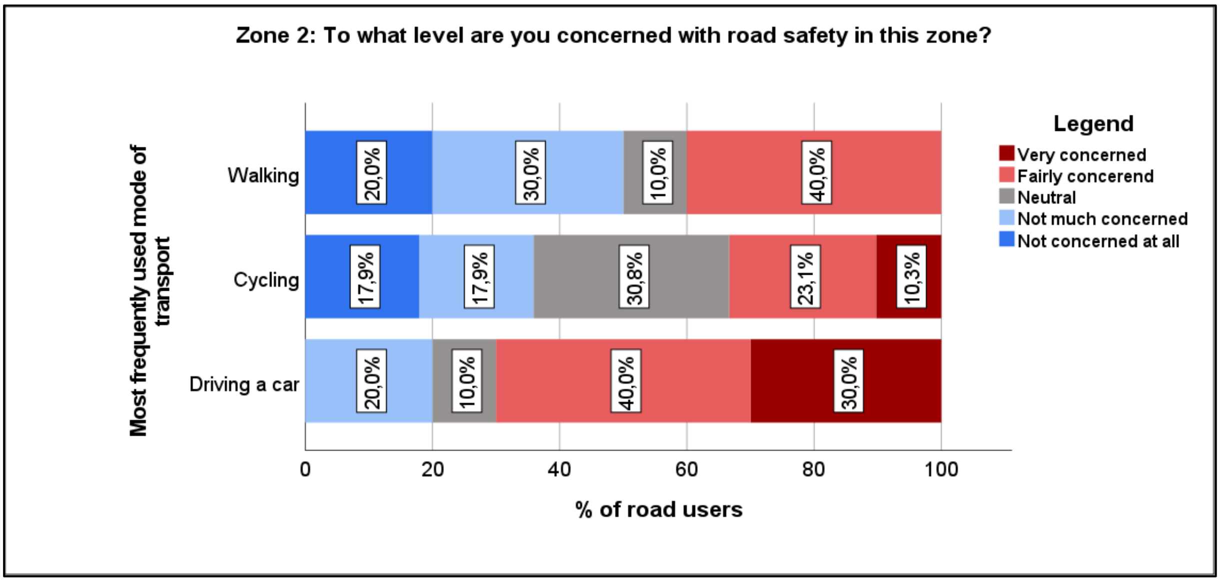


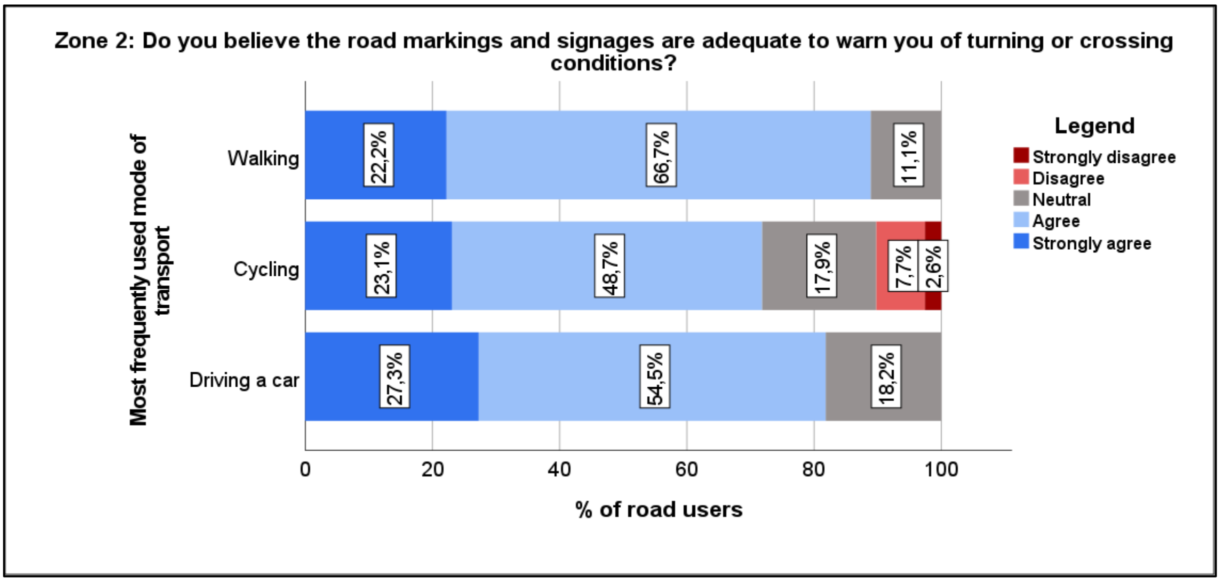
Annex 5: Perception in RTC hotspot zones

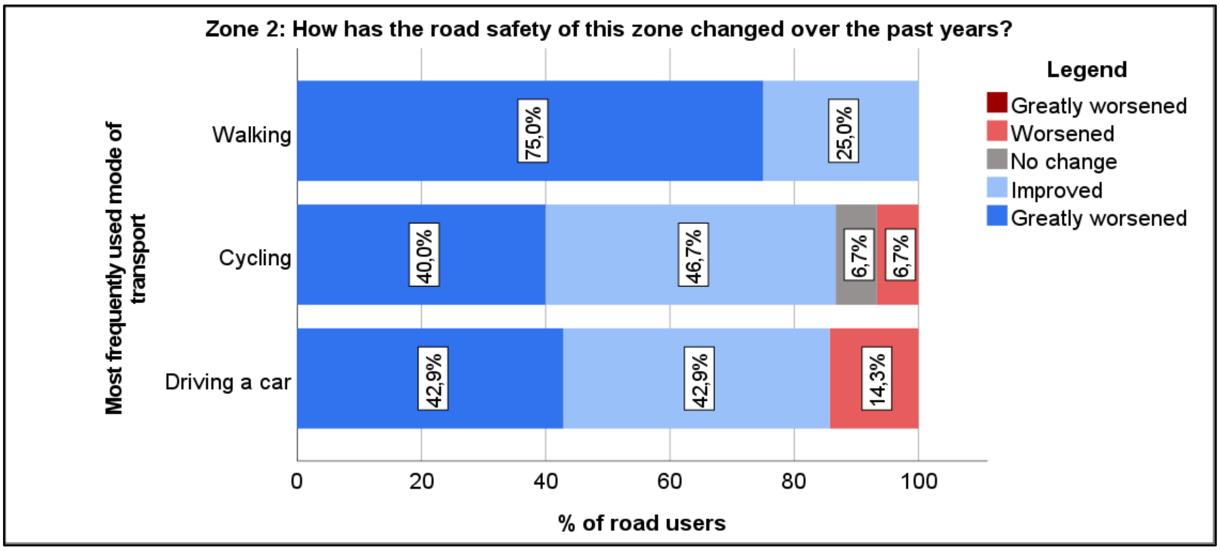




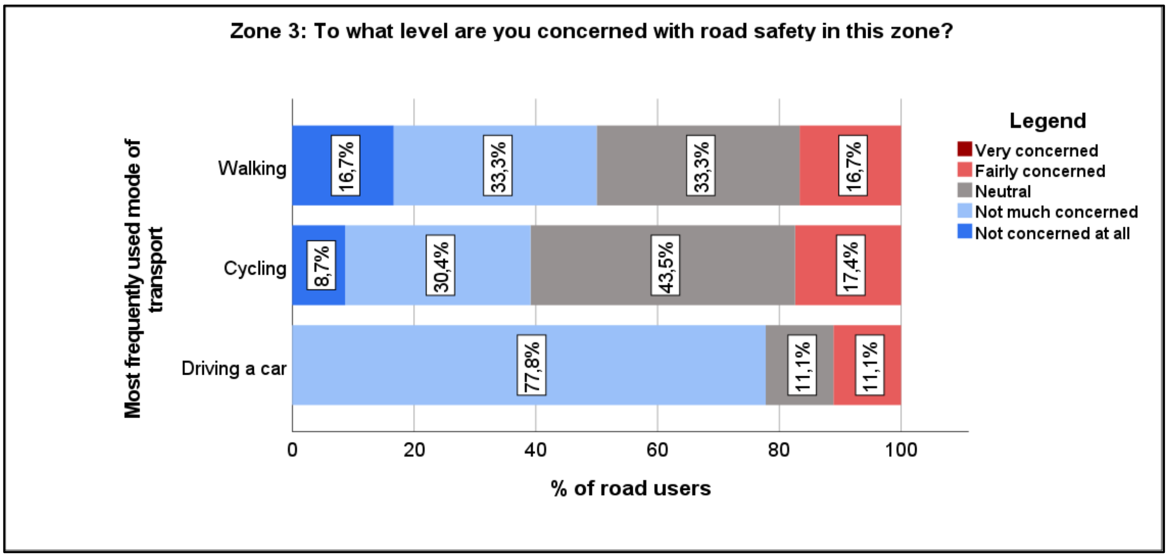


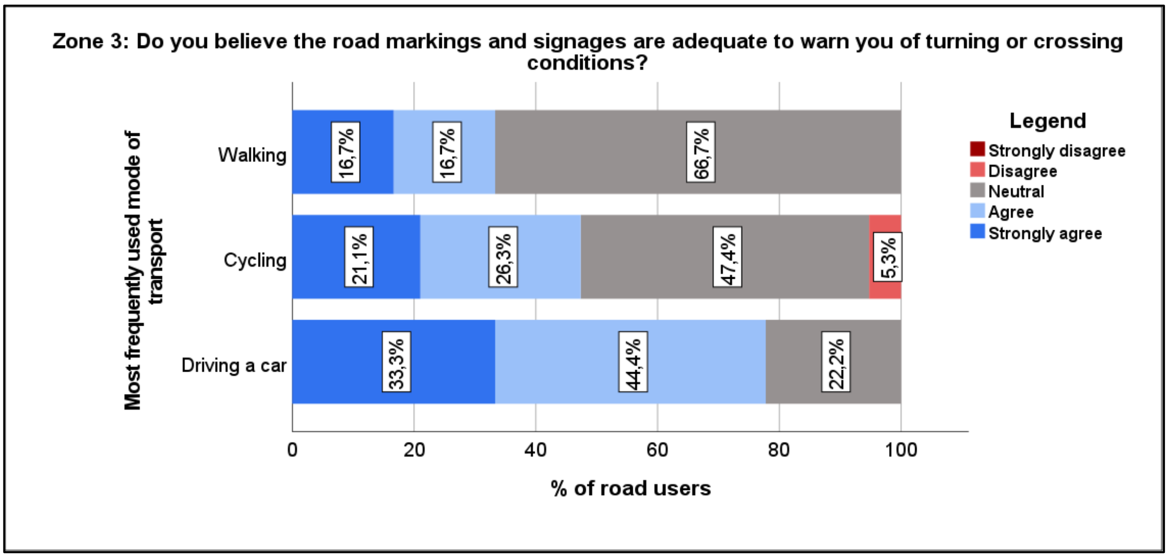

Zone 2: To what level are you concerned with road safety in this zone?
Most frequently used mode of transport
Walking
Cycling
Driving a car
20,0%
30,0%
10,0%
40,0%
17,9%
17,9%
30,8%
23,1%
10,3%
20,0%
10,0%
40,0%
30,0%
0
20
40
60
80
100
% of road users
Legend
Very concerned
Fairly concerend
Neutral
Not much concerned
Not concerned at all

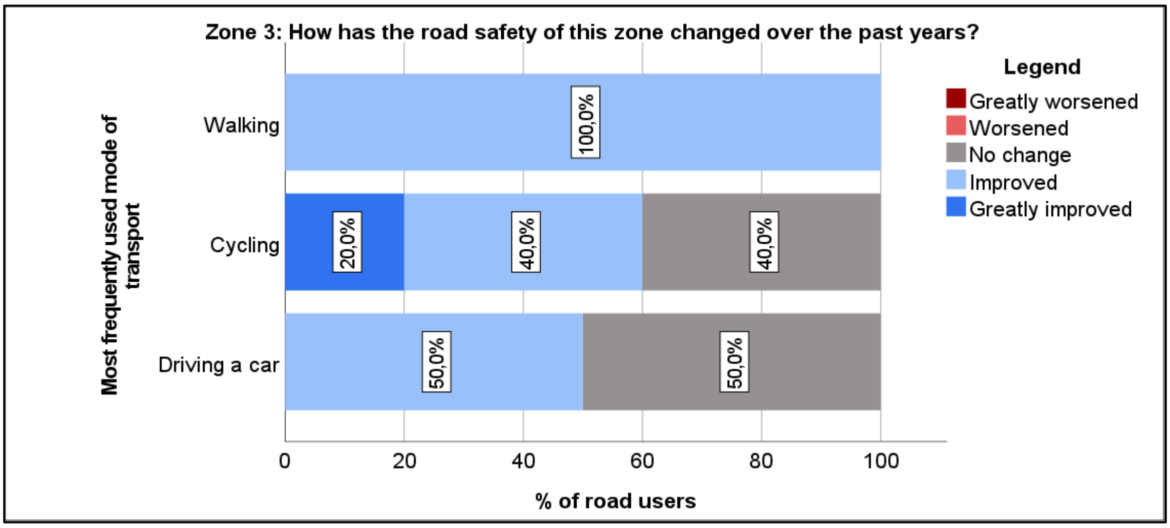

Zone 2: Do you believe the road markings and signages are adequate to warn you of turning or crossing conditions?
Most frequently used mode of transport
Walking
Cycling
Driving a car
22,2%
66,7%
11,1%
23,1%
48,7%
17,9%
7,7%
2,6%
27,3%
54,5%
18,2%
0
20
40
60
80
100
% of road users
Legend
Strongly disagree
Disagree
Neutral
Agree
Strongly agree

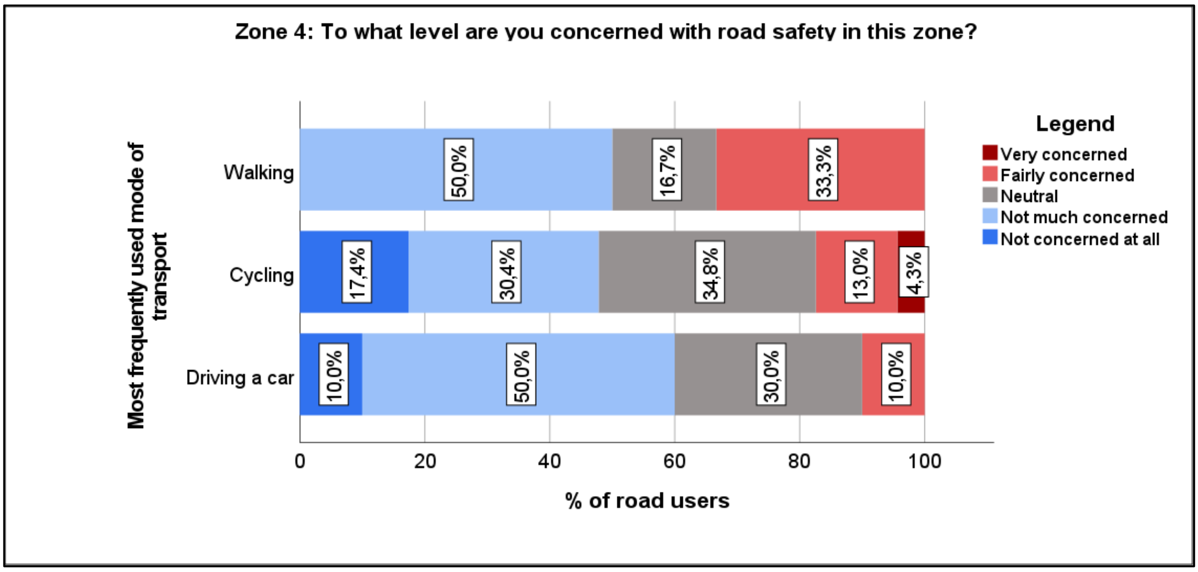

Zone 2: How has the road safety of this zone changed over the past years?
Most frequently used mode of transport
Walking
Cycling
Driving a car
75,0%
25,0%
40,0%
46,7%
6,7%
6,7%
42,9%
42,9%
14,3%
0
20
40
60
80
100
% of road users
Legend
Greatly worsened
Worsened
No change
Improved
Greatly worsened

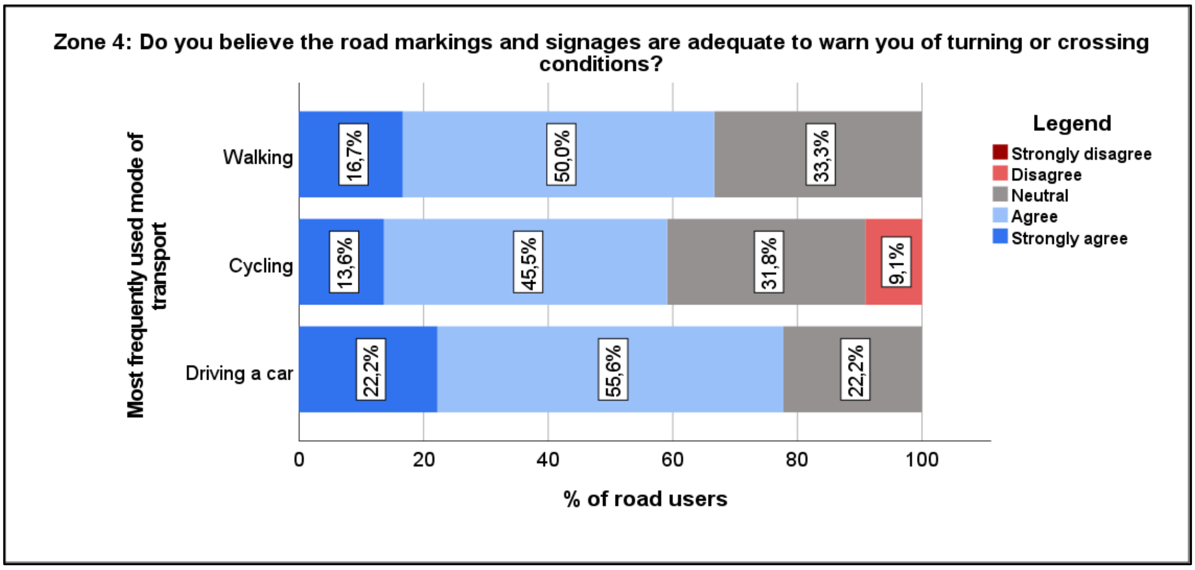
Annex 6: Perception in RTC coldspot zones

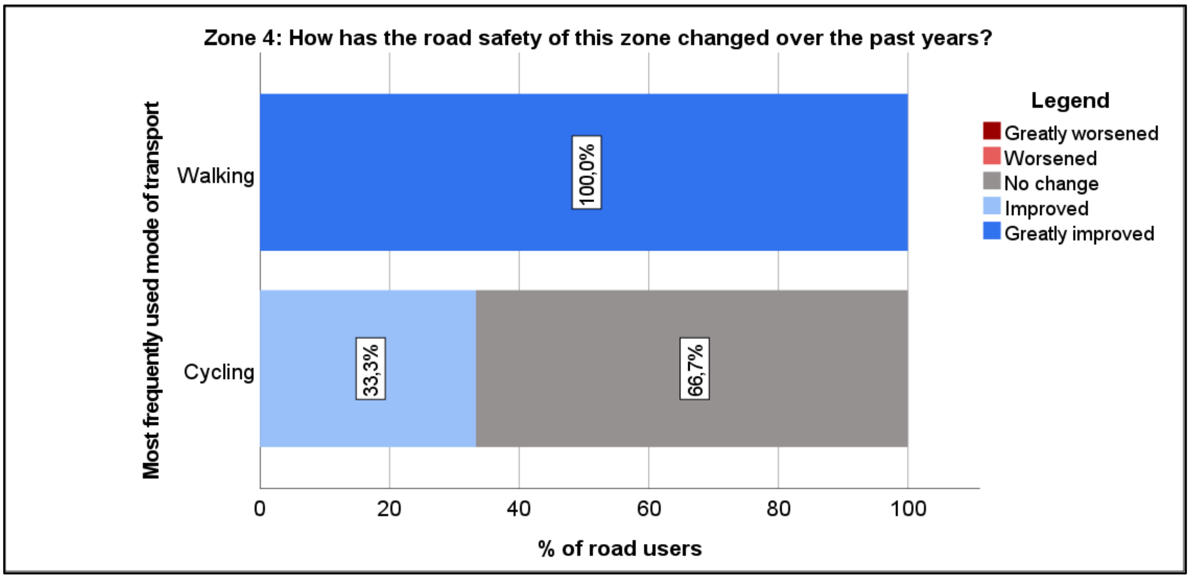




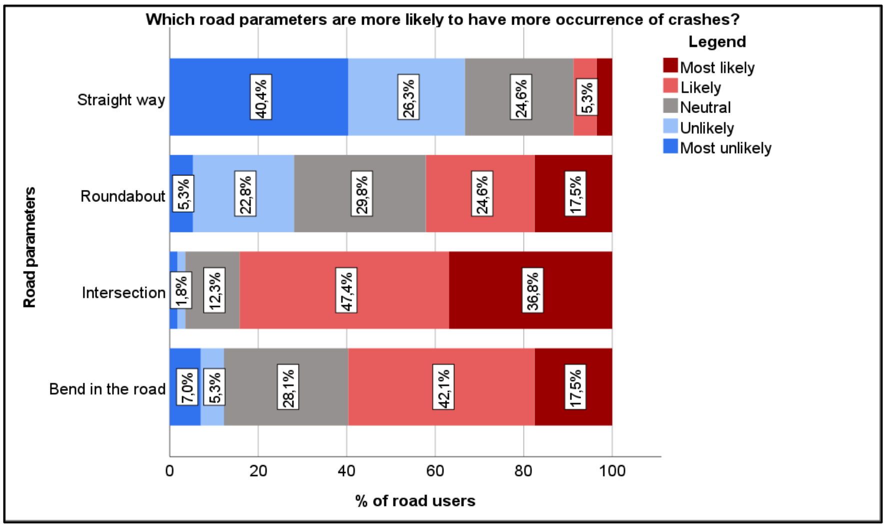


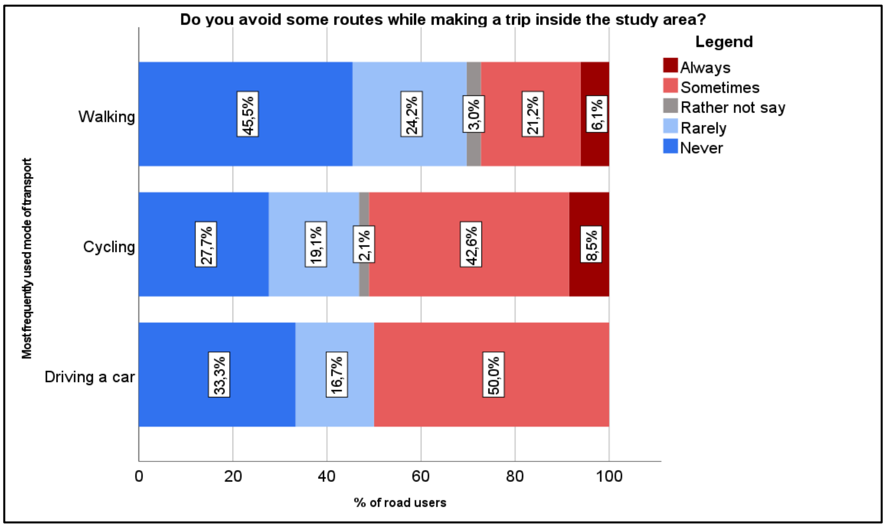

Zone 4: To what level are you concerned with road safety in this zone?
Most frequently used mode of transport
Walking
Cycling
Driving a car
50,0%
16,7%
33,3%
17,4%
30,4%
34,8%
13,0%
4,3%
10,0%
50,0%
30,0%
10,0%
0
20
40
60
80
100
% of road users
Legend
Very concerned
Fairly concerned
Neutral
Not much concerned
Not concerned at all

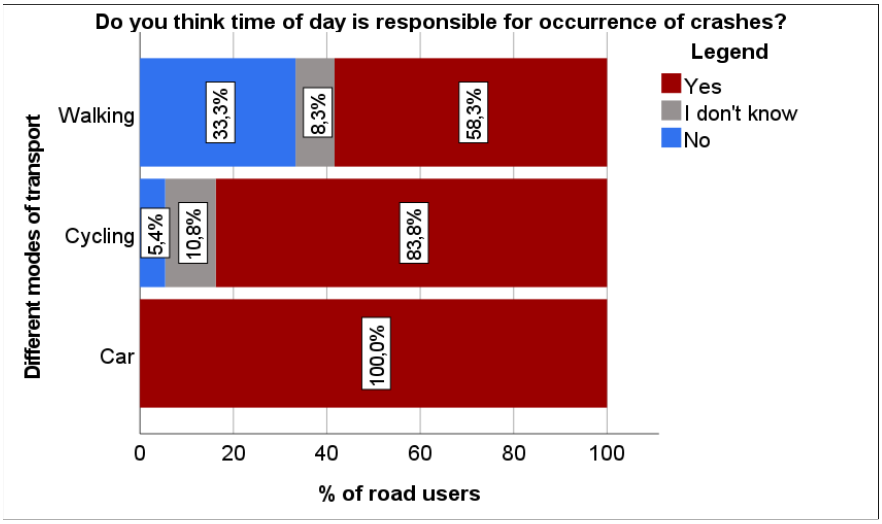

Zone 4: Do you believe the road markings and signages are adequate to warn you of turning or crossing conditions?
Most frequently used mode of transport
Walking
Cycling
Driving a car
16,7%
50,0%
33,3%
13,6%
45,5%
31,8%
9,1%
22,2%
55,6%
22,2%
0
20
40
60
80
100
% of road users
Legend
Strongly disagree
Disagree
Neutral
Agree
Strongly agree


Zone 4: How has the road safety of this zone changed over the past years?
Most frequently used mode of transport
Walking
Cycling
100,0%
33,3%
66,7%
0
20
40
60
80
100
% of road users
Legend
Greatly worsened
Worsened
No change
Improved
Greatly improved

Annex 7: Road users' understanding of the specific road parameters and their relation with RTCs







Annex 8: Attitudes towards existing policies (E.P.)

Each of the ten bars represents each existing policy for car drivers as listed below

E.P. 1: Increased penalty for drunk driving

E.P. 2: Lower blood alcohol limit for novice drivers (0.2%, compared to 0.5% for experienced drivers)

E.P. 3: License suspension for repeat offenders of drinking and driving

E.P. 4: Decreased speed limit on motorways to 100 km/hr (from 130 km/hr)

E.P. 5: Designated driver campaign (Bob)

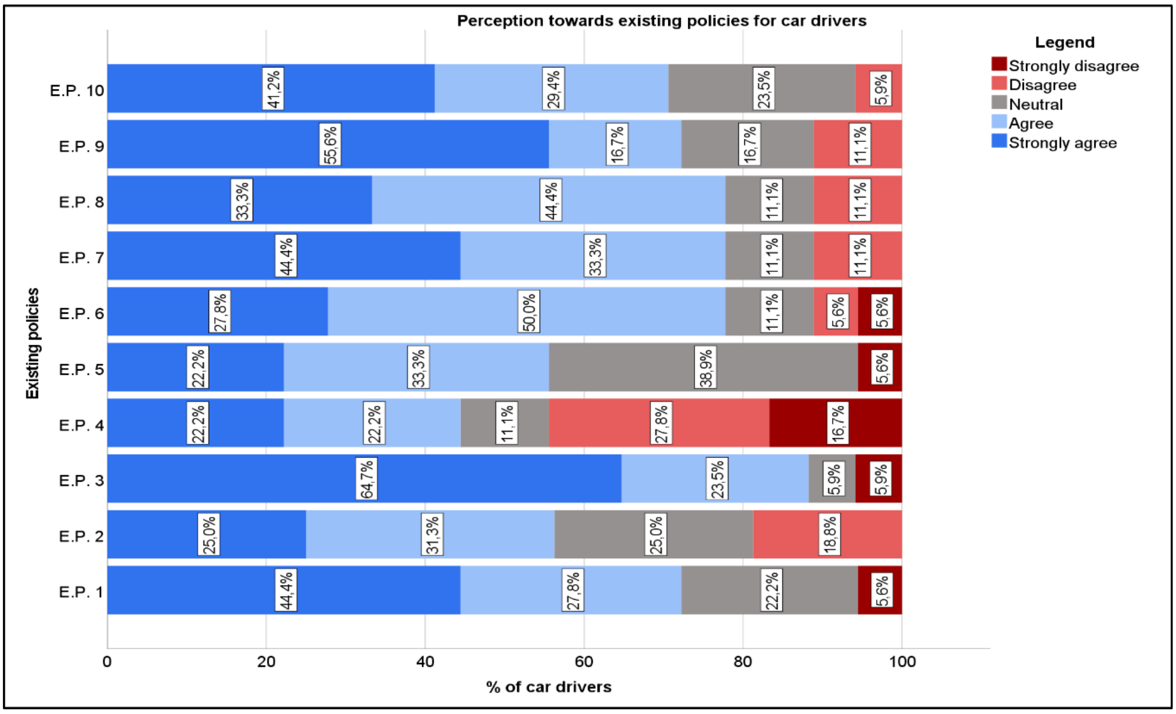
E.P. 6: Awareness courses for offenders of drink-driving

E.P. 7: Penalty for using a handheld device while using the road

E.P. 8: Penalty for being on the wrong side of the road

E.P. 9: Penalty for not having a license

E.P. 10: Penalty for not using the seat belt



Each of the five bars represents each existing policy for cyclists as listed below

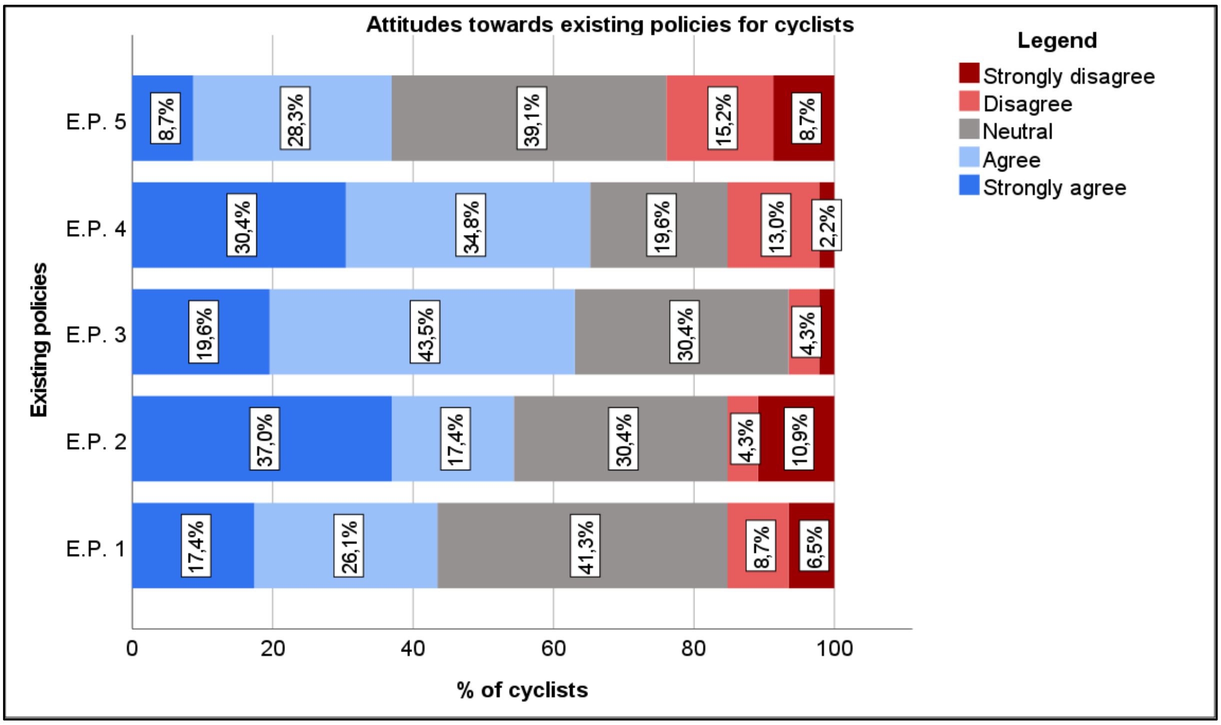
E.P. 1: Penalty for crossing when there is a red light on for a cyclist

E.P. 2: Penalty for blood alcohol levels above the limit

E.P. 3: Penalty for driving without bike lights in the dark

E.P. 4: Penalty for using a handheld device while using the road

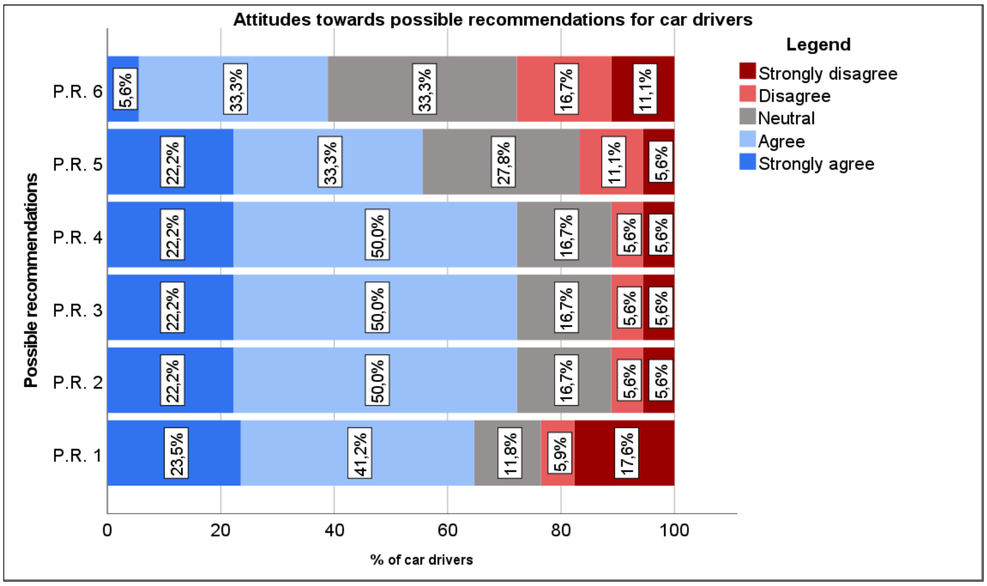
E.P. 5: Penalty for cycling on the wrong side



Annex 9: Attitudes towards possible recommendations (P.R.)

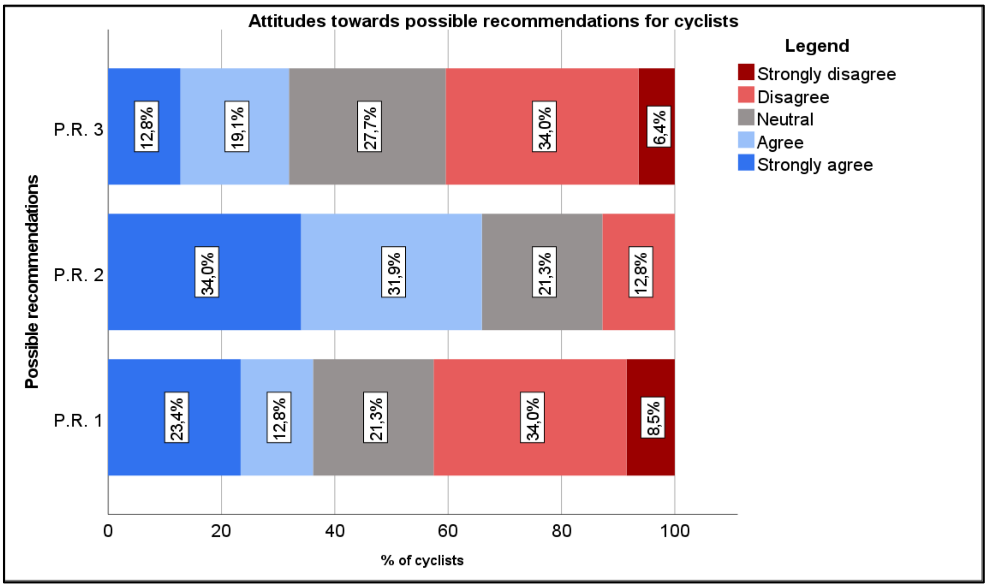
Each of the six bars represents each possible recommendation for car drivers, as listed below.

P.R. 1: Installing Speed limiting devices in your vehicle
P.R. 2: Alcolock for previous offenders
P.R. 3: Installing a black box for identifying the cause of the accident
P.R. 4: Fatigue detection devices
P.R. 5: Demerit point system (Progressive penalties based on the frequency of offenses)
P.R. 6: Use of semi/fully automated cars

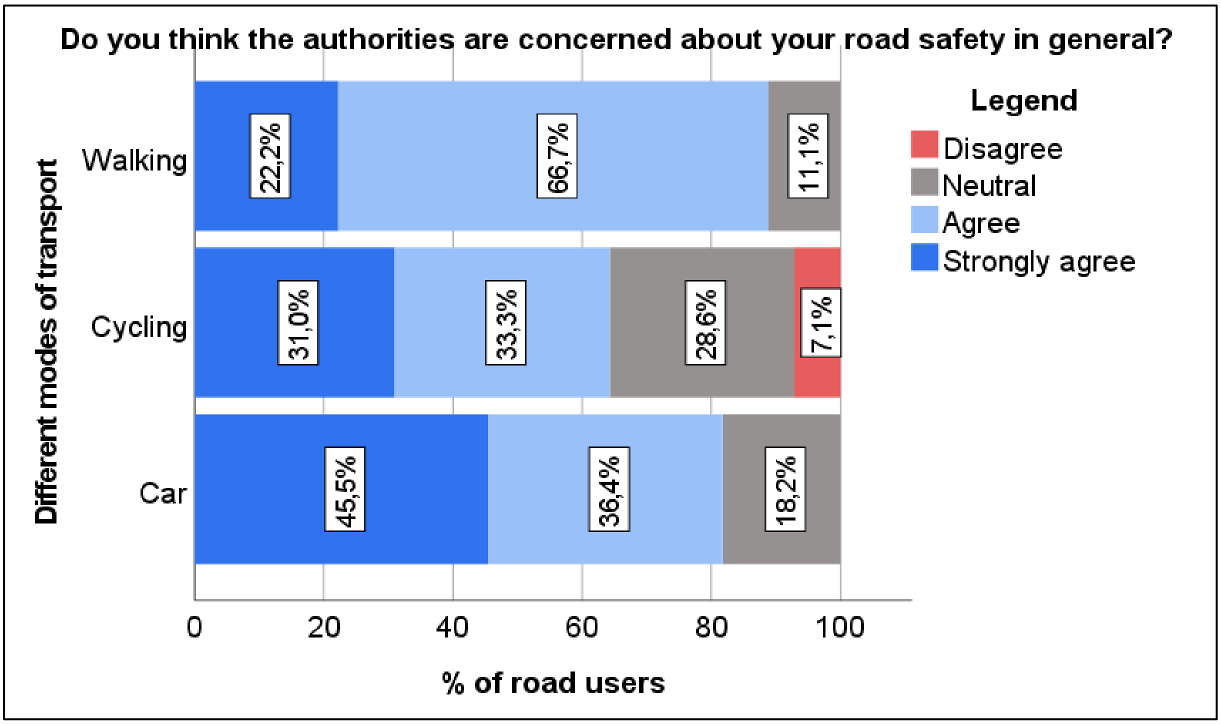


Each of the six bars represents each possible recommendation for cyclists as listed below.

P.R. 1: Use of a helmet
P.R. 2: Use of reflective materials to be seen in the dark (reflective tape on your bike or jacket)
P.R. 3: Adding rear-view mirrors to your cycle handlebars



Attitudes towards government/authorities



Annex 10: Questionnaire in English

(Link for the questionnaire in the Dutch language: https://ee.kobotoolbox.org/x/9u0gOeYR)

Face-to-face questionnaire in Rotterdam (Picture taken on: 08 February 2022)

(Questionnaire begins on next page)

English version: Spatial analysis of crashes from road users' perspective: A case study of Rotterdam municipality and surrounding conurbation

How long have you been living in Rotterdam (or the surrounding urban areas)?

____

1. Transport-related details

1.1 Which of the following modes do you use? Select all that apply to you. (If you use public transport, select the mode you use to reach the public transport)

- ☐ Car
- ☐ Cycling
- ☐ Walking

1.2 Which is the most frequent mode? (among the ones you chose)

____

1.3 If you use public transport, please specify the type.

____

1.4 Please specify how often you use car for transportation (in a week).

____

1.5 Please specify how often you cycle for transportation (in a week).

____

1.6 Please specify how often you walk in a week.

____

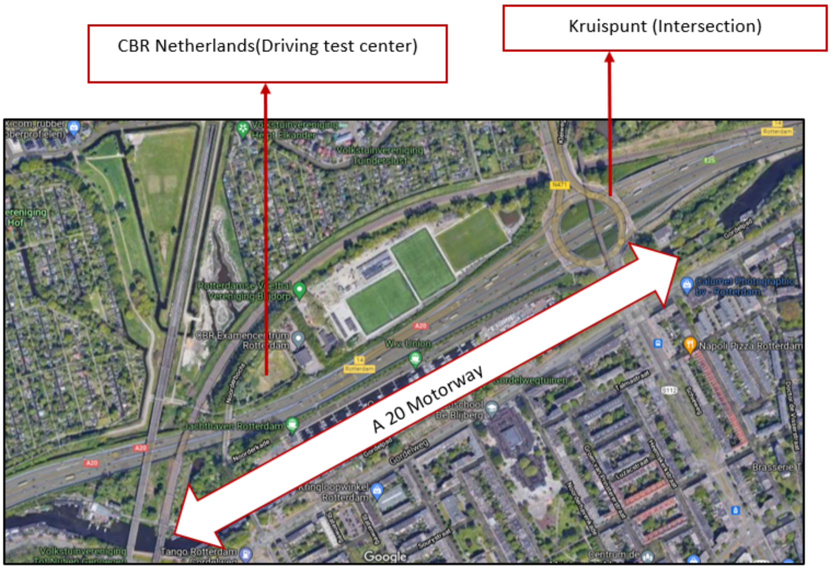
2. Perception towards road parameters

Now, you will see series of questions regarding road safety in specific zones in Rotterdam. You can skip if you do not know the zones well enough..

____

» 2.1 Zone 1

Zone 1: Road stretch from the intersection near the football ground on the A20 highway till train overpass near the driving test center



To what level are you concerned with the road safety in zone 1?	Very	Fairly	Neutral	Not much	Not at all
Zone 1	○	○	○	○	○

Would you like to add some points on why you consider this zone to be safe/ unsafe?

Do you believe the road markings and signages in this zone are adequate to warn/inform you of crossing or turning conditions?	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
Zone 1	○	○	○	○	○

If you disagreed, can you please explain why? Other comments?

Do you know if the safety of this zone has changed over the years?

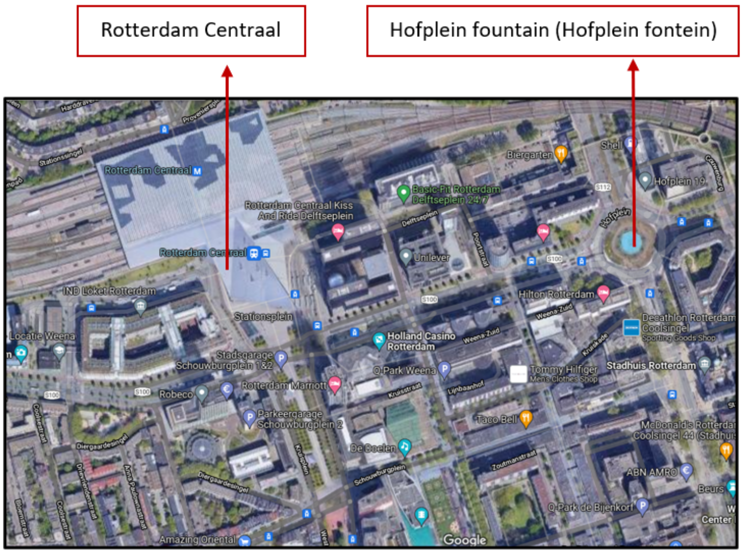
- ○ Yes
- ○ No
- ○ I don't know

How has the safety of this zone improved over the past years?	Greatly improved	Improved	No change	Worsened	Greatly worsened
Zone 1	○	○	○	○	○

In what way has the road safety changed in this zone? Please give some examples (eg: addition of signs or wider roads)

» 2.2 Zone 2

Zone 2: Way from Rotterdam central train station to Hofplein fountain rotary (around Hilton Rotterdam



To what level are you concerned with the road safety in zone 2?	Very	Fairly	Neutral	Not much	Not at all
Zone 2	○	○	○	○	○

Would you like to add some points on why you consider this zone to be safe/ unsafe?

Do you believe the road markings and signages in this zone are adequate to warn/inform you of crossing or turning conditions?	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
Zone 2	○	○	○	○	○

If you disagreed, can you please explain why? Other comments?

Do you know if the safety of this zone has changed over the years?

- ○ Yes
- ○ No
- ○ I don't know

How has the safety of this zone improved over the past years?	Greatly improved	Improved	No change	Worsened	Greatly worsened
Zone 2	○	○	○	○	○

In what way has the road safety changed in this zone? Please give some examples (eg: addition of signs or wider roads)

» 2.3 Zone 3

Zone 3: The ring road inside Groot-IJsselmondse ,outside Park De Twee Heuvels

To what level are you concerned with the road safety in the following zone 3?	Very	Fairly	Neutral	Not much	Not at all
Zone 3	○	○	○	○	○

Would you like to add some points on why you consider this zone to be safe/ unsafe?

Do you believe the road markings and signages in this zone are adequate to warn/inform you of crossing or turning conditions?	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
Zone 3	○	○	○	○	○

If you disagreed, can you please explain why? Other comments?

Do you know if the safety of this zone has changed over the years?

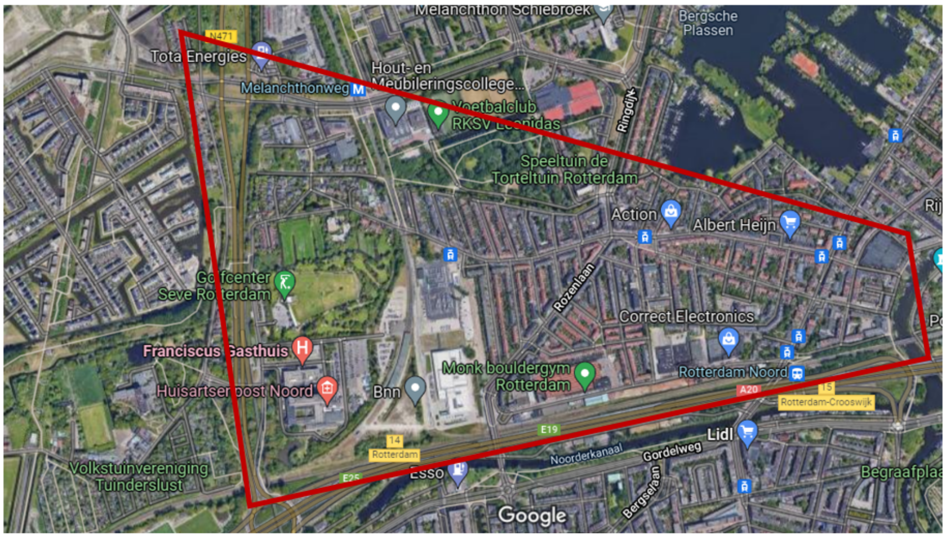
- ○ Yes
- ○ No
- ○ I don't know

How has the safety of this zone improved over the past years?	Greatly improved	Improved	No change	Worsened	Greatly worsened
Zone 3	○	○	○	○	○

In what way has the road safety changed in this zone? Please give some examples (eg: addition of signs or wider roads)

» 2.4 Zone 4

Zone 4: Inside the Hillegersberg Zuid area



To what level are you concerned with the road safety in the following zone 4?	Very	Fairly	Neutral	Not much	Not at all
Zone 4	◯	◯	◯	◯	◯

Would you like to add some points on why you consider this zone to be safe/ unsafe?

Do you believe the road markings and signages in this zone are adequate to warn/inform you of crossing or turning conditions?	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
Zone 4	◯	◯	◯	◯	◯

If you disagreed, can you please explain why? Other comments?

Do you know if the safety of this zone has changed over the years?

- ◯ Yes
- ◯ No
- ◯ I don't know

How has the safety of this zone improved over the past years?	Greatly improved	Improved	No change	Worsened	Greatly worsened
Zone 4	◯	◯	◯	◯	◯

In what way has the road safety changed in this zone? Please give some examples (eg: addition of signs or wider roads)

Now you will see questions about roads in general (about the the roads you use daily, not specific zones)

2.5 Which road parameters in your opinion are most probable to have higher number of crashes?	Most likely	Likely	Neutral	Unlikely	Most unlikely
Straight way	◯	◯	◯	◯	◯
Bend in the road	◯	◯	◯	◯	◯
Intersection	◯	◯	◯	◯	◯
Roundabout	◯	◯	◯	◯	◯

2.6 Do you think time of the day is responsible for accidents?

- ◯ Yes
- ◯ No
- ◯ I don't know

Can you please explain why?

____

2.7 If you have been involved in an accident before, which road parameter was involved with it?

____

3. For car users

» 3.1 Self declaration of risky behavior

When driving a car, how often do you...? *Self-declaration of risky behavior*	Always	Sometimes	Rarely	Never	Rather not say
Drive through red light	◯	◯	◯	◯	◯
Follow the vehicle in front of you too closely	◯	◯	◯	◯	◯
Make/answer a call with hand-held devices	◯	◯	◯	◯	◯
Give way to pedestrians at crossings	◯	◯	◯	◯	◯
Drive under influence of alcohol	◯	◯	◯	◯	◯
Use the wrong side of the road	◯	◯	◯	◯	◯

» 3.2 Attitudes towards existing policies

Which of these are you in favor of? *Existing policies/rules*	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
Increased penalty for drink driving	◯	◯	◯	◯	◯
Lower blood alcohol limit for novice drivers (0.2%, compared to 0.5% for experienced drivers)	◯	◯	◯	◯	◯
License suspension for repeat offenders of drinking and driving	◯	◯	◯	◯	◯

Decreased speed limit on motorways to 100 km per hour (from 130 km per hour)	◯	◯	◯	◯	◯
Designated driver campaign (Bob)	◯	◯	◯	◯	◯
Awareness courses for offenders of drink-driving	◯	◯	◯	◯	◯
Use of side shield to prevent serious collision with a pedestrian in cars/trucks	◯	◯	◯	◯	◯
Penalty for using a handheld device while using the road	◯	◯	◯	◯	◯
Penalty for being on wrong side of the road	◯	◯	◯	◯	◯
Penalty for not having a license	◯	◯	◯	◯	◯
Penalty for not using seat belt	◯	◯	◯	◯	◯

If you disagreed/ strongly disagreed to any of the above, can you give the reason why? Other comments?

____

» 3.3 Attitudes towards other road users

How often do you..? *Perception to other road users*	Always	Sometimes	Rarely	Never	Rather not say
Get very annoyed with car drivers	◯	◯	◯	◯	◯
Get very annoyed with cyclists	◯	◯	◯	◯	◯
Get very annoyed with pedestrians	◯	◯	◯	◯	◯
Get very annoyed with motorcyclists	◯	◯	◯	◯	◯

» 3.4 Avoiding routes

How often do you avoid certain road sections because in your opinion they are dangerous? *Perception to road parameters*	Always	Sometimes	Rarely	Never	Rather not say
Avoiding certain routes	◯	◯	◯	◯	◯

Can you specify which road section that is?

____

» 3.5 Attitudes towards possible recommendations

Are you in favor of using the following? *Possible recommendations*	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
Installing Speed limiting devices in your vehicle	◯	◯	◯	◯	◯
Alcolock for previous offenders	◯	◯	◯	◯	◯
Installing a black box for identifying cause of accident	◯	◯	◯	◯	◯

Fatigue detection devices	○	○	○	○	○
Demerit point system (Progressive penalties based on frequency of offences)	○	○	○	○	○
Use of semi/fully automated cars(This could lead to reduced severity and occurrence of crashes)	○	○	○	○	○

If you disagreed/ strongly disagreed to any of the above, can you give the reason why? Other comments?

____

4. For cyclists

» 4.1 Self declaration of risky behavior

How often do you...? *Self-declaration of risky behaviour*	Always	Sometimes	Rarely	Never	Rather not say
Cross a road at red light	○	○	○	○	○
Make/answer a call with hand-held devices	○	○	○	○	○
Give way to pedestrians at crossings	○	○	○	○	○
Cycle in wrong path/direction	○	○	○	○	○
Cycle under the influence of alcohol	○	○	○	○	○

» 4.2 Attitudes towards existing policies

What are your opinions on current penalties for following offences? *Existing policies/rules*	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
Penalty for crossing when there is red light on for cyclist	○	○	○	○	○
Penalty for Blood alcohol levels above limit	○	○	○	○	○
Penalty for driving without bike lights in the dark	○	○	○	○	○
Penalty for using a handheld device while using the road (except while walking)	○	○	○	○	○
Penalty for cycling on wrong side	○	○	○	○	○

If you disagreed/ strongly disagreed to any of the above, can you give the reason why? Other comments?

____

» 4.3 Attitudes towards other road users

How often do you..? *Perception to other road users*	Always	Sometimes	Rarely	Never	Rather not say
Get very annoyed with car drivers	○	○	○	○	○

Get very annoyed with cyclists	○	○	○	○	○
Get very annoyed with pedestrians	○	○	○	○	○
Get very annoyed with motorcyclists	○	○	○	○	○

» 4.4 Avoiding routes

How often do you avoid certain road section because in your opinion they are dangerous? *Perception to road parameters*	Always	Sometimes	Rarely	Never	Rather not say
Avoiding certain routes	○	○	○	○	○

Can you specify which road section that is?

____

» 4.5 Attitudes towards possible recommendations

Which of these are you in favor of? *Possible recommendations*	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
Use of a helmet	○	○	○	○	○
Use of reflective materials to be seen in the dark (reflective tape in your bike or jacket)	○	○	○	○	○
Adding rear-view mirrors in your cycle handlebars	○	○	○	○	○

If you disagreed/strongly disagreed to any of the above, can you give the reason why? Other comments?

____

5. For pedestrians

» 5.1 Self declaration of risky behavior

How often do you..? *Self-declaration of risky behaviour*	Always	Sometimes	Rarely	Never	Rather not say
Cross when it is red light for you	○	○	○	○	○
Walk on the cycle path or carriageway	○	○	○	○	○
Walk when you are under influence of alcohol	○	○	○	○	○

» 5.2 Attitudes towards other road users

How often do you..? *Perception to other road users*	Always	Sometimes	Rarely	Never	Rather not say
Get very annoyed with car drivers	○	○	○	○	○
Get very annoyed with cyclists	○	○	○	○	○

Get very annoyed with pedestrians	◯	◯	◯	◯	◯
Get very annoyed with motorcyclists	◯	◯	◯	◯	◯

» 5.3 Avoiding routes

How often do you avoid certain road section because in your opinion they are dangerous? *Perception to road parameters*	Always	Sometimes	Rarely	Never	Rather not say
Avoiding certain routes	◯	◯	◯	◯	◯

Can you specify which road section that is?

____

6. Demographics

6.1 Please select your age range

- ◯ Younger than 17
- ◯ 17-26
- ◯ 27-36
- ◯ 37-46
- ◯ 47-56
- ◯ 57-66
- ◯ 67-76
- ◯ Older than 76
- ◯ Rather not say

6.2 Please select your marital status

- ◯ Single
- ◯ Couple (No children)
- ◯ Full nesters I (Youngest child from 0 to 5 year old)
- ◯ Full nesters II (Youngest child from 6-17 year old)
- ◯ Full nesters III (Youngest child above 18)
- ◯ Rather not say

6.3 What is your level of education?

- ◯ Primary
- ◯ Secondary
- ◯ Vocational education and training (MBO)
- ◯ Higher education
- ◯ Rather not say

6.4 Are you currently employed?

- ◯ Employed
- ◯ Self-employed
- ◯ Unemployed
- ◯ Rather not say

7. Perception/ Involvement in crashes

7.1 In your opinion, which of these human behavior are most responsible for occurrence of crashes? Please rank them.

1st choice

◯ Alcohol ◯ Drugs ◯ Fatigue
◯ Use of devises that distract the driver (eg. mobile phone) ◯ Inexperience (young drivers)
◯ Speeding above the limit

2nd choice

◯ Alcohol ◯ Drugs ◯ Fatigue
◯ Use of devises that distract the driver (eg. mobile phone) ◯ Inexperience (young drivers)
◯ Speeding above the limit

3rd choice

◯ Alcohol ◯ Drugs ◯ Fatigue
◯ Use of devises that distract the driver (eg. mobile phone) ◯ Inexperience (young drivers)
◯ Speeding above the limit

4th choice

◯ Alcohol ◯ Drugs ◯ Fatigue
◯ Use of devises that distract the driver (eg. mobile phone) ◯ Inexperience (young drivers)
◯ Speeding above the limit

5th choice

◯ Alcohol ◯ Drugs ◯ Fatigue
◯ Use of devises that distract the driver (eg. mobile phone) ◯ Inexperience (young drivers)
◯ Speeding above the limit

6th choice

- ◯ Alcohol
- ◯ Drugs
- ◯ Fatigue
- ◯ Use of devises that distract the driver (eg. mobile phone)
- ◯ Inexperience (young drivers)
- ◯ Speeding above the limit

7.2 Would you like to add some more human behaviors that are responsible for occurrence of crashes in your opinion?

7.3 Have you been involved in a crash in the past three years?

- ◯ Yes
- ◯ No
- ◯ Rather not say

7.4 Can you state how many times you have been involved in a crash in the past three years?

- ◯ 1
- ◯ 1 to 5
- ◯ More than 5
- ◯ Rather not say

7.5 Have you been fined in the past?

- ◯ Yes
- ◯ No
- ◯ Rather not say

7.6 Can you state what you were fined for?

7.7 Do you think you are less probable to be involved in a road accident compared to people around you?	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
You are less probable to be in a road accident	◯	◯	◯	◯	◯

7.8 Do you consider yourself to be a safe road user?

- ◯ Yes
- ◯ No
- ◯ Rather not say

If you answered yes/no, can you please explain further?

7.9 To what level do you think the government/ authorities are concerned with road safety in general?	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
They are concerned	◯	◯	◯	◯	◯

Other comments?