Determinants of a safe interaction between Vulnerable Road Users and Automated Vehicles using Fuzzy Cognitive Mapping

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Preface

This graduation project 'Determinants of a safe interaction between Vulnerable Road Users and Automated Vehicles using Fuzzy Cognitive Mapping' concludes my study at the faculty of Civil Engineering and Geosciences at Delft Univeristy of Technology for the master programme Transport, Infrastructure and Logistics. I was engaged in the research from February 2017 to August 2017.

I have numerous people to thank for their support and guidance in the execution of this research. First, I want to thank Prof. Dr. Marjan Hagenzieker for her supervision, role as chair woman and for getting me into contact with relevant professionals in the field of automated driving. Marjan also got me in contact with Pablo Nûnez Velasco. I would like to thank Pablo for the brainstorm session preliminary to the research, the daily supervision and the fact that Pablo is willing to review the final document during his vacation. It is worth mentioning that Pablo, without having much experience in supervising graduate students, showed great expertise and was even more supportive and willing to assist. Furthermore, I would like to thank Dr. Jan Annema for his supervision. It is no secret that Jan Anne is not a big fan of the methodology that I have used in this research. Nevertheless, Jan Anne challenged (always supportive) me to try and make the methodology applicable for transport planning.

The research has been executed in collaboration with City of Amsterdam. I would like to Drs. Eric de Kievit for his guidance and support. Eric has the natural gift to identify weaknesses or threats without knowing the full context, which prevented me from making mistakes in the workshop and documentation of the report. Furthermore, Eric provided me with the opportunity to organize the workshop as part of the kick-off meeting '*Kenniskring Zelfrijdend'* in Amsterdam. I would like to thank the participants of the workshop for their input and interest in the results (Anne Blankert, Barry Ubels, Johan Olsthoorn, Jorden Steenge, Taede Tillema, Kees-Willem Rademakers, Lose Goossens, Tom Kuipers, Chris de Veer and Pieter Bos). I would furthermore like to thank the professionals that took the time for me to interview them. I would like to thank Kasper Kok, assistant professor at Wageningen University in the department of Environmental Sciences. Kasper provided me with feedback on the applied methodology and showed me interesting topics for discussions and recommendations. I also would like to thank Saskia de Craen, Rob Methorst, Rob Eenink and Riender Happee for their state-of-the-art knowledge.

I hope you enjoy reading this thesis.

Herman Hendrik (Erik) Arends,
Delft, 2017

Abstract

Key words: Automated Vehicle | Vulnerable Road User | Determinants | Interactions | Fuzzy Cognitive Mapping | Urban Environment | Amsterdam

The technology of automated driving systems that assist the human driver are in ongoing development and could potentially improve traffic safety and efficiency. At this moment, a lot of research into automated vehicles is carried out. The City of Amsterdam wants to know what impact AVs can have on traffic safety in their city. Most studies focus on the technology of the vehicle itself and its impact on society. An increasing number of studies is focussing on the human aspects, although most of these researches focus on the driver, while questions remain unanswered on vulnerable road users. At this moment, it is challenging to gain insights in the system of interaction. Due to the still-evolving technology of AVs, the impact on traffic safety cannot be accurately predicted. City of Amsterdam want to start pilots to test AVs on the public roads in order to gain insight in te system of a safe mutual interaction between automated vehicles and vulnerable road users.

First, the system of interaction needs to be known. Using the methodology of Fuzzy Cognitive Mapping (FCM), the determinants and behaviour of the system is identified. FCM is a fairly new method in the field of transport planning, but showed potential for this specific research in which scientific data is limited. The original approach to develop a FCM model is adapted. Therefore, the time it took to develop a conceptual FCM model during a workshop could have been limited and disadvantages of one strategy is balanced or mitigated with the advantages of other stragegies. This research is therefore also assessing if FCM can be a useful method in the field of transport planning.

The FCM model that describes that system of interaction is developed via a literature study and subsequent workshop. This resulted in a model of 21 determinants with 72 connections or relationships. Computations showed that the most important (key) determinants were the following concepts: Safe crossing behaviour, VRU friendly road design, AV friendly road design, Intelligent infrastructure and Identification and recognition. These key determinants, who each describe an idea of something formed by mentally combining all its characteristics or particulars, are considered most important in the system of interaction and should therefore be first be researched in pilots.

The results of the workshop and computations provide a first glance at the system and results. Interviews provided extensive state-of-the-art knowledge on the key determinants. The findings from the interviews are translated into an advice for the City of Amsterdam te develop and execute pilots. These pilots should be able to answer the most important and relevant research questions on the safe mutual interaction between automated vehicles and vulnerable road users in the urban environment.

FCM is found to be useful in the field of transport planning for specific case in which scientific research is limited, with a lack of quantitative data, but available qualitative data from professionals and where human behaviour plays an important role. For the still developing technology of automated driving systems, the method can be useful for as long as quantitative data is not available. As soon as such data is available, other methods are found to be more useful.

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1. Introduction

This chapter starts with some background information on automated vehicles and the interaction with vulnerable road users (1.1). Additional detailed information on AVs is provided in Appendix – Background information AVs which the reader can read in order to get an improved understanding of automated vehicles. Paragraph 1.2 describes the research problem in this knowledge domain and identifies the research gap. The objective of this research and the research questions are presented in paragraph 1.3. Paragraph 1.4 describes the scope of this research. The scientific and societal contribution of this thesis is explained in paragraph 1.5. Finally, the report outline is presented in paragraph 1.6.

1.1. Background information

The technology of automated driving systems that assist the human driver are in ongoing development and could potentially improve traffic safety and efficiency. Potential benefits of autonomous vehicles, in which the vehicle operates independently, are across a wide array of impacts for safety, congestions and travel behaviour (Fagnant & Kockelman, 2015), such as a decrease in traffic jams, efficient use of travel times (Silberg & Wallace, 2012), efficient use of energy and a safer traffic system (van Nes & Duivenvoorden, 2017). Traffic is best described as the result of interaction between three components, namely (1) Human, (2) Vehicle and (3) Infrastructure (Hojjati-Emami, Dhillon, & Jenab, 2013; Othman, Thomson, & Lannér, 2009; Schepers, Hagenzieker, Methorst, van Wee, & Wegman, 2014; van Nes & Duivenvoorden, 2017).

> A system is best described as a purposeful structure that consists of interrelated and interdependent elements or determinants

Author dissent on the actual impact of this technology on traffic safety. Human error is associated with 94% (±2,2%) of motor vehicle crashes (National Highway Traffic Safety Administration, 2015). It is therefore tempting to claim that autonomous vehicles, which have to potential to eliminate human errors and do not deliberately violate regulations, will reduce traffic accidents with around the same percentage (Millard-Ball, 2017). However, some studies are more reserved on these predictions. The actual impact of automated driving on road safety remains unknown at this moment (ETSC, 2016) and traffic safety might even get worse according to Sivak and Schoettle (2015).

Automated vehicles (AVs) can be categorized in 6 levels of automation, from non-automated (level 0) to autonomous (level 5) (see Table 1). In a transition period towards autonomous driving, different levels of AVs share the road with other road users such as pedestrians and cyclists. Road maps from the European Road Transport Research Advisory Counsel and EUCAR provide a rough estimation in which full driving assistance (level 5) automation is expected by 2030 (ERTAC, 2017; van Nes & Duivenvoorden, 2017). Milakis et al. (2015) expect full driving assistance to be commercially available between 2025 and 2045, while conditional driving assistance (level 3) can be expected between 2018 and 2028. The Boston Consultancy Group (BCG) argues that a commercially and affordable system is available around 2035, where the entire fleet is replaced with AVs in the following 10 to 15 years (BCG, 2016). Litman (2016) expect the autonomous vehicle to be common and affordable between 2040 and 2060. According to Tillema et al.(2017) , there are two future scenarios that serve as a basis for the transition, namely path 1: the evolution of the private vehicle and path 2: sharing in blossom. Tillema et al. identify the following road maps for path 1 dependent on a fast or slow transition: level 1-2 between now and 2025/2045, level 3-4 between 2025/2045 and 2045/2065, and level 5 between 2045/2065 and 2065/2100+.

Table 1: Level of driving automation (SAE International, 2016)

Level	Name	DDT*		DDT Fallback	ODD***
		Sustained lateral and longitudinal vehicle motion control	**OEDR****		
Driver performs part of all the DDT					
0	No driving automation	Driver	Driver	Driver	n/a
1	Driver assistance	Driver and system	Driver	Driver	Limited
2	Partial driving assistance	System	Driver	Driver	Limited
Automated Driving System performs the entire DDT (while engaged)					
3	Conditional driving assistance	System	System	Fall-back ready user	Limited
4	High driving assistance	System	System	System	Limited
5	Full driving assistance	System	System	System	Unlimited

* DDT = Dynamic Driving Task
** OEDR = Object and Event Detection and Response
*** ODD = Operational Design Domain

The transition towards autonomous vehicles holds new threats in the urban environment, where road users have to interact with vehicles of different levels of automation. Conflicts arise when road users are unaware of which level of automation and thus what behaviour they can expect from a vehicle (van Nes & Duivenvoorden, 2017). On top of that, it could happen that AVs lead to an increase in traffic in the urban environment without having benefits for pedestrians and cyclists (Begg, 2014). Litman (2016) claims that increased traffic volume and speeds after introduction of AVs might even degrade the conditions for VRUs.

1.2. Problem definition

The City of Amsterdam desires to know what impact AVs can have on traffic safety in their city. The City of Amsterdam has asked the Boston Consultancy Group in August 2016 to execute a study on the impact of AVs on city goals and to identify which interventions could increase the advantages and decrease the disadvantages of AVs (BCG, 2016) In the urban environment, AVs will interact with other road users such as Vulnerable Road Users (VRUs) and vice versa. Amsterdam would like to play an active role in testing and preparing the city of Amsterdam for a safe introduction of AVs.

We refer to the mutual interaction between VRUs and AVs as '*System of interaction'* in the remainder of this report

At this moment, a lot of research is being carried out in the knowledge domain of AVs. Most studies focus on the technology of the vehicle itself and its impact on the society. An increasing number of studies is focussing on the human aspects (Vissers, Kint, Schagen, & Hagenzieker, 2016). However, most of the research to this point focus on the driver, while questions remain unanswered for other road users such as VRUs. There are great uncertainties in the system of interaction and the corresponding effects. Van Nes and Duivenoorden (2017) remark the importance of research on traffic safety for VRUs in a mixed automation level or full autonomous system.

At this moment, it is challenging to gain insights in the system of interaction. Due to the still-evolving technology of AVs, the impact on the system as a whole cannot be accurately predicted. As a consequence, it is challenging to estimate the effect on traffic safety of the transition towards autonomous vehicles. Even though a lot of research questions in this domain have been identified by for authors such as Alim & Veenis (2015) and Parking et al. (2016), scientific data remains incomplete or not available at all. Pilots can prove to be a useful tool to test and develop the automated driving technologies in real life scenarios, and therefore provide an answer to existing research questions. Due to the wide variety of research questions and topics, it would be useful to prioritize research for the most relevant and important research areas, which can be dealt with first.

The system of interaction can be described by determinants, how they influence and are being influence by other determinants. To this point, no scientific research has been performed to describe the system of interaction in such determinants and relationships. To get a better understanding of the relevant and important research areas, the system of interaction need to be researched into detail. Visser et al. (2016) supports this claim by arguing that in order to gain insight in such a system, research methodologies need to be developed and validated.

This study makes use of the method of Fuzzy Cognitive Mapping (FCM). FCM is a fairly new and hardly used method in the field of transportation planning (TRID, 2017), but show potential for this specific research problem. FCM is able to predict and identify changes of technologies that are still being developed, integrates complex subjects and translated qualitative data into (semi-)quantitative data. FCM is mostly applied in cases where human behaviour plays a significant role, but is hard to quantify, where scientific data is incomplete or not present at all and in complex cases where multiple expertise come together. A detailed description of the methodology can be found in Chapter 2. The knowledge domain lacks quantitative data on the system of interaction, although many professionals are actively participating in the AV research and development. With the scientific data and resources that are currently available, FCM might prove itself a useful method to gain insights in the system of interaction.

1.3. Objectives and Research questions

The problem description can be translated into two main objectives, namely:

- Gain insight in the system of a safe interaction between VRUs and AVs;
- Provide the City of Amsterdam with an advice on pilots to test AVs on the public road.

Following from the problem description and objectives, the main research question can be formulated as:

What are the practical and technical challenges faced due to the mutual interaction between vulnerable road users and automated vehicles?

In order to answer the main research question, several sub-questions are formulated. These sub-questions are used to provide focus for the research and are used as intermediate step to answer the main research question and meet the research objectives.

1. *What are the determinants of a safe mutual interaction between VRUs and AVs in the urban environment?*

First of all, the system of interaction should determine which elements are relevant for this type of interaction and will be used in the remainder of this research. These elements are described as determinants. The characteristics of a determinant vary for each user according to their expertise, world view and knowledge level. Therefore, a determinant is best described as a determining concept, which describes an idea of something formed by mentally combining all its characteristics or particulars, a directly conceived or intuited object of thought.

2. *How do the determinants of a safe mutual interaction between VRUs and AVs influence each other?*

The determinants have relationships with other determinants in the system by influencing or being influenced by other determinants. The structure of the system of interaction is determined and translated into a model, which provides insight in the structure and dynamic behaviour of the system.

3. *How are determinants of a safe mutual interaction between VRUs and AVs expected to behave for future scenarios?*

Automated driving systems are still in development. The impact of these systems on traffic safety is hard to predict due to uncertainties in the unknown driving behaviour. Future studies are executed for the model. The expected behaviour of the determinants is determined by comparing and combining different scenarios.

4. *What are the most relevant and important determinants of a safe mutual interaction between VRUs and AVs to use in further research and pilots?*

A lot of research is required in the knowledge domain of AVs. It is important for the City of Amsterdam to prioritize research. With a structure analysis of the model, the most relevant and important determinants are identified. Lastly, knowledge gaps are identified for the most relevant and important determinants.

1.4. Scope

The initial scope is presented in this paragraph. The model objectives (paragraph 4.1) elaborate upon the scope and criteria in more detail and are made fit for the methodology.

The scope of this research is initially set to a wide range to gain the most insights in the complexity of the system and to make sure that no relevant information is excluded in the analysis and development of the model. The model is expected to provide a first grasp at the problem. After model development, the scope is narrowed to gain an extensive understanding on the most important determinants in the interaction between VRUs and AVs. Finally, an advice report is made fit for the City of Amsterdam, thus narrowing the scope once more. Figure 1 shows a schematized visualisation of the scope.

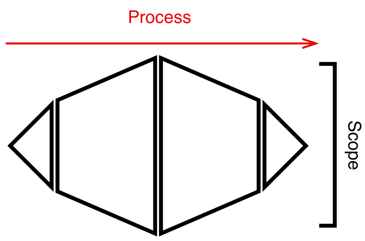


Figure 1: Schematized representation of scope

New risks can be expected to arise with the introduction of new technologies in the traffic system. Van Nes and Duivenoorden (2017) introduce an overview of these new risks (Figure 2). This research focusses on the interaction of the new technology with cyclists and pedestrians (as indicated in bold, red text). Cyclists and pedestrians are often classified as VRUs due to their unprotected state, but also because there is often a speed difference with other road users (SWOV, 2012a; Wegman & Aarts, 2006). Because moped riders and motorcyclists travel at higher speeds, they are not considered as VRUs in this report.

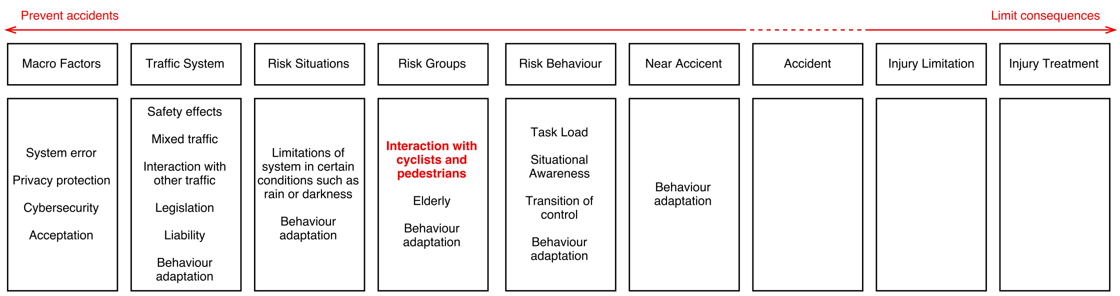


Figure 2: Overview of new risks that can arise with the introduction of new systems, based on (van Nes & Duivenvoorden, 2017)

Other risks indicated in Figure 2 relate in a greater or lesser extent to the focus risk, and are thus of importance, while others are of little or no influence. Macro factors are considered not to be relevant for the system of interaction and are therefore not taken into consideration for this research.

It is crucial to look into traffic safety in the broadest sense in order to understand the safety effects of automated driving systems. Traffic is the result of interaction between three components, namely (1) Human, (2) Vehicle and (3) Infrastructure (Hojjati-Emami et al., 2013; Othman et al., 2009; Schepers et al., 2014; van Nes & Duivenvoorden, 2017). These components serve as an initial categorisation for the literature study.

Finally, this research looks into the transition period towards autonomous vehicle. This means that all levels of automation are represented in the scope, starting from no driving automation (level 0) to full driving automation (level 5). There will be no distinction made between automated private vehicles or people movers that serve more as a mode for public transport. All types of automated (road) vehicles are considered an AV in this research.

1.5. Scientific and societal contribution

This thesis is aimed to contribute to both practise and science. The scientific and societal relevance of this study is described below.

1.5.1. Scientific relevance

As already been stated, a lot of research is currently being executed in the field of automated driving and an increasing number of studies is focusing on human aspects. Still, research on the impact on traffic safety for other road users can be found sporadically at this moment. This research shows relevance by filling the research gap described above and would have value to practitioners and researchers in the field of automated driving, with a focus on the urban environment.

This research serves as an intermediate step towards a safe introduction of AVs by filling the research gaps and by prioritizing further research. An accurate prediction on traffic safety is not the result of this thesis, but guidance is provided for further research such as pilots. Therefore, the research questions that are identified by other researchers will be prioritized by relevance and importance for the city of Amsterdam.

Furthermore, the system of interaction between VRUs and vehicles has never been scientifically researched by identifying determinants and their mutual relationships, let alone the system of interaction with AVs. This research will provide new insights in the system of interaction, which can have the opportunity to serve as information in other researches related to VRUs and AVs since it is decomposed into relevant determinants.

Lastly, the FCM is not yet a proven method in the field of transport planning. This research assesses the usefulness of this methodology for transport planning cases where human behaviour plays an important role, scientific data is incomplete or nor present and in complex cases where multiple expertise come together. The method seems promising for this research topic at this moment, where quantitative data is limited. An assessment is made to determine if this methodology is still useful to determine the system of interaction in the near future, when research and the introduction of AVs is expected to provide quantitative data.

1.5.2.Societal relevance

This research is expected to make a contribution to society by getting an improved understanding of the system of interaction. The better understanding can contribute the creating of pilots or measures in order to safely introduce AVs in the urban environment. The research is therefore not an end results in terms of accurate predictions, but offers guidance in further research into AVs which is expected to increase traffic safety for all road users in the urban environment over time.

If the methodology is found to be useful for the field of transport planning, other researchers and practitioners could use the method in similar cases where the impact of still-evolving technologies has to be determined. The method is used in such a way that it can be applied by practitioners such as consultants, planners and policymaker, by for example limiting the time it takes to develop the model. If the development time can be minimized, the method could proof itself useful to use in practise.

1.6. Report outline

Chapters 1-7 describe the theoretical part of this research. In these chapters, the sub questions are answered by developing an FCM model and computing the structure and dynamic behaviour. The model is developed by consecutively using two strategies, namely via literature study and a workshop. Interviews are used as a third strategy to use the results in a case study where an advice on AV pilots is provided for the City of Amsterdam. This case study uses the results from the theoretical part of the research and applies the knowledge in practise. A detailed description on these strategies and the approach are described in the next chapter.

Figure 3 provides a visual representation of the report outline.

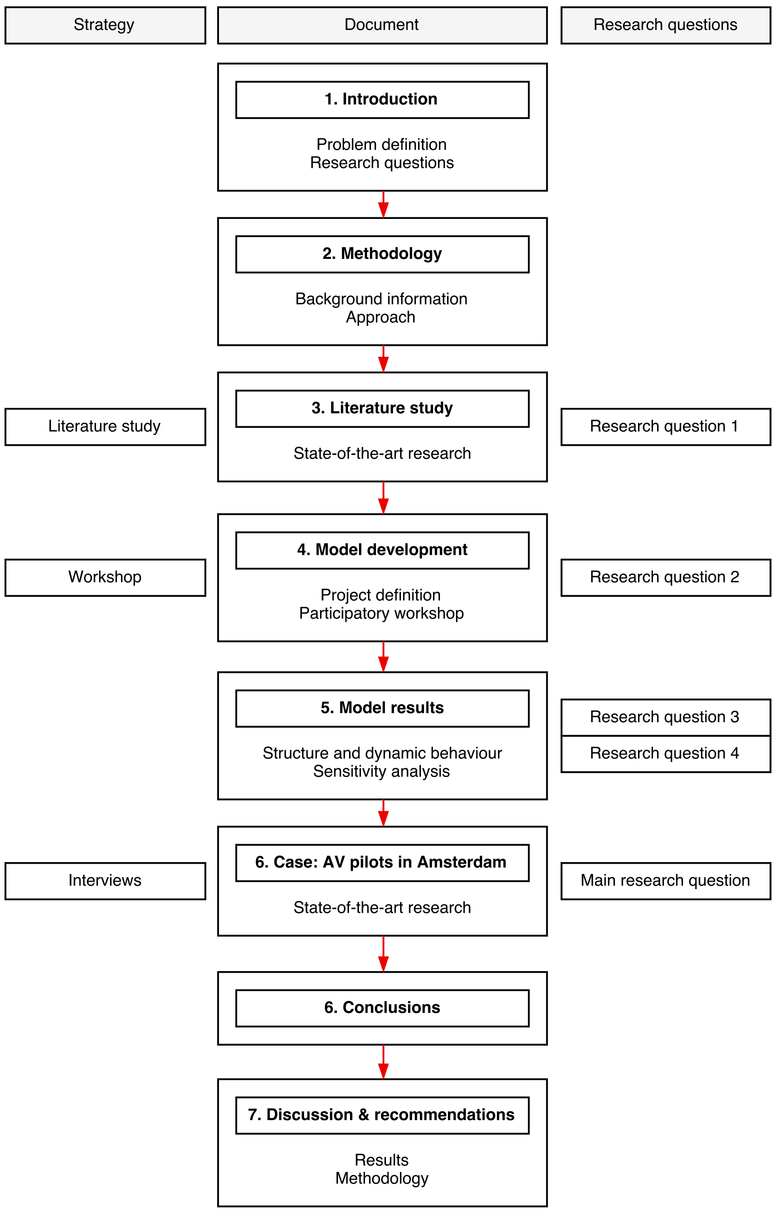


Figure 3: Report outline

2. Methodology

Impacts of future changes in transport are often difficult to express in quantitative terms. It is challenging to assess the potential impact of a still-evolving driving technology for AVs given the amount of uncertainty and limited availability of information. Therefore, predictions on such projects are often assessed by the judgement of multiple professionals with different backgrounds and expertise. A professional is best described as a person relating to, engaged in, or suitable for a profession and is a skilled practitioner in a given activity of knowledge domain. FCM offers a potential and promising tool for transportation planners to assess the impact on a system when quantitative information is limited and uncertain (Vogt, 2015).

This chapter starts with background information to FCM modelling (2.1). Paragraph 2.2 provides an explanation on why this method is useful for this research, together with advantages and disadvantages of the method. This research adepts the typical approach of FCM modelling. The original approach and adaptations are described in paragraph 2.3. The expected results are presented in 2.4. Finally, the conclusion on the methodology are given in paragraph 2.5.

FCM isn't a methodology that has proven itself in the field of transport planning at this moment. Although the methodology looks promising, it should be assessed if this method is a useful method for this research or similar cases. The assessment consists of validation by professionals in interviews and by a reflection of the student. The discussion and recommendations on the usefulness of this method can be found in chapter 8 at the end of this report.

2.1. Background information on Fuzzy Cognitive Mapping

A Fuzzy Cognitive Map is a map that describes causal reasoning both in diagrammatic terms involving links (relationships) and nodes (determinants), and in matrix terms (Kusdarjito, 1998). The method is developed by Kosko in 1986 to expand the ability of cognitive maps (a mental representation) with fuzzy logic (a form of many-valued logic in which the truth values of variables consisting of a value between zero and one)(Kosko, 1986). A step (iteration) at which an impact occurs can be determined by forward and backward chaining. A Fuzzy Cognitive Map is a transparent graphical model that shows the core presumptions and structure for scenario development, without using too much jargon definitions (Gray et al., 2015). The method can combine judgements obtained from multiple professionals into one model. The method has the ability to express both quantitative and qualitative data in one model. Qualitative data is captured from the mental maps (thoughts) of professionals. This qualitative data is furthermore translated into (semi-)quantitative data, meaning that a value is assigned to the data in terms of "strong", "medium" or "weak" (A. J. Jetter, 2006a, 2006b). These terms each have a value between zero and one, dependent on the scale that is used, e.g. three terms (Özesmi & Özesmi, 2004), five terms (A. J. Jetter, 2006b) or seven terms (van Vliet, 2011) and are therefore described as semi-quantitative instead of (pure) quantitative.

The model can be used to assess the structure of a system in terms of centrality, indegree and outdegree, but also shows dynamic behaviour of the determinants over time for future scenarios. Note that the model is not intended to provide a detailed forecast. The output values indicate a relative change of a determinant for different scenarios in future transportation, which are often highly uncertain and largely uncontrollable (Kok, 2009). The FCM model can be used to prioritize research and assist strategic planning efforts (Vogt, 2015).

FCM is a fairly new and hardly used in the field of transportation planning, but show potential for this specific research problem. The Transport Research International Documentation (TRID) database include a mere three relevant references that satisfies the keywords *Fuzzy Cognitive Map* or *Fuzzy Cognitive Mapping*, namely Application of a Fuzzy Cognitive Map for impact assessment of transportation projects (Kusdarjito, 1998), Potential changes to travel behaviour & patterns: a Fuzzy Cognitive Map modelling approach (Vogt, 2015) and Analysis of Vulnerability in Multinational retailing delivery systems: A case study of FamilyMart and Circle K (Huang & Feng, 2016) originating from respectively 1998, 2015 and 2016. With the understanding that this is a fairly new method in the transportation profession, a well-structured and scientific approach is essential for the development of the FCM model. A structured and scientific approach also helps to reflect accordingly on the method and its applicability to other, similar cases in transport planning.

2.2. Why use FCM

2.2.1. Relevance of the method for this research

FCM modelling is suitable for the demands of future studies and offers a mix of qualitative and quantitative approaches (A. J. Jetter & Kok, 2014). Multiple and diverse knowledge sources can be included to overcome limitations by professionals' opinions and makes mental models (implicit assumptions) explicit.

Forecasting the impact of a still-evolving technology is often ill-structured and based upon a lot of assumptions. Decision-makers should identify important system variables, their impact on the target concept (in this research the target concept is traffic safety (see 4.1.1)) and the underlying system dynamics in order to get a better understanding of the system (A. J. Jetter, 2006b). FCM is able to capture and combine the mental maps of multiple professionals in networks of simple causal rules. Therefore, the method makes individual worldviews explicit, testable and computable. Critical system elements can be easily identified of which decision-makers should focus when searching for decision alternatives.

FCM is able to:

- Predict and identify changes of technologies that are still being developed (A. J. Jetter & Kok, 2014)
- Translates qualitative data (mental maps) to semi-quantitative data (A. J. Jetter & Kok, 2014)
- Integrates complex subjects (Kosko, 1986)

FCM can be applied when:

- Human behaviour plays a significant role, but is hard to quantify (Wildenberg, 2010)
- Scientific data is incomplete or not present at all (Özesmi & Özesmi, 2004)
- Complex issues where multiple expertise's come together (Özesmi & Özesmi, 2004)

2.2.2. Advantages and disadvantages of FCM

This section provides a list of advantages and disadvantages of the development of the model and the model:

Advantages

- Able to identify and predict changes by technology that is still in development (Vogt, 2015)
- Translates qualitative data into semi-quantitative data (Kok, 2009)
- Feedback processes show dynamic behaviour over time (A. J. Jetter & Kok, 2014)
- Many variables can be combined, where some don't need to be well defined (Gray et al., 2015)
- Integration of complex subjects (Kosko, 1986)
- Can model relationships between determinants that are not known with certainty, but can be expressed in terms as "weak" or "strong" (A. J. Jetter & Kok, 2014)
- Can model a system where scientific information is limited or unknown (Amer, Jetter, & Daim, 2011)
- Different knowledge sources can be combined (Yoon & Jetter, 2016)
- Relatively easy to obtain cognitive maps in a short time (A. J. Jetter & Kok, 2014)
- Can model the impact of different policy options (Yoon & Jetter, 2016)
- Perception of different stakeholders is combined into one model (A. J. Jetter & Kok, 2014)
- Participants reach a shared understanding of the complexity of the system (A. J. Jetter & Kok, 2014)

Disadvantages

- The knowledge, ignorance, misconceptions and biases of participants are all included in the model (Amer et al., 2011)
- "What-ifs" can be modelled, but "why" cannot be determined (Kok, 2017)
- Does not provide real-value estimates, but a relative change (A. J. Jetter & Kok, 2014)
- Cannot deal with cases of co-occurrence which can be expressed by condition as "and", "if" and "then" (Özesmi & Özesmi, 2004)
- Post-processing is required to remove flaws and misconceptions (Kosko, 1988)
- Software and corresponding squashing function are designed as a "black box" (Kok, 2017)
- Overly complex models are visually hard to understand (A. J. Jetter & Kok, 2014)

2.3. Approach

This paragraph describes the approach that is chosen for this research, based on the six-step process of Jetter and Kok (2014). The six-step approach describes the steps that are needed in order to develop and use a FCM model and consists of the following steps: project objective (section 2.3.1), plan for knowledge elicitation (section 0), knowledge capture (section 2.3.3), post-processing (section 2.3.4), detailed design of FCM model (section 2.3.5) and interpretation of the results (section 2.3.6). As can be seen in section 0, the FCM model can be developed by using three strategies for knowledge elicitation, each with its own advantages and disadvantages. This research adapts the approach so that the advantages of one strategy can mitigate or eliminate disadvantages of other strategies. The modification of the original approach is described in section 2.3.7.

This chapter is aimed to provide knowledge on the FCM approach and which choices have been made for this research. Detailed information for each step is provided in the upcoming chapter of this report.

2.3.1. Project objective

The single-most important step in developing the model is project articulation, where the problems and purpose of the model are defined (Sterman, 2000). A successful modelling study requires a clear purpose and a thorough analysis of the model's objectives. A clear purpose and thorough analysis does not guarantee a non-misleading and easy to understand model, but it allows the users to ask questions whether the model is addressing the problem they are interested about in the right manner. An unclear purpose, lack of focus or unspecific mission statements might lead to an overly-complex model that is hard to use or understand according to Sterman.

In the project objective (paragraph 4.1) the initial scope described in paragraph 1.4 is extended and made fit for model use. The scope describes endogenous (internal to the system), exogenous (external to the system, which are likely inputs) and excluded determinants (excluded from consideration). Also, an explanation is provided of the time frame the model is using, for example "5 years", "in 50 years" etc. Finally, a geographical scope explains which location are taken into consideration in the model. The reason for the second scoping process is to make sure that the literature study is not limited by an overly defined scope and boundaries. The initial scope provides direction in which the literature study should be executed, but is not aimed to restrict the student from looking into a wide array of relevant topics.

Next, a project question is formulated. The project question is used throughout this research and is presented to the participants in each knowledge capture step. The project question gives direction and focus to the participants. Since FCM has the ability to combine the knowledge of multiple professionals, a stakeholder analysis is executed to identify relevant professionals that can be used to develop the model.

A detailed description of the project objective can be found in paragraph 4.1.

2.3.2.Plan for knowledge elicitation

FCM models can be constructed using three strategies, namely literature study, a participatory workshop and interviews. Each of these strategies have their own advantages and disadvantages, as can be seen in Table 2.

Table 2: Model development techniques (A. J. Jetter & Kok, 2014; Kosko, 1986; Özesmi & Özesmi, 2004)

Literature study		**Workshop**		**Interview**	
Advantage	Disadvantage	Advantage	Disadvantage	Advantage	Disadvantage
Detailed research within scope	Change of tunnel vision by the practitioner	Individuals gain knowledge from their peers	Only provides a first grasp at the problem, general results	No peer-pressure	Time consuming process
Knowledge is gained on all relevant determinants	Outdated knowledge	Limited amount of contact hours	Chance of overly complex model	Room for detail	Interviewers needs to be skilled
Efficient use of time		Directly results in a FCM Model	Requires extensive research for a better understanding on "why"	Multiple interview techniques can be applied	Change that the interviewer forces his/her own worldview
Input can be used in a workshop or interview		Knowledge is likely to be up to date	Hierarchical distance of overwhelming personalities	Participants have the time to be critical	
		New determinants can be introduced		Validation on previous results	

This research modifies the original approach and combines all three strategies. The disadvantages of one strategy can be mitigated or dealt with by the advantages of other strategies. The modified method starts with a literature study. This strategy has the disadvantage that the study is biased by the practitioner's worldview or opinion and therefore creating tunnel vision. Also, the knowledge from literature study could be outdated. A workshop could provide new insights and determinants that a practitioner did not found in the literature study. Interviews could provide with the latest updates on the knowledge domain. A visual representation of the workflow is presented at the end of this chapter in paragraph 2.3.7.

The number of respondents needed for constructing a Fuzzy Cognitive Map varies in previous studies between 7 and 46 (Hossain & Brooks, 2008; Özesmi & Özesmi, 2004; Rodriguez-Repiso, Setchi, & Salmeron, 2007). According to Jetter and Kok, each respondent can be expected to introduce 15 – 30 determinants, of which many will be shared with other respondents. However, the number of respondents needed and the expected amount of introduced determinants should also relate to the mission objective, the desired level of detail and the method for knowledge elicitation. The selection of professionals depends on several criteria, which are different for each strategy. The selection procedure is described into detail in the plans for knowledge elicitation in 4.1 and 0.

Literature study

Literature study is used to identify initial determinants in the system of interaction. This helps to find relevant aspects that fall within the scope, which can be used to focus the attention of participants in the upcoming strategies. In other words, by executing a literature study preliminary to the development of the model, the participants are given a head start. This should provide the participants direction and is expected to results in a faster process since the forming of initial determinants normally can take up to several hours (Özesmi & Özesmi, 2004).

Literature study for the traffic system as a whole is executed with attention to the interaction between AVs and VRUs. Several scientific databases are used such as Google Scolar, ScienceDirect, Research Gate

Transportation Research International Documentation, Knowledge Agenda (Connekt and the TU Delft Repository. Since scientific information on this topic is limited, grey literature is also used for this knowledge gathering, such as peer reviewed scientific papers, technical reports from research institutes and road safety organizations.

Participatory workshop

The results of the literature study, a set of initial determinants is used in the next step of model development. A participatory workshop, a type of workshop that is characterized by the participating character and involvement of the participant, is executed where professionals construct a conceptual FCM model. The main advantage of a participatory workshop is that it can provide a coherent and complete picture of the knowledge domain. This can be directly translated into a conceptual model. The participants can respond and built on each other's expertise and knowledge and therefore benefit from new insights (Goodier, Austin, Soetanto, & Dainty, 2010). A threat of this method is that there is chance of messy results due to a large number of determinants (Kok, 2017). Also, overwhelming personalities or hierarchical distances can create one-side-oriented results (A. J. Jetter & Kok, 2014).

The results from a participatory workshop most often provides only a first glance at the problem. Additional extensive research is desired afterwards to understand the model structure and its dynamic behaviour.

Interviews

To better understand and to reflect on the structure and dynamic behaviour of the FCM model, Interviews are executed and therefore narrowing the scope by applying focus to the most important aspects. The information that is gained from the interviews serve as a base for an advice on further research and pilots for the City of Amsterdam. In the interviews, the interviewees are asked to provide extensive information on key determinants, but also to validate assumptions made by the participants of the workshop. Unexpected results or strange behaviour in the output are presented to the interviewees and a validation for this behaviour is asked. By doing this, the strategy of interviews not only provides a better understanding of the system of interaction, but also validates the model.

2.3.3. Knowledge capture

The professional's knowledge is during the workshop captured and transferred into a causal map by cognitive mapping. This method is fairly easy and intuitive, but participants need additional coaching because they may be uncomfortable with a structured mapping approach or have training in other system thinking techniques (A. J. Jetter, 2005). Cognitive mapping helps the professional to express, share and challenge their mental models or subjective theories (A. J. Jetter, 2006a; LaFrance, 1987). The process of knowledge capture typically consists of several steps (A. J. Jetter, 2005, 2006b; Özesmi & Özesmi, 2004): (1) Knowledge activation, (2) Define determinants, (3) Organize determinants and (4) Capture dynamic behaviour. As described in the previous sections, literate study preliminary to the workshop provides an initial set of determinants. Therefore, step 2 in knowledge capture, define determinants, is no longer required. This speeds up the process and provides direction so the participants would have less trouble with model boundaries.

Participants express their knowledge from the short-term memory brain. With knowledge activation, the knowledge that is stored in the long-term brain is transferred to the short-term brain where the information is processed (A. J. Jetter, 2006b). With a video of a "typical" Amsterdam intersection, the complexity of the system of interaction if shown and remarkable behaviour is pointed out to the participants.

The definition of determinants is determined after literature study and provided to the participants and interviewees on a list of descriptions and on the back of determinant cards. Determinants cards are approximately 10x4 cm in size and show the title and definition of a determinant. The definitions does not have to comply with the dictionary, but should be chosen to illustrate the professional's view (A. J. Jetter & Kok, 2014). The participants of the workshop organize the determinants on a poster. Özesmi & Özesmi (2004) suggest to place all determinants in the centre of the workspace and let the professionals arrange the determinants. However, Jetter believes that this trigger the professionals to make unnecessary connections and could lead to causal links being no longer a good representation of the mental model. He believes that a better cognitive map can be achieved by placing the target concept on the right-hand edge of the workspace. All influencing determinants are added one at a time on the left – hand side of the workspace. This results in a better focus on core issues and connections according to Jetter (A. J. Jetter, 2005). The participants are advised to use the approach of Özesmi & Özesmi. The reason for this is that the workshop would only take up one hour (see for more detail paragraph 0). Özesmi & Özesmi (2004) assessed several studies using FCMs. Each study showed that a participatory workshop would take up two days. For this research, and probably also in practise, relevant professionals are hard to find that are willing to participate for two whole days. This research aims to limit the time for the participatory workshop. The approach of Özesmi & Özesmi is best advised since time restrictions would prevent an overly detailed map and therefore unnecessary connections. It is expected that the most essential relationships are assigned in a short time period.

Finally, the dynamic behaviour is captured. Participants assign causal links between determinants that describe the relationship (either positive or negative) and add weights to these relationships. A detailed description of the knowledge capture for the participatory workshop can be found in section 4.2.2.

For the interviews, one professional is found for each key determinants. The professionals are found by doing desktop research into relevant professionals in the specific knowledge domain. These professionals needed to meet a set of criteria, which is further described in Appendix – Interviews. An e-mail invite is send to each professional in which the student introduces the research and why they are considered an expert or professional for the specific knowledge domain. No further information is provided to this point to prevent any biased results, since the professionals might do additional research preliminary to the interview. They are asked to participate in an explorative interview in which extensive knowledge on a key determinant is gathered, but also to provide their opinion on some remarkable results of the model. They are asked if the interview can be recorded and if they allow the student to use their name in the report. If not, they would be documented as anonymous.

The lengths of the interviews vary between 30 to 60 minutes. After the interview, a transcript of the interview is made. The most relevant information from this transcript is translated into a written text. This text is emailed to the interviewees for validation. After validation, the results are included in the appendix.

2.3.4.Post-processing

The result of the workshop is a conceptual FCM model developed by the participants. Post-processing deals with typical problems that are in the conceptual model, such as disregard for model boundaries, definitional or overly detailed causal links, diagnostic variables and conditional causality (A. J. Jetter, 2006a; A. J. Jetter & Kok, 2014). Post-processing is therefore used to "clean-up" the conceptual model and eliminate any errors and mistakes. The result of post-processing is a detailed FCM model. Below are some typical problems described.

Disregard for model boundaries

The model boundaries are determined in the clarification of the project objectives and after literature study. However, it is possible that the participants come up with additional determinants that fall outside the model boundaries. When these determinants are considered to be outside of the model boundaries, the determinants and causal links have to be deleted from the model during post-processing by removing the determinant from the matrix and therefore removing all relationships to other determinants.

Definitional or overly detailed causal links

Professionals might consider their specific knowledge on a determinant particularly important or difficult to understand. They therefore tend to describe the determinants and links in greater detail compared to other determinants. Additional determinants may be added by the participants between determinants when they believe a relationship is not self-explanatory. This may result in a delay. Therefore, the influence of a determinant arrives at a point when other influences on them have already weakened. Causal maps have to be checked for potential definitional links. During post-processing, definitional determinants are combined into one determinant that describes the same determinant.

Diagnostic variables

Determinants without an '*out-arrow*' can indicate a target concept (receiver). When a determinant in the initial Fuzzy Cognitive Map has no out-arrows, but is clearly not a target concept, it might indicate an incomplete knowledge capture. However, in some cases these determinants describe a phenomenon closely related to a target concept because they are causally connected to the same determinants. These certain determinants are called diagnostic variables and provide information about the system (A. J. Jetter, 2006b).

If the diagnostic variables reflect objective information, they can be useful in the calibration of the FCM. Both the diagnostic variable as the target concept need to change in the same direction if the FCM's dynamic behaviour is to reflect to professional's knowledge. The diagnostic variables can therefore be used as a check. If a determinant without an out-arrow is not a diagnostic variable, the professionals are asked to provide additional information on the causal relations of this determinant.

Conditional causality

If for example determinant C depends on both the input of determinant A and B, the causal relations are conditional e.g. '*Rain'* and '*Temperature below 0 °C'* cause determinant C, "*a slippery road*", to happen. The threshold of the activation function of determinant C is met by creating a nested FCM that composes the determinants in sub-determinants (Dickerson & Kosko, 1994). For example, Temperature can be divided into low and high temperature.

Determinants with conditional causality are nested and described in such a manner that it represents both and includes the conditional causality in for example high and low.

2.3.5. Detailed design of FCM model

The post-processing results in a detailed design of the FCM model. The detailed FCM model is translated into the software developed by FCMappers (FCMappers, 2009), which is a spreadsheet in excel. The software uses a logistic squashing function that keeps the value of the vector matrix between 0 and 1. The choice of squashing function impacts the system behaviour (A. Jetter & Schweinfort, 2011). Even though the model results depend strongly on the type of squashing function, literature does not place much emphasis on this topic (FCMappers, 2009). Equation 1 and Equation 2 describe the logistic squashing function that is used in the FCMappers software.

$$A_i^{(k+1)} = f\left(A_i^k + \sum_{\substack{j \neq i \\ j=1}}^{N} A_j^k \times W_{ji}\right)$$

Equation 1: Iterative formula

$$f(x) = \frac{1}{(1 + e^{-(x)})}$$

Equation 2: Logistic squashing function

A_i and A_j are determinant values with a relationship between determinants *j* and *i.* The weight of a relationship from *j* to *i* is denoted by W_{ji}. K represents the iteration-step. N describes the total number of determinants in the system. A visualisation of the logistic function is presented in Figure 4.

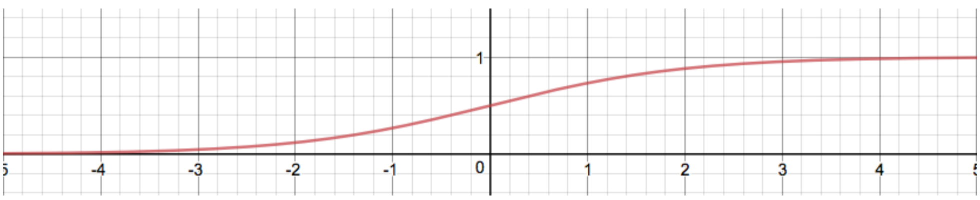


Figure 4: Graph of logistic function

Both the model structure and dynamic output are calculated using the software. The software Gephi is used to visualize the model and to get a better understanding of the structure and dynamic behaviour. The structure consists of indices such as centrality, indegree and outdegree. These values are used to determine key determinants that are considered most important in the system. The dynamic behaviour of the determinants is assessed for four different scenarios, namely three scenarios with an exogenous determinant with a high centrality and one scenario with a combination of these three exogenous determinants.

2.3.6. Model use and Interpretation of results

The last step in the process is model use and interpretation of the results. A model reflection on structure is performed to get a better understanding of the meaning of the indices. Also, a sensitivity analysis is performed to assess the robustness of the model.

2.3.7.Modification to the original approach

Adapted approach by using all three strategies for knowledge elicitation
Uitleggen waarom dit tijd technisch goed uit pakt

The approach described in the previous sections showed that some modifications have been made in the original approach of FCM modelling. The following list summarizes the reasons to modify the approach:

- Advantages of one strategy mitigates or eliminate disadvantage of other strategies
- Shorten the development time of the model by providing guidance and scoping to the participants, making it useful in practice (where the available time of professionals is limited)
- Wide scope in the first steps (to guarantee all relevant factors are used), narrowing of the scope in the later steps (to provide a substantiated interpretation of the results and to provide a substantiated advisory report

The modified approach is illustrated in Figure 5. It can be seen that the theoretical part describes the process up until the results and interpretations. In the practical part of this research, the knowledge gained from the theoretical part is used in practise. This results in an advisory report on AV pilots in Amsterdam. A detailed step-by-step flow chart can be found in Appendix – Flow Chart Methodology.

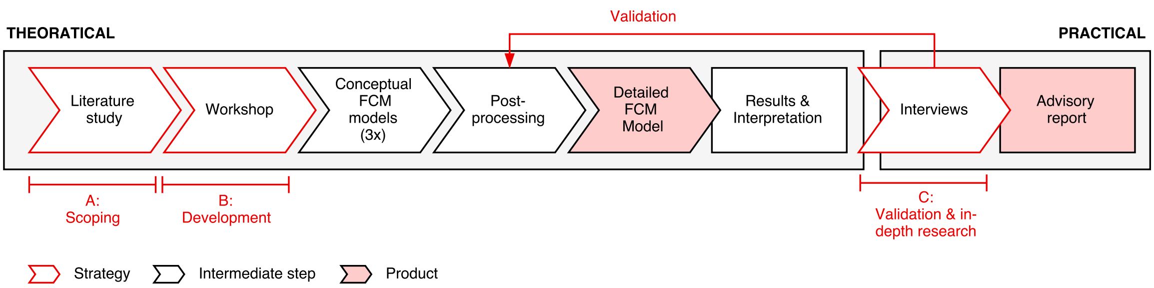


Figure 5: Modified approach that is used for this research

2.4. Expected results

The user of the model is not expected to provide and answer for the '*truth'*, but for '*conceptual adequacy'* (A. J. Jetter, 2006b). By using the six-step approach, a detailed FCM model is constructed using the worldviews of a wide variety of professionals. This research modifies the six-step process as described in the previous paragraph. This process finally leads to recommendations on additional research and pilots that the City of Amsterdam should develop in order to achieve a safe system of interaction.

This results in the following products:
- Detailed FCM model (for ongoing model use)
- Advice on further research and pilots for the City of Amsterdam

2.5. Conclusions on methodology

This research uses the methodology of fuzzy cognitive mapping, a combination of fuzzy logical and cognitive maps. The method can be used in cases where scientific data is limited, technologies are still evolving, human behaviour plays a significant role and complex issues are integrated in the same system. The method consists of a cognitive map build up with nodes (determinants) and links (relationships) that describe the system of interaction. The cognitive map is used to compute the indices of the structure and the dynamic behaviour of the model.

This research adapts the original approach to develop a FCM model by combining the strategies of literature study, workshop and interviews. The advantages of the one strategy will balance or mitigate the disadvantages of another strategy.

3. Literature study

This chapter focuses on the first sub-question: What are the determinants of a safe mutual interaction between VRUs and AVs in the urban environment? Paragraph 3.1 briefly describes the traffic system, consisting of the components Human, Vehicle and Infrastructure. The interactions between these three components are of importance for this research. Paragraph 3.2 describes a literature study on relevant aspects of the safe interaction. This literature study serves two causes, namely providing relevant background information on the knowledge domain as well as to find the initial set of determinants that will be used in the development of the model.

Several (scientific) databases are used such as Google Scolar, ScienceDirect, Researche Gate, Transportation Research International Documentation, Knowledge Agenda (Connekt) and the TU Delft Repository. Additionally, grey literature such has peer reviewed scientific papers and technical reports from research institutes and road safety organizations is used. Lastly, paragraph 3.3 concludes this chapter. The literature study started by searching for scientific documents relating to the keywords: Automated vehicle, autonomous vehicle, self-driving vehicle, vulnerable road users, cyclists, pedestrians, interaction, characteristics, traffic system. Other keywords were added to the study following from the information that is gathered during the study.

3.1. Traffic System

As already stated in Chapter 0, traffic is the result of interaction between three components, namely (1) Human, (2) Vehicle and (3) Infrastructure (Hojjati-Emami et al., 2013; Othman et al., 2009; Schepers et al., 2014; van Nes & Duivenvoorden, 2017). A traffic system is therefore a purposeful structure that consists of interrelated and interdependent elements or determinants between these components. Literature study on the interaction between these components provides the determinants of a safe mutual interaction between VRUs and AVs.

A visual representation of the traffic system and its components can be found in Figure 6. The next paragraph focusses on the mutual interaction between human and vehicle, vehicle and infrastructure, and human and infrastructure.

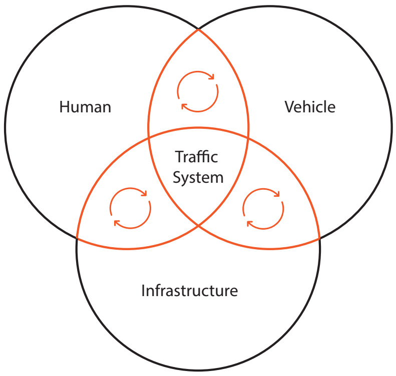


Figure 6: Visual representation of the components of the traffic system

3.2. Interactions in the traffic system

It is challenging to assigns determinants in the safe interaction to the component of either human, vehicle or infrastructure since a lot of overlap exists in the interaction between one, two or three components. This paragraph describes the literature study for a number of topics. After each topic, relevant determinants are summarized that are found from the literature. These determinants serve as an initial set of determinants, that will be assessed in the scope description in section 4.1.1. We defined the definition of a determinant as a determining concept which describes an idea of something formed by mentally combining all its characteristics or particulars, a directly conceived or intuited object of thought. The true definition of a concept depends therefore on the worldview of the reader and user. A description on the definitions can be found in Appendix – Initial determinant descriptions.

Human characteristics

The average human does not exist, which makes it challenging for AVs to predict behaviour of VRUs. Automated driving systems would have little problems when all human shows uniform characteristics. A normal distribution defines share of behavioural patterns that can be expected for VRUs. It is not practical to design a system for the average characteristics, since variations show extreme cases (upper and lower percentages of the normal distribution). Most standards are designed for characteristics of 85% of the population (Amiripour, N.D.) Characteristics that are relevant in the traffic system, and especially in the interaction between AVs and VRUs, are age, gender, experience, skill level, motivation, fatigue, stress and many more according to Amiripour. To illustrate, in 43% of the vehicle – pedestrian collisions, the driver of the vehicle was aged below 25. The share of drivers between 25 and 45 is 35%, 45 – 70 is 18% and a mere 4% of the drivers was 70 years or older (Rifaat, Tay, & de Barros, 2011). There is a correlation between gender and collisions as well. Men are more likely to have an accident than woman according to Lancaster and Ward (2002). Also, more abstract characteristics such as motivation and stress show a difference in characteristics of a VRU. For example, pedestrians who are stressed or late tend to ignore the basic safety rules. They are more likely to show unsafe crossing behaviour and typically results in walking on the streets or crossing on non-designated crossing areas (Amaroso & Caruso, 2008; Lancaster & Ward, 2002).

Vehicles show characteristics that can be used to describe certain behaviour. In most cases, these characteristics are the result of a human driver. An increase in automation takes over driving tasks of the human driver, and therefore determines the vehicle characteristics. Vehicle characteristics that describe the behaviour in the traffic system are for example speed, lane choice, acceleration/ deceleration, braking, overtaking etc. Numerous studies have reported a relationship between speed and crash involvement (Solomon, 1964). According to Solomon, the most important aspect of speed in crash involvement is not the mean travel speed, but the speed variance relative to the travel speed. Solomon argues that slow driving vehicles are more likely to be involved in accidents than vehicles that drive with a higher speed. This can be explained by the fact that vehicle that drive with a higher speed encounter fewer road users with a large speeds difference compared to slow driving vehicles that encounter road users such as VRUs. The severity of injury however, is substantially greater for accidents with a higher impact speed. This also depends on the type of vehicle, weight of the vehicle, type of collision and safety measures (Fildes, Rumbold, & Leening, 1991).

Determinants: Age, gender, experience, skill level, motivation, fatigue, stress.

Human behaviour

The majority of collisions between VRUs and vehicles occur at crosswalks or within their vicinity (Park & Li, N.D.). Such collisions may be caused either by violations of traffic- and VRU control regulations or by the inattention of drivers and VRUs. In the Netherlands, the number of fatalities among pedestrians has decreased by 43% in the period 2005-2016 to 51 deaths in total (CBS, 2016). The number of fatalities of cyclists did not show a decrease in numbers of the last decade with a total of 189 deaths in 2016 (CBS, 2016; Weijermars, Schagen, Goldenbeld, Bos, & Stipdonk, 2016)). Almost 90% of the pedestrian causalities in the Netherlands occur in the urban environment (Rodríguez, 2017).

The crossing behaviour of VRUs can be described with explanatory variables such as pedestrian distance from the kerb, number of VRUs crossing simultaneously, vehicle speed, VRU speed, gap distance, time to collision etc. (Schmidt & Färber, 2009). To illustrate, Schmidt and Färber showed that critical limits in gap distance is at 3 and 7 seconds, meaning that no one is willing to cross with a gap distance below 3 seconds, and everyone is willing to cross with a gap distance above 7 seconds. The willingness to cross depend on a variety of factors as well, such as human characteristics, weather, motivation, stress, number of failed attempts etc. An interesting result in the study of Schmidt and Färber is that VRUs base their choice mostly on the distance of the approaching vehicle, and thus leaving vehicle speed out of consideration, instead of the time to collision.

Although AVs are expected to respond faster to emergency situation compared to human driver, and would therefore be able to provide optimal braking performance, it still might not be able to stop in time because of braking limitations (Sivak & Schoettle, 2015). A false sense of safety can therefore be a negative result in the interaction between AVs and VRUs.

Determinants: Safe crossing behaviour, expected behaviour, weather.

Communication

To this point, AVs are not found on the roads where VRUs have to communicate with them. Little is known on how VRUs can or should communicate with VRUs, especially for informal rules and non-verbal communication (Rodríguez Palmeiro, 2017), since hardly anyone has ever encountered an AV. With the introduction of automated vehicles, it might be essential that additional knowledge on AVs and the behaviour of such vehicles is needed. This can either be achieved by training or promotional instructions in television ads or other campaigns. Van Betuw and Vissers (2002) say that owners of a driving license should maintain certain level of knowledge, risk awareness and skill. Training can be included in the driver's education lessons. Road safety campaigns are a mean to influence the public to behave more safely in traffic (Hoekstra & Wegman, 2011), but are also useful to inform the public of new or little known traffic rules, increase problem awareness of educate them in new technologies. Surprisingly, a small number of such campaigns is evaluated thoroughly, to the impact is hard to quantify. The literature provides little support for the hypothesis that formal driver instruction is an effective safety measure (Mayhew & Simpson, 2002). Nevertheless, some strategies might be required to improve the knowledge on AVs by other road users.

Assessing human behaviour is one of the main responsibilities of a driver in order to participate safely in road traffic. It is already stated that the assessment of human behaviour is challenging for human drivers. The assessment and prediction of other road users' behaviour relies on two factors: (1) a more or less rule-abiding behaviour of road users for traffic rules and (2) evaluating intentions by communication between the road users via actions and gestures (Färber, 2016). The latter means that there exists a set of informal rules that help to communicate in traffic, facilitate flow and compensate for errors.

This paragraph described a lot of determinants from the human perspective. By eliminating the human component in driving, safer and a more efficient traffic system can be expected. AVs have the potential to improve the communication between vehicles and VRUs. The system can detect VRUs to a larger extent than human drivers, who might not be paying attention the whole time or simply cannot see a VRU because it is behind an object such as a parked car or behind a bush. Wireless communication through Wi-Fi and handhelds has the potential to support road safety by enabling road users to exchange information (Anaya, Merdignac, Shagdar, Nashashibi, & Naranjo, 2014). In contrast to vehicle to vehicle (V2V) communication and vehicle to infrastructure (V2I) communication, very limited efforts are made on communication mechanisms for pedestrian safety.

AVs have the ability to increase traffic safety and traffic management by communicating with other (automated) vehicles (Arslan & Saritas, 2017). While these technologies can be highly beneficial, Vehicle to Vehicle (V2V) communications represents an additional step in helping to warn the driver about impending danger. V2V communications use on-board dedicated short-range radio communication devices to transmit messages about a vehicle's speed, heading, brake status, and other information to other vehicles and receive the same information. This enables the vehicle to "see" around the corner and "through" other vehicles so that V2V-equiped vehicles perceive some threats sooner than sensors, cameras or radar and warn the driver accordingly (Harding et al., 2014). V2V communication can also enable platooning, in which vehicles drive close to each other by using Cooperative Adaptive Cruise Control (CACC).

According to Färber (2016), there are several informal communication options: Schema formation, anticipatory behaviour, non-verbal communication (facial expression, eye contact, gestures and body movement). With schema formation, expectation patterns are formed based on specific human characteristics groups (e.g. elderly, youngsters, owners of a family car, owners of a sports car). Such schemata are often not accurate, but can serve as initial guiding principles. Anticipatory behaviour describes small actions that makes the behaviour predictable for other road users, such as decelerating and pre-sorting for a turn. Non-verbal communication is often send out unconsciously and are challenging for AVs to capture and assess. On top of that, non-verbal communication varies within cultures.

Determinants: Informal rules and non-verbal communication, user knowledge on AVs, training and promotion, Vehicle to Pedestrian communication (V2P), Vehicle to Infrastructure communication (V2I), Vehicle to vehicle communication (V2V)

Legislation and law enforcement

With the introduction of the new technologies for automated driving, it can be expected that new rules and legislations are needed. Participating members of the United Nations (such as the Netherlands) have an accord on the 1968 Vienna Convention on Road Traffic. The convention covers road traffic safety regulations and as such establishes principles to govern traffic laws. One of the fundamental principles of the convention has been the concept that a driver is always in control and responsible for the behaviour of a vehicle in traffic (ETSC, 2016).

At European level, there are a number of areas of legislation which should be reviewed in the light of increase automation, such as the EU vehicle type approval (Directive 2007/46/EC), which ensure that AVs can respect all specific obligations for safety set out in different traffic laws across the EU. Vehicles must be tested in all different situations where a vehicle will replace a human driver to the extent that an automated vehicle will pass a comprehensive equivalent to a driving test. Another directive that should be reviewed is the Driving Licence Directive (2006/126/EC), which should be amended to include specific training and licencing on semi and full automation and how to use the technology including disengaging and re-engaging. Depending on new traffic rules and regulations, additional law enforcement might be needed. On top that, automated vehicles might provoke abuse by other road users. Law enforcement might prevent such abuse.

Determinants: Law enforcement, formal traffic rules and regulations

Automated driving systems

The current generation of automated driving systems are designed to support, rather than replace, the human driver (Llaneras, Salinger, & Green, 2013). Such supportive driving systems are Advanced Cruise Control (ACC), Following Distance Warning System and many more (SWOV, 2012b). Ultimately, full autonomous driving is achieved for level 5 automation, in which the human is no longer required to perform any driving tasks or monitor the driving environment.

The ability to detect other road users such as other (automated) vehicles and VRUs increases gradually with each level of automation. Passive and active optical sensors enable detection of objects, intent recognition, tracking, kerb recognition and free-space analysis (Sun, Bebis, & Miller, 2004). Optical sensors such as short-range radar systems, long-range radar systems, cameras and stereo cameras scan the environment (see Figure 7).

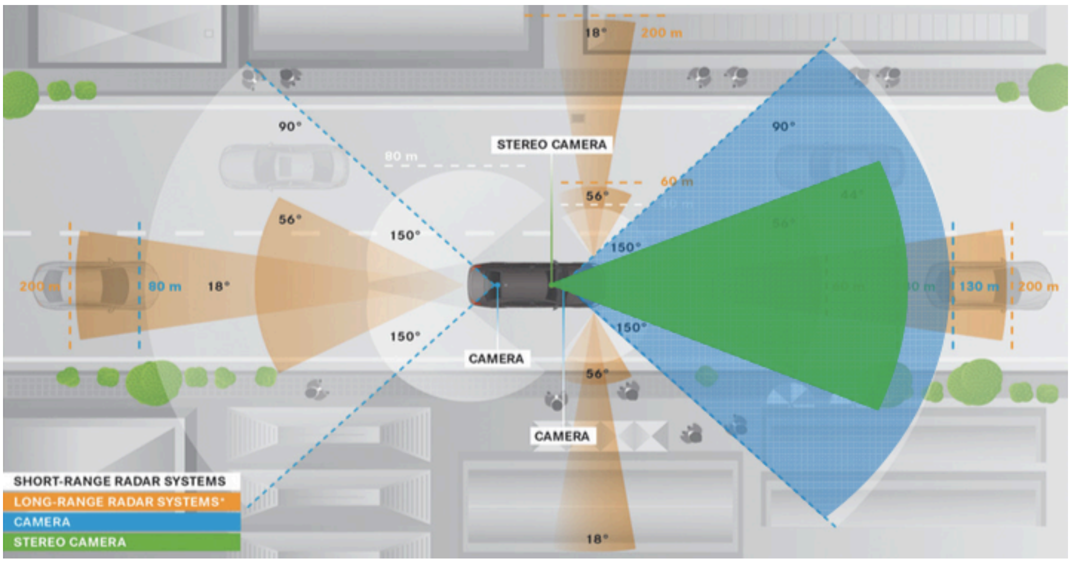


Figure 7: Optical sensors (Franke, 1998)

Active sensors such as laser, LIDAR and millimetre-wave radars have several drawbacks, for example low spatial resolution, slow scanning speed and interference among sensor of the same type when a large number of vehicles are moving simultaneously in the same direction. Passive sensors can be used to track more effectively cars entering a curve or moving from one side of the road to another. Visual information such as lane detection, traffic sign recognition and object identification (e.g. VRUs, obstacles) is gathered with these passive sensors. A combination of active and passive sensors enable a broad range of detection levels. On the other hand, vehicle detection based on optical sensor is very challenging due to variabilities in classes (Sun et al., 2004). These sensors can either be mounted on the vehicle or with static use in a traffic monitoring system.

It is challenging to determine expectation patterns for mixed traffic in which manual driven vehicles and AVs share the same road. Identification and recognition of AVs might help to distinguish AVs from manual driven vehicles, and strengthen pattern development of the vehicles by other road users. However, little scientific research is known on this topic, and the question remains unanswered if AVs should be identified as such.

With an increasing level of automation, more and more driving tasks of the driver are taken over by the automated driving system. However, without autonomous driving, a human driver is still needed to be able to regain control over the vehicle. Reasons to take over control again may be the inability of the automated system to manage a particular driving situation/environment or when the driver wishes to depart from the current driving environment, e.g. by leaving the motorway environment with infrastructure supporting vehicle automation, to enter an unsupported urban environment. Research on the understanding of the human factors and how drivers are involved in the occasional control are very limited (Eriksson, Banks, & Stanton, 2017; Merat, Jamson, Lai, Daly, & Carsten, 2014). Human factors research on automation vehicles argued that increases in automation could lead to reductions in drivers' situation awareness, contributing to impaired performance during system limitations or failures (Endsley, 1999).

Merat et all. (2014) found that drivers' pattern of eye movement fixations remained variable for some time after automation was switched off. Carsten et al. (2012) showed that the drivers' visual attention to the road decreases as the level of automation increases and that when drivers are supported by a lateral controller (lane-keeping system) but had to maintain their longitudinal control, their visual attention towards the road centre was lower than when driving was manually controlled, yet similar to when both lateral and longitudinal support were provided. Certainly, the attraction of such systems to drivers is the freedom they offer for engaging in other tasks. However, engagement in other tasks is directly linked to the removal of drivers' attention from the road, and as outlined above, may lead to reduced driving performance. It is therefore important for an automated system to be aware of drivers' state, and have the power to re-engage the driver back into the loop, when the driving environment necessitates such re-engagement (Merat et al., 2014). Llaneras et all. (2013) provide strong evidence to suggest that when afforded the opportunity to hand over control to automated driving systems, most driver will engage in secondary task activities such as reading, texting or reaching for an object in the back seat. Moreover, drivers tend to have longer glances off-road instead of looking forward on the roadway.

Determinants: Level of automation, transition of control, ability to detect a VRU, identification and recognition of AVs, expected behaviour

Road design

AVs would be functional if they are able to drive on the existing roads or on dedicated tracks. Road design and dimensions influences the behaviour of VRUs and (automated) vehicles. For example, smaller gaps are chosen by VRUs for crossing the road when roads have a smaller with (Schmidt & Färber, 2009). But also, road typology plays an important role in the behaviour. Naturally, road users navigate in a different manner on shared space compared to roads where they have primacy. Logically, a busy road will result in different driving behaviour compared to roads with less traffic. Studies disagree on the actual impact of AVs on the traffic density.

Even road patterns in a city have an influence on the driving behaviour of vehicles and crossing behaviour of VRUs. Rifaat, Tay and de Barros (2011) found that 37% of collision in a city occurred in areas with a grid-iron pattern, 23% occurred in loops and lollipop patterns, 18% in warped parallel patterns and 21% of the collisions occurred in mixed pattern areas. Also, they found that there is a relation between road class and the number of collisions. Most collisions occurred on undivided two way roads (51%), while the least collisions are found on divided roads with no barrier (6,5%). Traffic control measures also influence the number of collision. No measures present result in 43% of the collisions. Traffic signals/lights have a share of 27% and a pedestrian cross walk holds 20% of the collisions. A mere 4% of the collision was located at a stop sign.

Separation distance is expected to play a role in the interaction between AVs and VRUs. This describes the distance between the vehicle and the cyclist of pedestrian in the process of overtaking. The main variables affecting the separation distance are facility type, vehicle presence in the adjacent lane, the presence of an open drainage gulley, the number of lanes, speed limit and the total width of the road. (Parkin et al., 2016). Dutch design guidance (CROW, 1993) identified three categories of cross-section in relation to joint cycle and motor traffic use as follows: 'tight' cross-sections along which it is not possible for an overtaking manoeuvre to be made without encroaching into the oncoming traffic lane; 'spacious' cross-sections which provide for adequate passing distance without having to cross the centre-line; and 'critical' cross-sections (which include the typical lane width of 3,65 as adopted in the UK). The critical cross-section provides sufficient width for drivers to overtake, but in so doing they will leave inadequate distance to the cycle user they are passing.

The road geometry determines driving behaviour. Most of the speeding takes place in the left (and middle) lane according to Shbeeb, Awad and Suliman (2005). Drivers often change lanes on the road to maintain speed and to avoid slow vehicles, pedestrians, obstacles and lane closures (Li & Sun, 2017). There are three different reasons to change lanes, namely free lane changing, lane reduction and moving bottlenecks (Li & Sun, 2017). The decision of a driver or driving system to change lanes depends largely on the gap acceptance between the vehicles on the target lane (Keyvan-Ekbatani, Knoop, & Daamen, 2016). An aggressive driving behaviour characterized by high speed together with numerous and sudden changes in instantaneous speed, cause sudden accelerations or decelerations (Mehar, Chandra, & Senathipathi, 2013). Such driving behaviour indicated an uneven driving style and often results in accidents because other road users have trouble determining the expected behaviour. It can therefore be said that driving behaviour, but also crossing behaviour of VRUs, depend on road design and road dimensions.

The above describes factors that occur on roads with mixed traffic. AVs show great potential on dedicated tracks in which they only have to interact with other AVs making use of this road. Local dedicated infrastructure will be ready for a fully AV system with higher reliability and accuracy. This will result in a shift of implementation costs from consumer towards government, and will therefore lower the costs of AVs for consumers (Funk, 2014). At this moment, dedicated tracks are only used for people movers such as the ParkShuttle in Cappele aan de Ijssel in the Netherlands. Downside of dedicated tracks is that it requires a lot of space compared to AV operation on current roads. Such space can be hardly found in dense cities such as Amsterdam, Utrecht and The Hague.

Intelligent Transport Systems (ITS) could be applied to dedicated tracks, but can also be used in the existing infrastructure. ITS is developing in promoted in developed countries all over the world for over 35 years (Krivolapova, 2017), and aims to improve traffic safety and traffic management. Vehicles are able to communicate with the roads and surrounding infrastructure such as traffic lights and signs. With real-time-data, vehicles can adjust their speed or route to improve traffic flows. Such technologies also provide the opportunity to detect other road users thought static sensors.

Determinants: VRU-friendly road design, AV-friendly road design, Vehicle to Infrastructure communication (V2I), traffic density.

3.3. Conclusions on literature study

A literature study has been executed to determine the determinants of a safe mutual interaction between VRUs and AVs in the urban environment. Interactions in the traffic system, consisting of human, vehicle and infrastructure, is used to identify the relevant determinants for this research. This results in the following list of determinants: Age, gender, experience, skill level, motivation, fatigue, stress, safe crossing behaviour, weather, law enforcement, formal traffic rules and regulations, informal rules and non-verbal communication, user knowledge on AVs, training and promotion, Vehicle to Pedestrian communication (V2P), Vehicle to Infrastructure communication (V2I Vehicle to vehicle communication (V2V) Level of automation, transition of control, ability to detect a VRU, identification and recognition of AVs, expected behaviour, VRU-friendly road design, AV-friendly road design and traffic density.

These determinants will be used (after assessed in model boundaries) as initial determinants in the model development.

4. Model Development

This chapter describes the process of model development. The project objective (paragraph 4.1) describes the scope, project questions and stakeholders that are used in the participatory workshop. This execution of the participatory workshop, the results and post-processing are described in paragraph 0. The result of this chapter is a detailed FCM model.

4.1. Project Objective

The problem orientation helps to describe the need for a model. Initial determinants and stakeholder groups, whose views and knowledge can be useful, are identified in an early stage. In order to gain insight in the model objective, the need for the model has to be described.

As already mentioned in the previous chapter, the impact and effects of automated driving systems are hard to predict due to the fact that the technology is still in development. Nevertheless, the City of Amsterdam wants to know if AVs can contribute to a safe traffic system. A broad range of research domains are filled with unknowns at this moment, resulting in the inability to identify actions that the City of Amsterdam should take to facilitate or withhold automated driving systems in (specific parts of) the city. Since not all research domains can be dealt with at the same time, it is desired to prioritize which research domains require most attention of the City of Amsterdam. Pilots should be identified and executed in order to facilitate a possible introduction of AVs in the city as soon as the systems enters the market.

This thesis focuses on a user group that might be at risk when AVs are introduced in the city, namely VRUs. Several determinants are of importance in the safety of VRUs when they have to interact with AVs. However, not all of these determinants are of equal importance and some are expected to change positively or negatively after introduction of AVs. To gain insights in the most important and most changing determinants, the current and future traffic system need to be understood.

A model that describes the system of interaction between VRUs and AVs cannot be found in any scientific research, and is thus one of the goals of this thesis. For the development of such a model, the knowledge from a variety of professionals in urban transport is captured. Qualitative data (mental maps) is documented and translated into a causal loop diagram that describes the dynamic behaviour of the system. Due to the unknown characteristics of automated driving technologies, room for interpretation for the professionals and modeller is essential in the assessment of the results.

The above can be summarized into one mission statement:
This project develops a model that is able to capture the structure and dynamic behaviour of the system of a safe mutual interaction between VRUs and AVs, so that key determinants and future changes can be identified.

The determinant for a safe mutual interaction between VRUs and AVs is defined as Traffic Safety.

4.1.1. Scope

Scoping is important in the preparation for the model development. It is clear that this research focus on the system of interaction in the urban environment, a relatively small field of study in the knowledge domain of AVs. The results of the literature study of the previous chapter is a set of determinants. These determinants are used to apply additional scope for the next step in the development of the FCM model, namely the participatory workshop.

Model Boundaries

The scope of de model can be summarized in a model boundary chart by listing endogenous, exogenous and excluded determinants (Sterman, 2000). Endogenous determinants are determinants that are part of the system that is under consideration. Traffic safety is chosen as a target concept, since the model will be used to assess determinants of a safe system of interaction. Also included in the system are exogenous determinants. These are likely to provide an input to the system. Policymaking is expected to be an input for the model. Two determinants are added to the exogenous determinants for AV supportive policymaking and VRU supportive policies making. These concepts describe policies that aim to use respectively AVs and VRUs to their full potential. Finally, the excluded determinants indicate which determinants have not been taken into consideration, and are thus out of the scope.

The Model Boundary Chart is presented in Figure 8. A description of the determinants, which was also provided to the participants of the workshop, can be found in Appendix – Initial determinant descriptions.

Excluded variables

The following determinants are excluded from the model: Age, Gender, Skill level, Motivation, Weather, Seasonal effects, Cultural effects, Adaptiveness, Connected vehicles (V2V), Costs, Public's opinion, Image, System error, Privacy Protection, Cybersecurity, Acceptation.

These determinants are excluded because they either cannot be influenced (age, gender, weather etc.). Özesmi and Özesmi argue that such determinants are not useful in the method of FCM, since the method is looking into determinants that can be influenced by e.g. policy makers or planners (Özesmi & Özesmi, 2004). Determinants that are considered not of any importance in the interaction between VRUs and AVs (adaptiveness, connected vehicles, costs, cybersecurity etc.) or macro effects that are hard to estimate for future technologies (See Figure 2: Cultural effects, system errors, privacy protection, acceptation, public opinion (Rodríguez, 2017) etc.) are also excluded from the model.

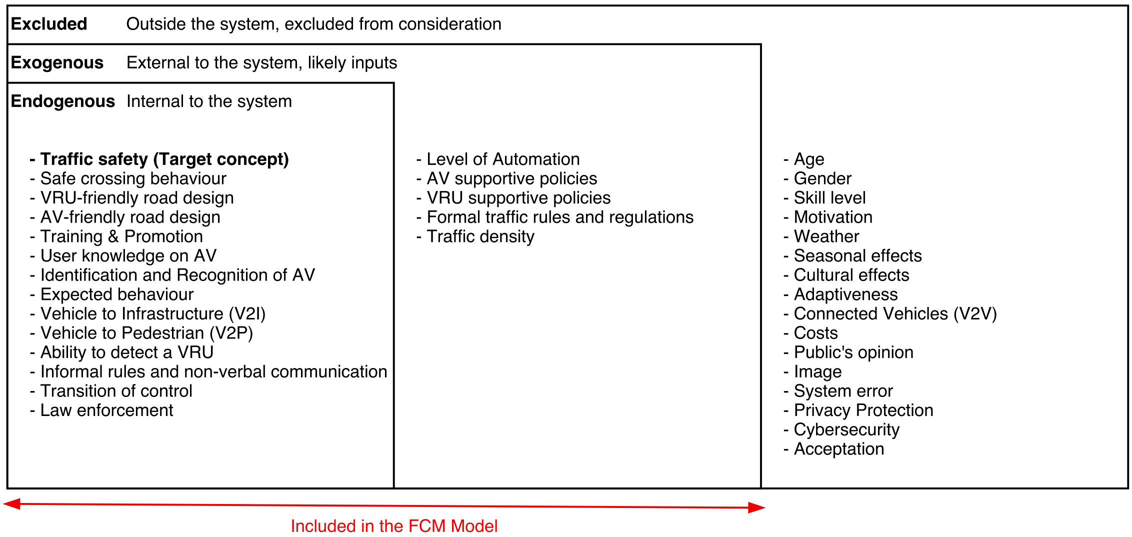


Figure 8: Model Boundary Chart

A total of nineteen determinants is chosen to be within the scope of this research. These determinants are provided to the participants of the workshop as initial determinants.

Time frame

This research is looking into the scenario with mixed traffic, where both manual driven vehicles and AVs share the same road.

Time lag, which can cause a delay in effects in the model, is not considered to be part of this model. For example, the process to educate road users in the effects of AVs is expected to take longer than the introduction of a new detection system in the AV. This complex behaviour will be difficult for the professionals to translate this into the model. The intermediate iterations are therefore considered not of any importance for the results.

Geographical scope

The urban environment in general is considered the geographical scope. No specific road section, with a unique design and characteristics, is chosen. Therefore, the model is expected to represent the traffic system for the urban environment and can thus be used for multiple, if not all, locations in an urban context where vehicles and VRUs interact.

4.1.2. Project Questions

When interviewing professionals, several project questions have to be formulated prior to the interview. For the participatory workshop, one main project question is sufficient. This question is asked to all participating professionals and serves as initial guidance in the construction of the model. The main project question for the participatory workshop is: "*To what extent do AVs have a changing influence on the traffic safety of VRUs in the urban environment?*"

4.1.3. Stakeholders

The rise of AVs is directly affecting numerous sectors. None of these sectors have a one-sided leading role in the process. The new technology of automate driving systems can be introduced on the public roads if there is an intensive collaboration between stakeholders (Stoffels & Sore, 2017). A stakeholder is considered a person, group or organization that has an interest or concern in an organization or knowledge domain. Professionals are persons within a stakeholder group or organization, and are relating to, engaged in, or suitable for a profession and are skilled practitioners in a given activity or knowledge domain.

FCM requires input from multiple professionals and can therefore profit from the desired collaboration between stakeholders. Professionals from all relevant sectors in the industry are chosen as a professional for either the participatory workshop or interview. Stakeholders are grouped into four sectors, (1) Government, (2) Industry, (3) Knowledge institution and (4) Other. This section describes the objectives of each stakeholder group. Next, relevant stakeholders for this research are identified. Professionals in these stakeholder groups are sent an invitation to participate in the workshop.

Stakeholder groups

A short description of objectives is presented for each stakeholder-group except for *other*, since this stakeholder-group is not specified. It is reasonable to state that that each group has other objectives in principal, but only the aspects that are relevant for the safe interaction in the broadest sense are presented.

The government has to develop legislative acts and strategies regarding AVs, while looking after the best interest for its inhabitants. New technologies and developments have to be stimulated and facilitated. Governmental parties should invest in projects and infrastructure, stimulate development and research in automated driving and facilitate experiments on public roads. Governmental parties can play a central role in organising a collaboration between different stakeholder-groups.

The industry has the main goal to develop and sell their automated driving systems. These stakeholders are likely not to share specific information on their technology and progress, since competitors can use this information to their advantage. Nevertheless, these stakeholders should collaborate with governmental parties to execute tests and pilots. A collaboration between market parties can result in accelerated developments.

Knowledge institutions such as high schools, universities, platforms and professional networks perform (scientific) research on the knowledge domain of AVs in the broadest way. Knowledge institutions play a major role in collaboration between all stakeholder-groups by performing experiments and developing strategies.

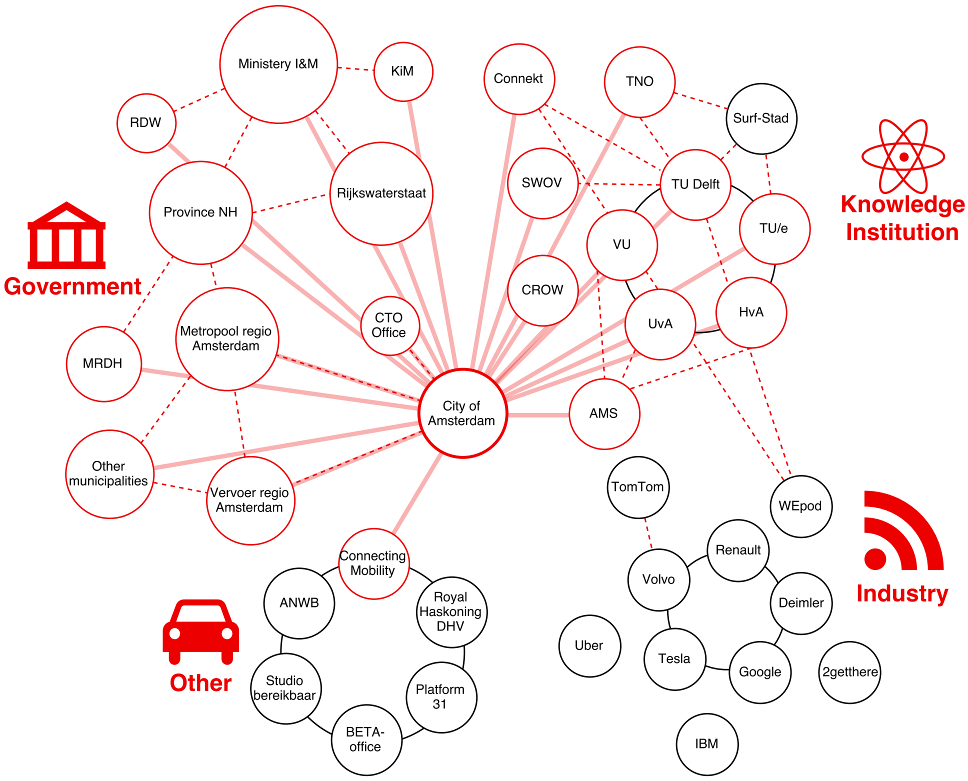


Figure 9: Stakeholder map relevant for the city of Amsterdam

Figure 9 provides an overview of the stakeholders in the field of AVs and VRUs, that are relevant for the City of Amsterdam. The dotted lines represent already existing links between stakeholders. Stakeholder groups that are invited to the participatory workshop are circled with red. Notice that Surf-STAD is not indicated as a group that is invited for the workshop. The reason for this is that this stakeholder is a collaboration of several stakeholders that can already be found, such as the TU Delft, SWOV, MRDH and others. Also notice that only governmental institutions, knowledge institutions and relevant platforms are invited for the workshop. Stakeholders with a strong personal interest, for example the industry, are excluded.

Criteria and invitation

For each stakeholder group, two or three professionals are listed. These professionals have to be objective and willing to share their knowledge and should meet at least one of the following criteria:

1. Expertise in traffic safety;
2. Expertise in AVs
3. Expertise in autonomous vehicles
4. Expertise in policy making
5. Expertise in human behaviour in the traffic system

A total of 44 professionals in 21 stakeholder groups was send an e-mail with an invitation to participate in a "knowledge group", a new created platform organized by the City of Amsterdam to share knowledge on AVs between governmental institutions, knowledge institutions and the industry. The program of the first meeting consists of two parts, namely (1) sharing of knowledge and (2) the participatory workshop.

It should be noted that the results of the workshop highly depend on the type of participants. For this research, professionals from governmental and research institutions participated. Other stakeholders, which are more likely have a strong personal interest in the knowledge group, are not invited in order to make sure that every participant is objective and willing to share knowledge.

4.2. Participatory workshop

The conceptual FCM model is constructed in the participatory workshop, which is characterized by the participating character and involvement of the participant. This section describes the process of the workshop. The professionals that provided input for the model, and the results of the model. The post-processing step towards an aggregated model is described and the combined model is presented in its cognitive maps and corresponding matrix.

4.2.1. Participating professionals

A total number of 12 professionals took part in the workshop, varying from the following stakeholder groups:

- City of Amsterdam
- KiM Netherlands Institute for Transport Policy Analysis
- Amsterdam University of Applied Sciences
- Delft University of Technology
- Vervoerregio Amsterdam
- AMS Institute
- Province of Noord-Holland
- CROW / Radbound University Nijmegen.

The professionals, together with the company or institution they represent and their position, are described in Appendix – Participants workshop. Since the participating professionals all are found to be objective and willing to share information, they are all considered to be relevant for the construction of the model. Each professional has a certain degree of knowledge on traffic, traffic safety or transportation. But most importantly, every professional has an above average knowledge of AVs.

The participants are asked in the introduction of the workshop if they agree that their names are documented in this report. If they would prefer anonymous, their name would not be used in the appendix.

4.2.2. Knowledge capture

The workshop was introduced and explained in a presentation of 10 minutes. By showing the professionals a short video of a typical Amsterdam junction, illustrating the complexity of interaction between VRUs and AVs in the city of Amsterdam, the short-term memory has been activated. Next, the method of Fuzzy Cognitive Mapping is introduced and explained to the professionals. The abilities and strengths of the methods are explained. Finally, the use of determinants and causal links is explained and an example of a Fuzzy Cognitive Map is shown.

It would not be efficient to work with 12 professionals on one FCM model. FCM workshop therefore often use multiple (smaller) groups to develop FCM models. The group is divided into three smaller groups. The professionals were asked to form the three groups and start working on the construction of a model that describes the interaction between VRUs and AVs. The participants were asked to form the group by mixing stakeholder groups. The sentence: "*To what extent do AVs have a changing influence on the traffic safety of VRUs in the urban environment?*", was shown on the projector screen to illustrate the objective of the workshop. A set of 19 determinant cards was provided for each group, together with six blanc determinant cards which could be used by the professionals to introduce new determinants. The professionals were free to choose their own strategy to position the determinants on the poster. Two groups (A and C) positioned the determinant *Traffic Safety* in the centre of the poster, while the third group started with *Level of Automation* and worked their way down to the effects. Two groups (A and B) used all of the initial determinants, while the other (C) deleted some determinants and only used eleven of the initial determinants. Two groups (A and C) introduced new determinants such as *Perception driver on abilities of the driving system*, *Perception VRU on traffic safety*, *Imaging/Politics* and *Penetration rate AVs*. Each group showed difficulties with handling the meaning of the determinant card: *Level of Automation*. It was clear that this determinant should have been better defined. The meaning of the determinant was explained to each group after which they continued the process.

After thirty minutes of positioning and linking the determinants, the professionals were told that they would have fifteen minutes to assign weights to the links, either by assigning 0.2, 0.4, 0.6, 0.8, 1.0 or --, -, 0, +, ++. This scale represents respectively a very weak link, weak link, reasonable link, strong link or a very strong link and is based on the scale used by Özesmi and Özesmi (Özesmi & Özesmi, 2004). One group (B) misjudged the classification range and used the negative signs to indicate a negative link (--=strong negative link, - negative link) or the plus signs to indicate a positive link (+=positive link, ++=strong positive link).

In the last five minutes, one representative of each group briefly presented their strategy to construct the model to the other groups and showed which difficulties they had encountered. The professionals took part in the workshop for exactly sixty minutes including introduction and ending.

4.2.3. Conceptual FCM models

The workshop resulted in three conceptual FCM models developed by three different participant groups. These causal maps need to be translated into adjacency matrices that describe the relationships and weights assigned by the participant groups in order to create a FCM model. These maps frequently need adjustments to enable FCM computation and meaningful interpretations, by deleting relationships, adding relationships, renaming determinants and/or introducing dummy variables (A. J. Jetter & Kok, 2014). Figure 10 shows the structure of the conceptual FCM models after post-processing, but does not show detailed information on the determinants and the link weight. Those detailed results, as well as the steps of post-processing, can be found in Appendix – Results participatory workshop. Figure 10 illustrates that the structure between the three conceptual FCM models differs a lot, but also some similarities can be found.

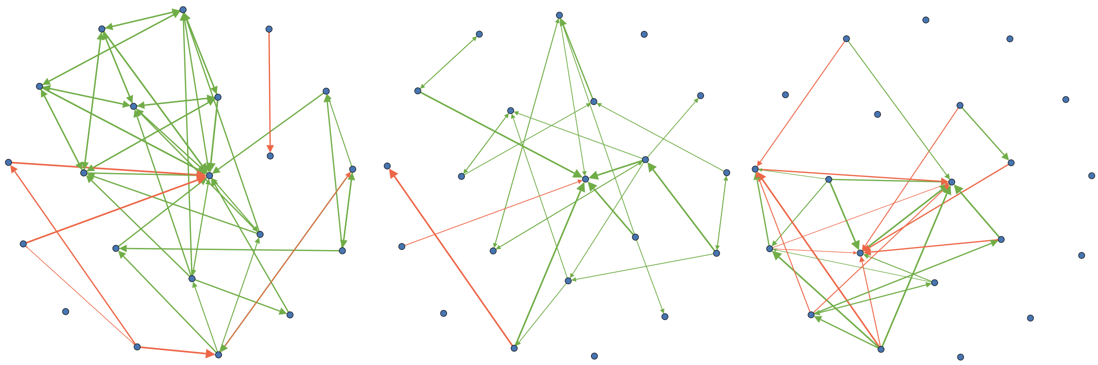


Figure 10: Conceptual FCM Model Group A (left), B (centre) and C (right)

- Group A used a total of 20 determinants and assigned 55 relationships. Three new determinants are introduced by the group, of which they believed should be in the system of interaction but is not included in the initial set of determinants. The new introduced determinants are *Positive perception driver on abilities driving system*, *Positive perception VRU on traffic safety* and *Imaging/Politics*
- Group B used a total of 18 determinants and assigned 29 relationships. No determinants are introduced
- Group C used a total of 12 determinants and assigned 29 relationships. One new determinant is introduced by the group, of which they believed should be in the system of interaction but is not included in the initial set of determinants. The new introduced determinant is *Penetration rate AVs*

The difference in conceptual FCM maps is explained by the fact that a time restriction was set on the workshop. Therefore, the participants might not assign all relationships that they might have assigned when they would have more time. A potential pitfall of this strategy is that neither of the groups assigned a relationship within the time window. However, it is expected that the most important relationships are assigned due to the time limitation. Jetter, Kok, Özesmi and Özesmi argue that a large time window is likely to lead to an overly detailed FCM map that does not accurately describe reality (A. J. Jetter & Kok, 2014; Özesmi & Özesmi, 2004).

Please note that the composition of the groups is expected to have large influence on the assigned links. For example, a group with only urban planners would assign other relationships and weights compared to a group of professionals from the industry. Each professional has its own believe on what relationships are important. Often, professionals assign larger weights to relationships they have experience with then relationships between links that they are rather unfamiliar with. By mixing the stakeholders in the group forming, any differences in believe are dealt with on the spot by the participant group.

Jetter and Kok warn for the pitfall too little care for post-processing, as well as post-processing without sufficient involvement of participants (A. J. Jetter & Kok, 2014). Both practises might lead to a FCM model that does not represent the system that the participants tried to develop. Due to time limitations, the participants were not involved in post-processing. It is therefore chosen to keep the adjustment to a minimum by only adjusting the essential flaws, such as relationships with no weights or determinants that fall outside of the scope. The lack of involvement is mitigated by validation during the interviews in a later stage.

The list below itemizes the post-processing actions that have been taken. A description of these actions can be found in Appendix – Post-processing.

- Remove determinants with disregard of model boundaries
- Combine definitional links
- Deal with misinterpretation of determinants
- Sharpen description of the added determinants
- Add weights to links without weights based on weight assigned by other groups
- Removing links without weights that have no link assigned by the other groups

4.2.4. Detailed FCM model

The conceptual FCM models in the previous section does represent a small portion of the system of interaction, but is not useful to describe the system of interaction yet. Individual FCM models could indicate differences between stakeholder groups if they were divided into groups of the same stakeholders, interests or expertise. This research is not directly looking into difference between stakeholder groups, but is aimed to gain insight in the system of interaction. Therefore, the conceptual FCM models have to be combined into one detailed model.

To mathematically combine the cognitive maps, the conceptual maps are translated into adjacency matrixes of the same size, added and divided by the total number of matrixes (Kosko, 1988). This operation results in a new matrix, of which the entries are the average of the edge weights assigned by the professionals. The combined matrixes and new matrix can be found in Appendix – Combining conceptual FCM models.

Two conflicts arise in the process of combining the matrix. The participant groups have opposing believes of the relationship between de following determinants:

- *Expected behaviour – Safe crossing behaviour*
- *Level of automation – Traffic density*

The first conflict describes the relationship between expected behaviour and safe crossing behaviour. Please note that this is a directed relationship. Therefore, *expected behaviour* is influencing *safe crossing behaviour*, not the other way around. Group A did not assign a relationship between these determinants. Group B assigned a positive relationship with a weight of 0,5. Group C assigned a negative relationship of – 0,8. The second conflict describes the relationship between *level of automation* and *traffic density*. Please note that this is a directed relationship. Group A assigned a negative relationship between these determinants with a weight of -0,2. Group B did found a relationship, but couldn't determine if this relationship was either positive or negative. Group C assigned a positive relationship of 1,0.

It is chosen not to adjust this data. A difference in opinion is a likely result when asking different groups of professionals for their mental maps. Therefore, these links are taking into extra consideration in the sensitivity analysis (paragraph 5.2). In order to make use of these relationships in the detailed FCM model, the relationship is mathematically combined. This results in a negative relationship of -0,1 for *expected behaviour – safe crossing behaviour* and 0,4 for *level of automation – traffic density*. These values represent the average value that the professionals assigned to the links and could therefore be used in the model use. Since the professionals differ in opinion on the relationships, these links are useful for recommendations on further research.

The combined map results in a complex system with a lot of relationships. By mathematically combining the three group models, the change on relative short feedback loops increased. Short feedback loops are back-and-forth arrows between two determinants. Simple causal reasoning on such a feedback system is often difficult. One determinant influences the second determinant, where the second determinant influence the first determinant in the next iteration. This leads to a circular reasoning and understanding de system behaviour is often counterintuitive (Aström & Murray, 2010). It can create dynamic instabilities, cause oscillations or runaway behaviour. On top of that, it might not represent the behaviour that the participants described in the initial models. For example, if group A would have indicated a very strong relation between determinant A and determinant B, and group B indicated a very strong relation between determinant B and determinant A, the resulting links in the combined map would be a short feedback loop between these determinants. This does not represent the mental maps of both groups.

Kok deals with this typical problem by asking participants of a workshop to choose the most important link. The other link is deleted from the model. If possible, the results of the workshop are immediately combined and a group discussion where the participants choose the best option on the spot results in the optimized system (Kok, 2017). Due to time limitations, this post-processing step has not been performed during the workshop. A total of 20 short feedback loops are indicated in the combined matrix (See Appendix – Post-processing).

With a "most votes count" approach, a total of 7 short feedback loops has been removed. This approach uses the number of groups that indicated the link between the determinants. If for example two groups indicated a link between determinant A and determinant B, and only one group indicated a link between determinant B and determinant A, the latter is deleted from the model. The remainder short feedback loops, 13 in total) are assessed by a professional with experience in this knowledge domain and on Fuzzy Cognitive Mapping. Pablo Nuñes Velasco, also a participant of the workshop, indicated which links he found most important. The process and reasoning can be found in Appendix – Post-processing. Please note that different outcomes can be expected by asking a different professional to assess the remainder short feedback loops.

The adjacency matrix of the detailed FCM model and the corresponding visual representation are shown in respectively Figure 11 and Figure 12 on the next page.

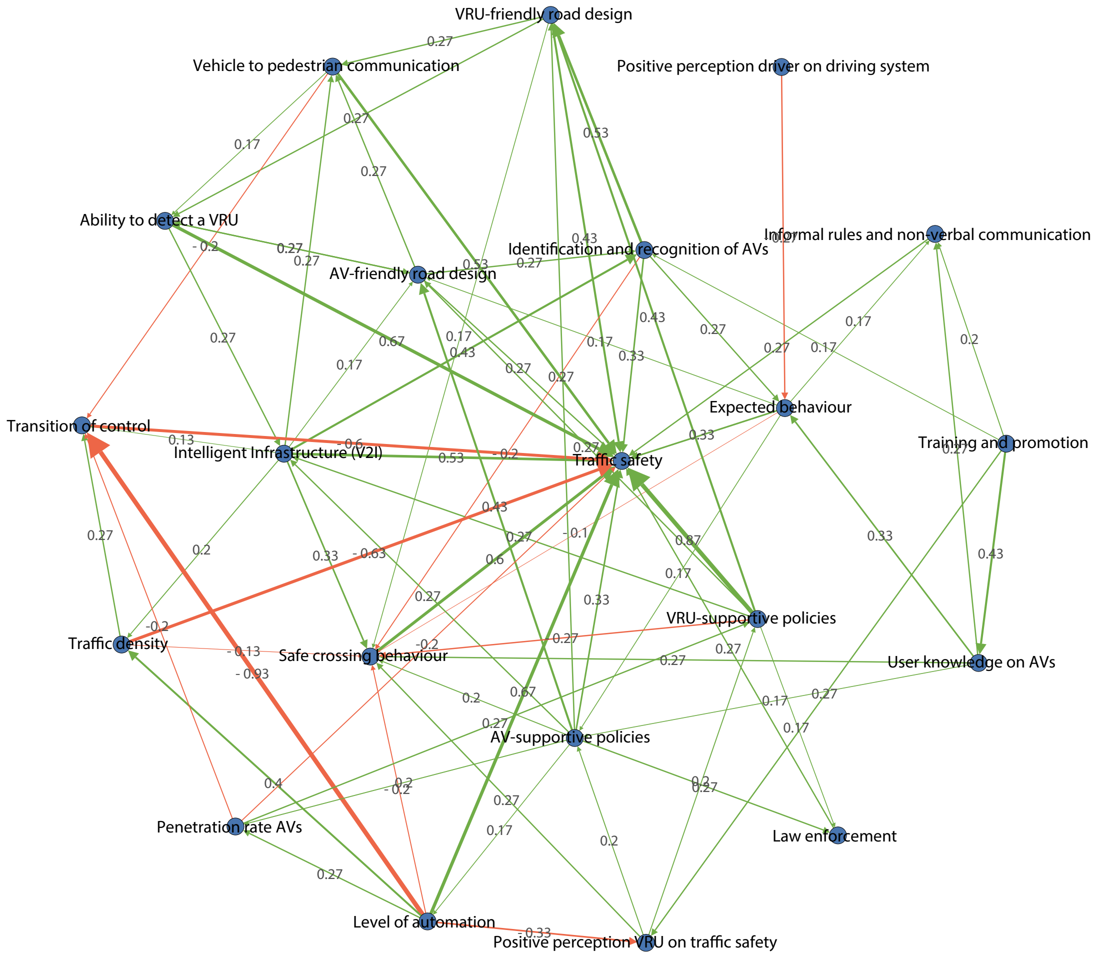
4.3. Conclusions on model development

The objective of this chapter is to develop a model that is able to capture the structure and dynamic behaviour of the system of a safe mutual interaction between VRUs and AVs, so that key determinants and future changes can be identified. The initial set of determinants from the literature study are assessed in the model boundary, which described which determinants will be used in the model and which are considered outside of the scope. A stakeholder analysis provided stakeholders from knowledge and governmental institutions that have participated in a workshop. Goal of this workshop was to develop a model that showed to what extent AVs have a changing influence on the traffic safety of VRUs in the urban environment?

Three groups (a total of 12 professionals) developed three conceptual FCM models. Post-processing dealt with typical error, after which a detailed FCM model is developed by mathematically combining the conceptual models. The detailed FCM model is the results of this chapter and will be used for computations. The detailed FCM model describes how the determinants of a safe mutual interaction between VRUs and AVs influence each other.

		Traffic safety	Safe crossing behaviour	VRU-friendly road design	AV-friendly road design	Training and promotion	User knowledge on Avs	Identification and recognition of Avs	Expected behaviour	Intelligent infrastructure (V2I)	Vehicle to pedestrian communication (V2P)	Ability to detect a VRU	Informal rules and non-verbal communication	Transition of Control	Law enforcement	Level of automation	AV-supportive policies	VRU-supportive policies	Traffic Density	Positive perception driver on driving system	Positive perception VRU on traffic safety	Penetration rate Avs
		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21
Traffic safety	C1																					
Safe crossing behaviour	C2	0,60																				
VRU-friendly road design	C3	0,43	0,17								0,27	0,27										
AV-friendly road design	C4	0,27						0,27			0,27	0,27										
Training and promotion	C5						0,43	0,17					0,20								0,27	
User knowledge on Avs	C6		0,27						0,33				0,27				0,17					
Identification and recognition of Avs	C7	0,33	-0,20	0,53					0,27													
Expected behaviour	C8	0,33	-0,10		0,17								0,17				0,17					
Intelligent infrastructure (V2I)	C9	0,53	0,33		0,17			0,43			0,27			0,13					0,20			
Vehicle to pedestrian communication (V2P)	C10	0,53										0,17		-0,20								
Ability to detect a VRU	C11	0,67			0,27					0,27												
Informal rules and non-verbal communication	C12	0,27																				
Transition of Control	C13	-0,60																				
Law enforcement	C14	0,27																				
Level of automation	C15	0,67	-0,20											-0,93					0,40		-0,33	0,27
AV-supportive policies	C16	0,33	0,20	0,27	0,43					0,27					0,27	0,17						0,20
VRU-supportive policies	C17	0,87	-0,27	0,43	0,27					0,27					0,17							
Traffic Density	C18	-0,63	-0,13											0,27								
Positive perception driver on driving system	C19								-0,27													
Positive perception VRU on traffic safety	C20		0,27														0,20	0,20				
Penetration rate Avs	C21	-0,20												-0,20				0,27				

Figure 11: Adjacency matrix of the combined cognitive map after post-processing (yellow=negative, blue=positive)



Positive relationship

Negative relationship

Figure 12: Visual representation of the detailed FCM model (green=positive relationship, red=negative relationship)

5. Model results

This chapter provides the model results. Results on the model structure and dynamic behaviour are presented in paragraph 5.1). A sensitivity analysis is executed to assess the robustness of the model (5.2). Paragraph 5.3 provides conclusions on this chapter.

5.1. Model structure and dynamic behaviour

5.1.1. Model structure

This section provides the results of the detailed FCM model.

Table 3: Matrix indices

Indices	Value
Density	0,16326
Total # determinants	21
Total # connections	72
# Transmitters	2
# Receivers	1
# Ordinary	18

The indices show that a total of 21 determinants describe the system of interaction with 72 unique links assigned between the determinants. The density shows the degree to which the determinants are connected to each other, and is calculated by the total amount of connections divided by the number of possible connections between all determinants (Wildenberg, 2010). Two determinants are considered a pure transmitter, a determinant that only has outbound relationships and no ingoing relationships. There is one pure receiver, a determinant that as only ingoing relationships and no outbound relationships. The total number or ordinary determinants (determinant with both ingoing and outbound relationships is 18.

Centrality

The centrality of the determinants is considered the most important index in the model (Obiedat, Samarasinghe, & Strickert, 2011) and indicates the importance of a determinant in the system. The centrality of each determinant is presented in Figure 13. The 5 most important determinants, called key determinants, are used in the next phase of the FCM approach to gain extensive knowledge. The key determinants have logically the highest centrality in correspondence with Obiedat, Samarasinghe and Strickert. Five key determinants are chosen to make sure that the most important determinants are being further assesses, while the least important determinants are outside of the scope for the remainder of this research (thus prioritizing).

Traffic safety shows the highest centrality with a value of 7,53. This high value compared to the other determinants is caused by the fact that this determinant is used as a target concept. Therefore, each participant group focussed on the effect that determinants have on the *traffic safety*. It would be wrong to assess the centrality of the target concept relative to other determinants. This determinant is therefore not qualified to be a key determinant. Also, the exogenous determinants, which are likely inputs in the system, does not qualify for a key determinant. The FCM model is used to compute the effect exogenous determinants have on the system. Therefore, we are not interested in the centrality of the exogenous determinants.

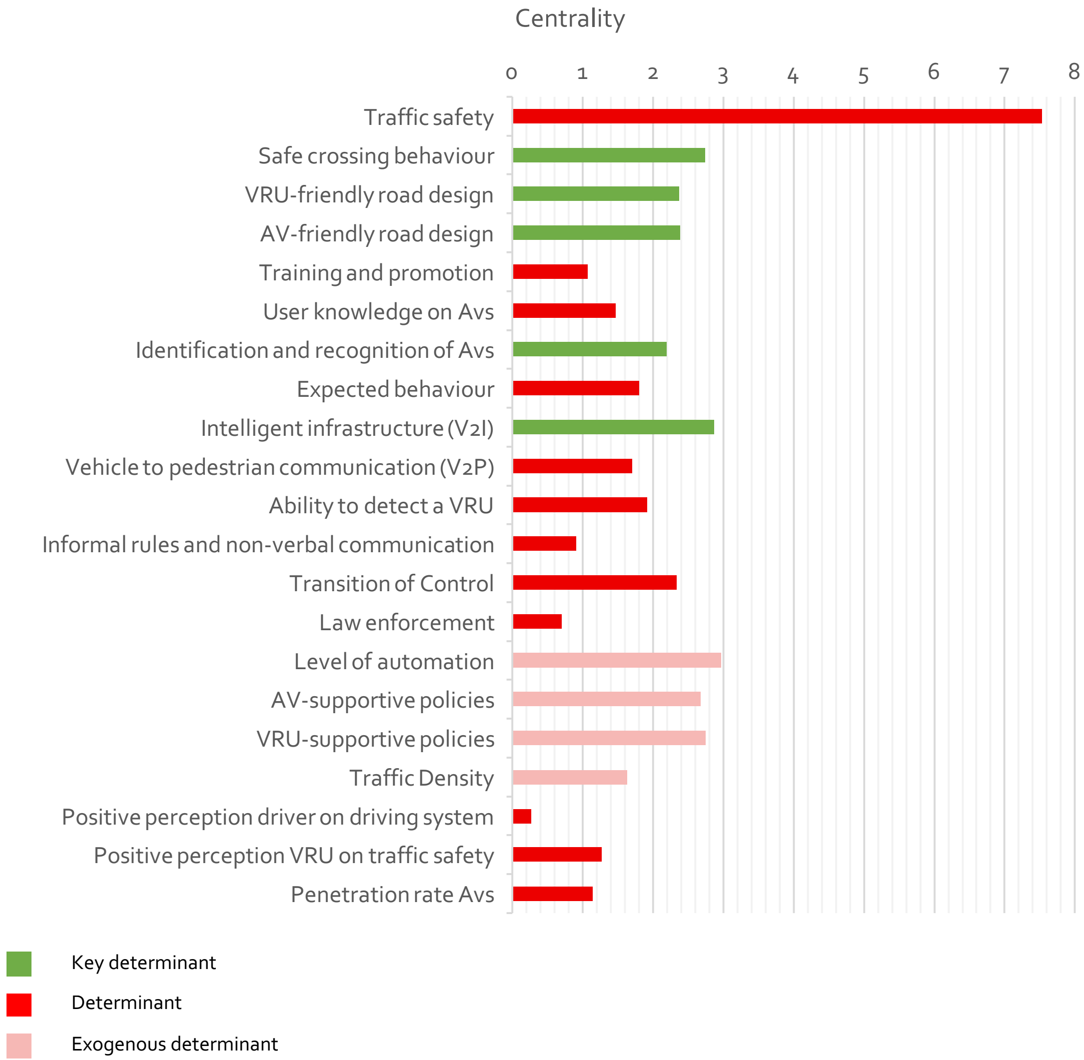


Figure 13: Centrality

The following list summarizes the top 5 determinants with the highest centrality in descending order:

- Intelligent infrastructure (V2I) (2,87)
- Safe crossing behaviour (2,74)
- AV-friendly road design (2,39)
- VRU-friendly road design (2,37)
- Identification and recognition of AVs (2,20)

Please note that determinant *Transition of control* should also be a key determinant with a value of 2,33. Unfortunately, this determinant increased in value after an additional post-processing step has been performed shortly after the interviews were planned for the key determinants as described above. Due to a lack of time, an additional interview on this determinant is not executed. The recommendations provide further information on this matter.

The following list summarizes the top 5 determinants with the lowest centrality in ascending order:

- Positive perception driver on driving system (0,27)
- Law enforcement (0,71)
- Informal rules and non-verbal communication (0,91)
- Training and promotion (1,07)
- Penetration rate AVs (1,14)

Indegree

The indegree describes the cumulative strength of connections to which a determinant is affected by other determinants (Yoon & Jetter, 2016). The following determinants are strongly affected by other determinants in descending order:

- Traffic safety (7,53)
- Safe crossing behaviour (2,14)
- Transition of control (1,73)
- AV-friendly road design (1,31)
- VRU-friendly road design (1,23)

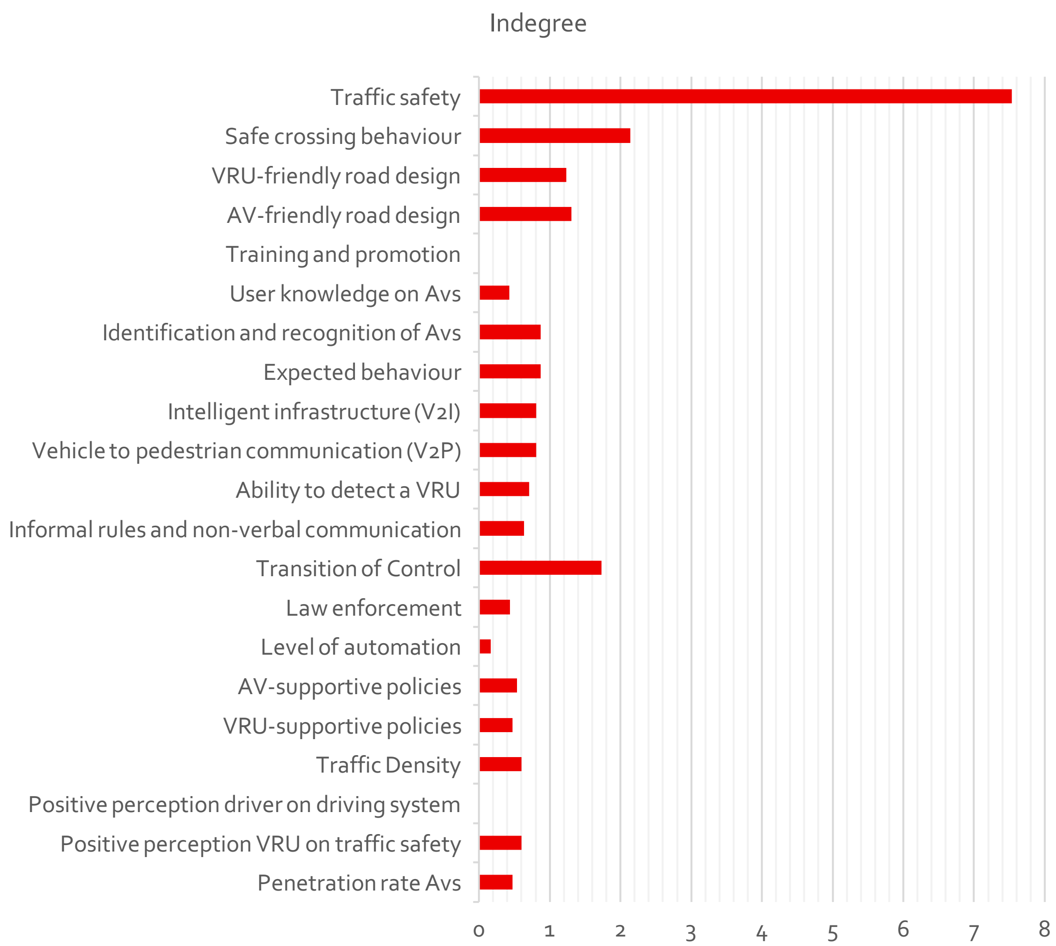


Figure 14: Indegree

Traffic safety, the only pure receiver, is again not taken into consideration. The other four determinants with a high indegree are classified as ordinary determinant with both incoming and outgoing arrows. The determinants each show a higher indegree compared to the average indegree of other determinants, although the number of indegree is relative low. This value represents the cumulative strength (weight) of the incoming arrows. Therefore, a negative relation towards the determinant does not lower the indegree, but is added to the cumulative strength, which resembles reality.

It can be seen that *Training and promotion* and *Positive perception driver on driving system* have an indegree of 0, and are therefore classified as pure transmitters (if they have an outdegree).

Outdegree

The out degree describes the cumulative strength of connections with which a determinant influences other determinants (Yoon & Jetter, 2016). The following determinants strongly influence other determinants in descending order:

- Level of Automation (2,80)
- VRU-supportive policies (2,28)
- AV-supportive policies (2,14)
- Intelligent Infrastructure (V2I) (2,06)
- Identification and recognition of AVs (1,33)

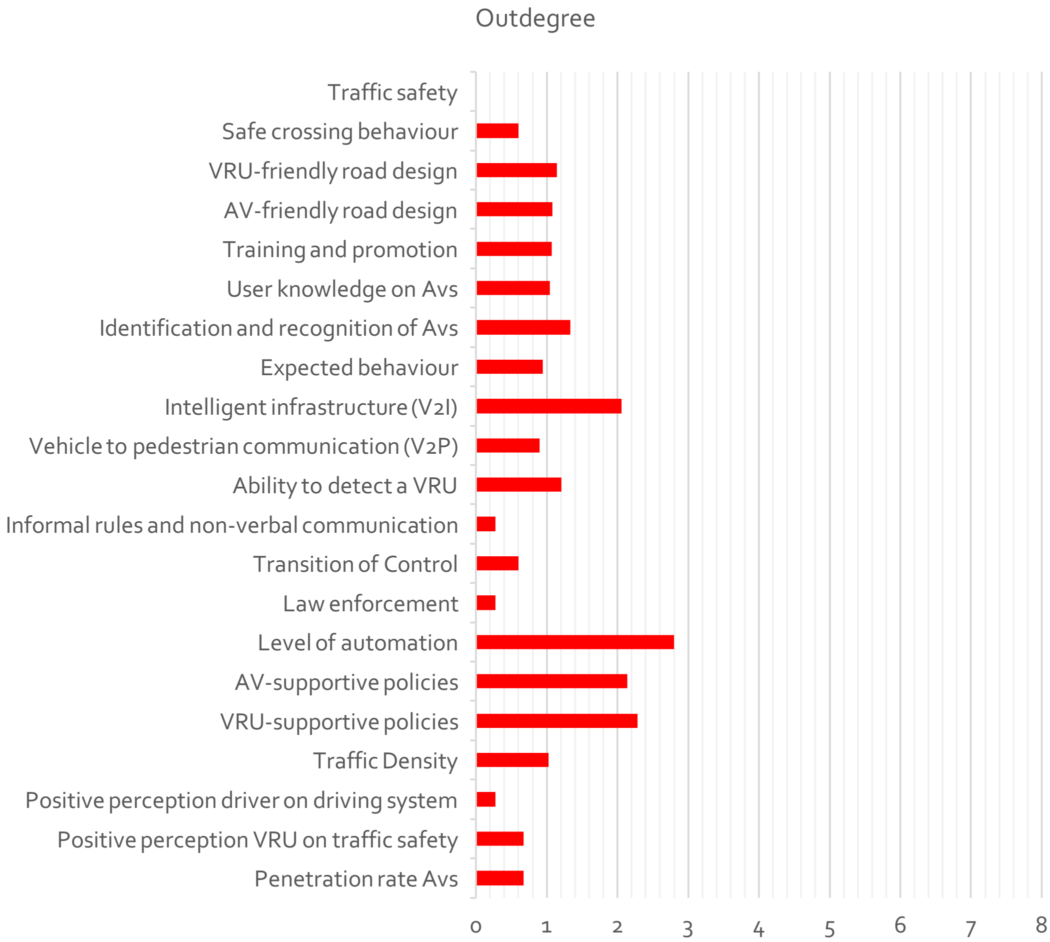


Figure 15: Outdegree

The value represents the cumulative strength (weight) of the outgoing arrows. Therefore, a negative relation outwards of the determinant does not lower the outdegree, but is added to the cumulative strength. Even though *Level of automation* and *VRU supportive policies* have fewer outgoing arrows (each 6), they have a higher outdegree compared to *AV supportive policies* and *Vehicle to pedestrian communication (V2P)* (each 7). This can be explained by the fact that both determinants have one or two strong relationships towards other determinants.

It can be seen that *Traffic safety* has an indegree of 0, and is therefore classified as a pure receiver (if it has an indegree).

5.1.2. Dynamic behaviour of the model

FCM modelling allow a quantitative analysis of the dynamic behaviour and therefore helps to understand the influence exogenous determinants (inputs) have on other determinants in the system of interaction. This allows for planners to agree on plausible combinations of exogenous determinants for independent FCM determinants and assess the complexity of the problem (A. J. Jetter & Kok, 2014). The model is run for four different scenarios based on exogenous determinants with a high centrality. This means that *traffic density* is no longer considered an input of the system. Considering an average value for both indegree and outdegree, this determinant can be classified as an endogenous determinant.

In each scenario, a state vector assigns a value 1 to one of the exogenous determinants. In the fourth scenario, a state vector combines all three determinants by assigning a value 1 to each of the exogenous determinants. The software calculates the new values of the determinants when the system reaches a steady state. The newly gained value indicates how strong determinants have changed (positive or negative) relative to other determinants. This section shows the results for each scenario.

The FCMappers software classifies the following strengths in value changes for a difference in value between the base scenario and the calculated scenario:

- (+/-) Δ 0,01 Strong change
- (+/-) Δ 0,001 Medium change
- (+/-) Δ 0,0001 Weak change
- (+/-) Δ 0,00001 Very weak change

As can be seen in the list above, the changes can be very small. The graphs in this paragraph can therefore be hard to read to very weak or weak changes. This is not a problem, since the most interesting results can be found in medium and strong changes. If a value exceeds the axis, the graph element is given a gradient at the top. Such large values are neither of any importance to represent in a graph, since we classify the value changes the four categories described above. A visualisation (heat map) of the determinants changes for each scenario is presented in Appendix – Heat maps scenarios.

Each scenario concludes with a reflection on the strong and medium changes. Please note that the "why" component, thus why certain behaviour occurs, is not part of the methodology (Gray et al., 2015). FCM is not able to assist in such behaviour, and the reflection is therefore based on the interpretation by the student. In interviews with four professionals, assumptions made by the participants and remarkable results are discussed (see Appendix – Interviews).

Level of automation

The state vector assigns a value of 1 to determinant *Level of automation*. This scenario describes the behaviour of the system when the level of automation increases. The value changes of the determinants for this scenario are presented in Figure 16, where the managed determined is indicated in light green.

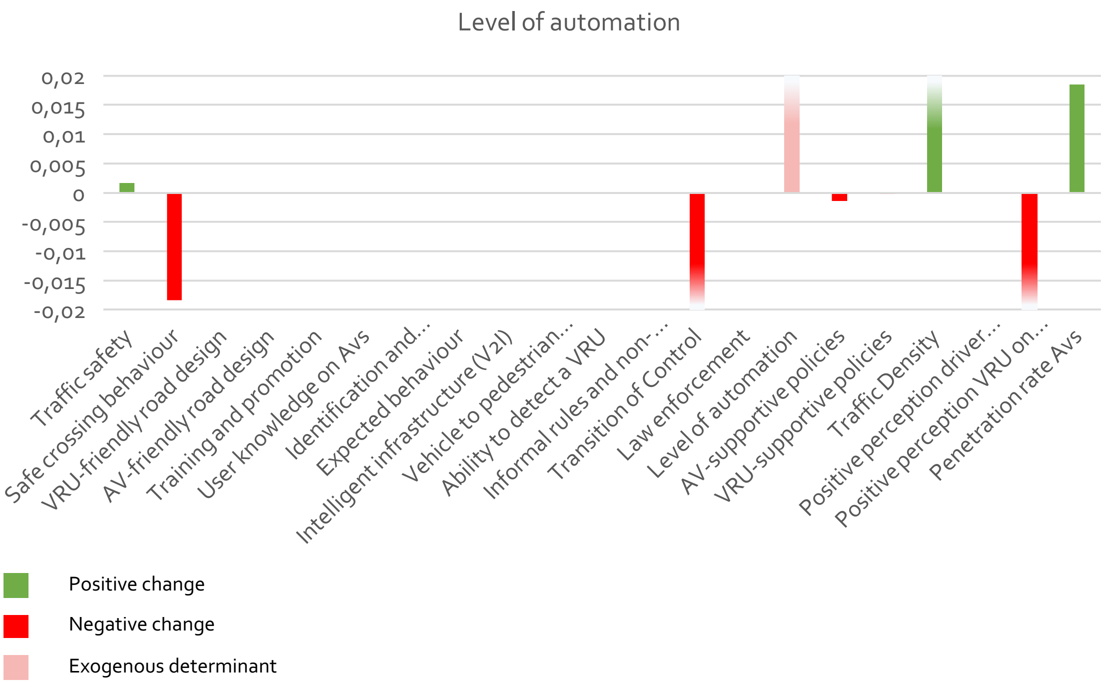


Figure 16: Value changes for scenario Level of automation

Merely three determinants show a positive value, namely *Traffic safety (medium)*, *traffic density (strong)* and *penetration rate of AVs (strong).* This means that if *the level of automation* increases, *traffic density* is expected to strongly increase. This can be explained by the fact that AVs with a high level of automation can drive with a lesser gap acceptance compared to manual driven vehicles. Therefore, the average number of vehicles that occupy one kilometre of road space can strongly increase. When automated driving systems are increasingly developed, the result will lead to more and more AVs on the market (increasing penetration rate).

The majority of the determinants show a negative value, of which most changes are very weak (and therefore hardly visible). *Safe crossing behaviour*, *transition of control* and *positive perception VRU on traffic safety* each show a strong negative change. More and better systems to identify VRUs and automatic brake responses are expected for a higher level of automation. The strong negative change in value for *Safe crossing behaviour* can be therefore be caused by VRUs that rely increasingly on the automated driving systems. They would make other, less safer decisions while crossing when they know that the AV is going to stop for them. Note that a strong negative change does not automatically mean that the crossing behaviour will be automatically dangerous, but can also mean that the behaviour will be less safe (but still be safe). The strong negative change for a *positive perception VRU on traffic safety* can be explained by the decrease in safe crossing behaviour. VRUs behave less safe at crossing, and therefore might perceive a less safer perception of traffic safety.

A higher level of automation leads to a strong negative change in *Transition of Control*. When automated driving systems are more advanced, the attention of the driver is to a lesser extent required. The driver is able to drive on more roads and for longer distances without having to pay attention to the road. This results in a longer time to regain full focus when regaining control over the vehicle.

AV-supportive policies

The state vector assigns a value of 1 to determinant *AV-supportive policies*. This scenario describes the behaviour of the system when policymaking as a whole favours the development, introduction and usage of AVs. The determinant changes for this scenario are presented in Figure 17, where the managed determined is indicated in light green.

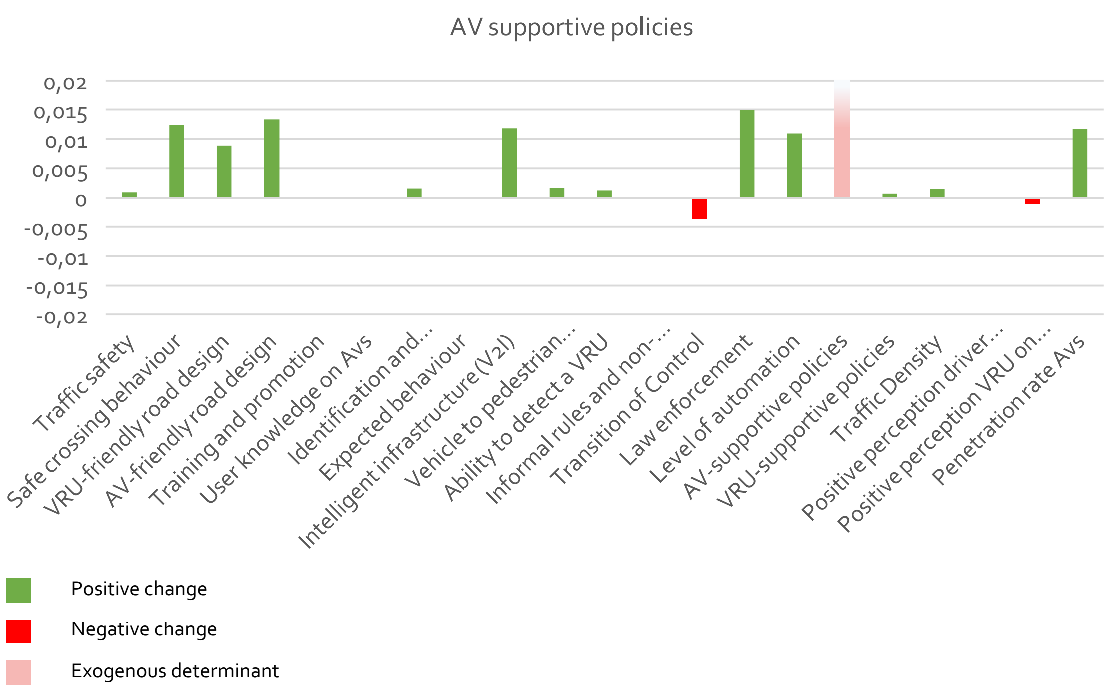


Figure 17: Value changes for scenario AV supportive policies

A lot of determinants show a strong positive change in value, namely *Safe crossing behaviour, AV-friendly road design, Intelligent infrastructure (V2I), Law enforcement, Level of automation and Penetration rate AVs*. AV supportive policies lead to a strong positive change for level of automation, which is a logical result. Remarkably, the higher level of automation does not automatically lead to a negative safe crossing behaviour in this scenario, even though this was the result in the previous scenario. Influences by other determinants therefore caused the value of safe crossing behaviour to shift to a positive change. Naturally, when policies support the development and usage of AVs, road design focus to a greater extent readiness of AVs. This potential of intelligent infrastructure also increases positively by for this road design and the availability of automated driving systems, with which the V2I-system can communicate. The penetration rate of AVs is similar to the previous scenario a logical result. Remarkable is the strong positive change for law enforcement. This can be caused by the fact that AVs might provoke abuse. Law enforcement need to make sure such abuse will not take place. The determinants *VRU-friendly road design* shows a medium positive change. Apparently, when AVs are introduced to the urban environment, focus on road design for VRUs is also required, for example new designed bike paths or crossings.

Just as was the case for the scenario of Level of automation, *Transition of control* and *Positive perception VRU on traffic safety* show a medium negative value change. However, in this case the change is no longer strong. This is caused by other determinants influencing these determinants in such a manner that the negative change is less strong.

VRU-supportive policies

The state vector assigns a value of 1 to determinant *VRU-supportive policies*. This scenario describes the behaviour of the system when policymaking as a whole favours measures that supports the traffic conditions for VRUs. The determinant changes for this scenario are presented in Figure 18, where the managed determined is indicated in light green.

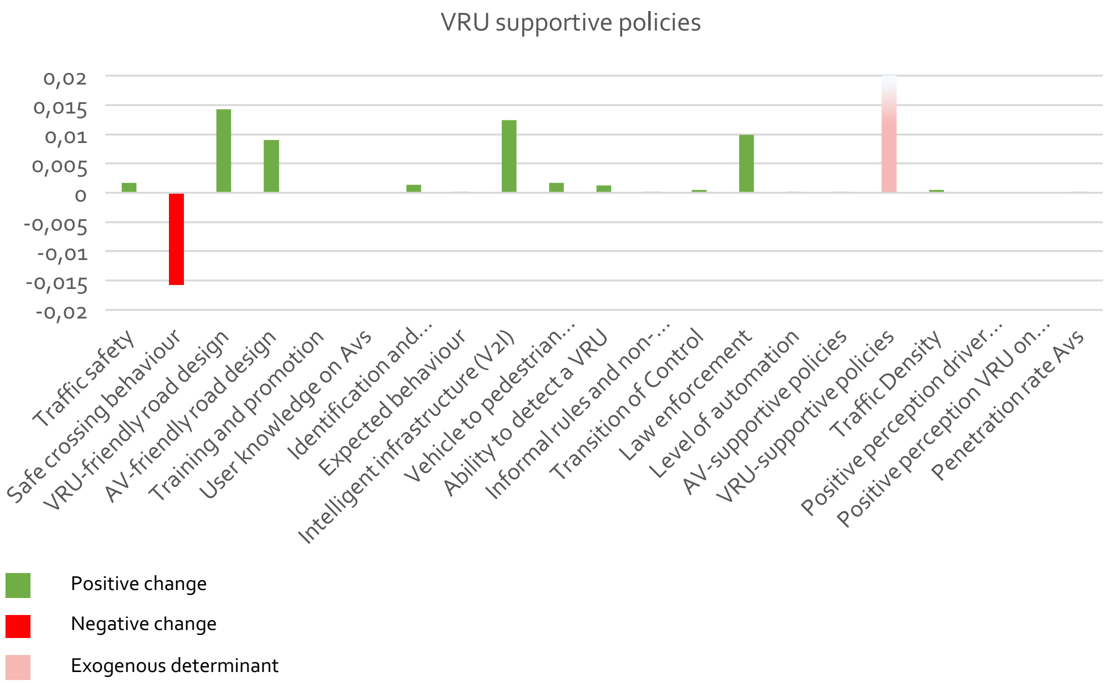


Figure 18: Value changes for scenario VRU supportive policies

Determinants *VRU friendly road design* and *Intelligent Infrastructure (V2I)* show a strong positive change. Road design that supports VRUs is a logical result for a focus on VRU supportive policies since this determinant need to make sure that VRUs can use the road network safe and to their full potential. The potential of intelligent infrastructure is also increased in this scenario. This can be explained by the fact that V2I systems can increase the safety for VRUs when AVs are warned of the position of VRUs by the surrounding infrastructure. *AV-friendly road design* and *law enforcement* show a medium positive change. Similar to the previous scenario, apparently increasing focus is required for AV road design, for example for new designed crossings.

A strong negative change is computed for *Safe crossing behaviour*. VRUs have an increasing primacy on public roads and therefore might get unaware of the dangers in the interaction with other (automated) vehicles. The increase in law enforcement can be related to this negative change in crossing behaviour. Note that a strong negative change does not automatically mean that the crossing behaviour will be automatically dangerous, but can also mean that the behaviour will be less safe (but still be safe)

Combination of determinants

In reality it can be expected that a focus on a combination of determinants is used. The previous sections showed scenarios where only one determinant was assigned a value of 1 by the state vector. For this scenario, the state vector assigns a value of 1 to all three exogenous determinants. The determinant changes for this scenario are presented in Figure 19.

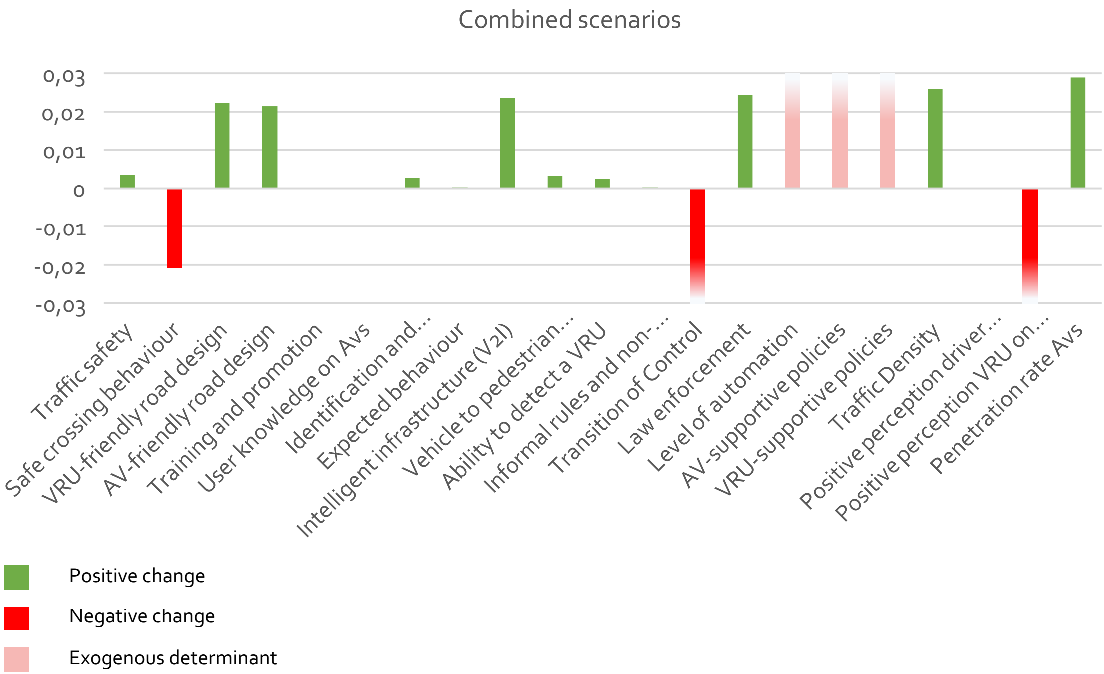


Figure 19: Value changes for combined scenarios

The combined scenario resulted in a larger number of strong changes compared to the individual scenarios. A strong positive change can be found for the determinants *VRU-friendly road design, AV-friendly road design, Intelligent Infrastructure (V2I), Law enforcement, Traffic density* and *Penetration rate of AVs*. A strong negative change is found for determinants *Safe crossing behaviour, Transition of control and Positive perception VRU on traffic safety*.

In general, determinants with a higher centrality are more affected by the scenarios. However, *Transition of control* and *Positive perception VRU on traffic safety* have a low centrality, by are important to take into consideration for scenario planning.

5.2. Sensitivity analysis

Two conflicts came up during the development of the aggregated matrix. The participant groups indicated conflicting relationships between the determinant duo's *Expected behaviour – Safe crossing behaviour* and *Level of automation - Traffic density*. This resulted in a value that does not describe the behaviour of the system that the participants initially indicated. This section assigns different values to these determinants to assess the sensitivity of the model. For each conflict, two alternatives are used in the analysis. The dynamic behaviour is assessed for two scenarios, namely with a focus on *AV-supportive policies* and *VRU-supportive policies*.

Alternatives for Expected behaviour – Safe crossing behaviour

This alternative assesses the relationship between *Expected behaviour* and *Safe crossing behaviour*. The participant groups assigned value to this relationship of 0, 0,5 and -0,8. The aggregated matrix summed these values and divided it by three, resulting in a link weight of -0,10. If the values were either both positive (a) or both negative (b), different results may occur in the dynamic behaviour. The link weight for the sensitivity analysis is (a) $\frac{(0+0{,}5+0{,}8)}{3} = 0{,}43$ and (b) $\frac{(0-0{,}5-0{,}8)}{3} = -0{,}43$.

Little change is found in the dynamic behaviour of the model. When looking at the scenario of AV-supportive policies, only one determinant, *Safe crossing behaviour*, shows a medium increase instead of a strong increase for both the positive and negative value. The other determinants showed no change. The determinants showed no change for the scenario of VRU-supportive policies.

Alternatives for Level of automation – Traffic safety

This alternative assesses the relationship between *Level of automation - Traffic density.* The participant groups assigned value to this relationship of -,2, ? and 1. The group that assigned the question mark found a relation between these two determinants, but was unable to come to a consensus on the value. The aggregated matrix summed these values and divided it by three, resulting in a link weight of 0,27. If the values were either both positive or both negative, different results may occur in the dynamic behaviour. A value of -0,5 and 0,5 is chosen for the question mark, since this is the exact mid in the range [0,1] The link weight for the sensitivity analysis is (a) $\frac{(0{,}2+0{,}5+1{,}0)}{3} = 0{,}57$ and (b) $\frac{(-0{,}2-0{,}5-1{,}0)}{3} = -0{,}56$.

Again, little change is found in the dynamic behaviour of the model, although with a higher impact in the dynamic behaviour compared to the previous alternative. When looking at the scenario of AV-supportive policies, one determinant, *Traffic density*, shows a significant change. Instead of a medium increase in the alternative with positive value, it will show a medium decrease in the alternative with a negative value. The other determinants showed no change. The determinants showed no change for the scenario of VRU-supportive policies.

Value change

A third sensitivity analysis is performed for a small change in the system. The link weights are assigned an increase of 10% or a decrease of 10%. The minimum and maximum value is set to -1 and 1 the make sure the link weights remain in the model range.

An increase of 10% results in a small change in the dynamic output when focussing on AV-supportive policies. *Expected behaviour* shows a weak increase instead of a very weak increase compared to the base scenario. In the scenario with focus on VRU-supportive policies, *Law enforcement* shows a strong increase instead of a medium increase compared to the base scenario. The other determinant show no change in the same dynamic behaviour.

A decrease of 10% results in a small change in the dynamic output when focussing on AV-supportive policies. *Traffic safety* shows a medium increase instead of a weak increase compared to the base scenario. A second change for this scenario is found for *Positive perception VRU on traffic safety,* which shows a weak decrease instead of a medium decrease compared to the base scenario. In the scenario with focus on VRU-supportive policies, no change is found in the dynamic behaviour.

Self-loops

Self-loops can be assigned to determinants in fuzzy cognitive maps, resulting in a value between -1 and 1 (not equal to zero) in the diagonal of the matrix. Self-loops describe the behaviour of an influence the determinant has on itself, thus direct feedbacks. If a determinant is in an increasing or decreasing trend, a self-loop would strengthen this trend.

In the practise of FCM it is accepted that a determinant cannot have an effect on itself (Buruzs, Koczy, & Hatwagner, 2015). This means that the diagonal in the matrix only contains of zeros. Reason for this is that the determinant can growth without limits when a self-loop is assigned. However, because of the ability of feedback-loops in a FCM model, this behaviour can occur nevertheless. Burusz et all. believe that a self-loop could be permitted because a large number of positive cycles can be found in most FCM matrices. The effect is such cycles would be the same as self-loops.

The participants in the workshop did not assign any self-loops to the model. Therefore, this behaviour is not used in the FCM model. To assess the influence of self-loops, they are assigned to *AV-supportive policies* and *VRU-supportive policies*. The dynamic output showed small changes in the strength of increase of decrease. Almost 70% of the determinants will show a reduced increase or decrease, where the maximum change is 1 step (from strong change to medium change, from medium change to weak change, from weak change to very weak change). It can be said that self-loops have little influence on the system and are therefore not taking into further consideration.

Conclusion on sensitivity analysis

The sensitivity analysis shows that little change in dynamic behaviour is expected when the conflict area *Expected behaviour* and *Safe crossing behaviour* changes its value. A difference between positive or negative value is not found. A small difference, a medium increase instead of a strong increase, is found for *Safe crossing behaviour* when both participant groups assigned either a positive or negative value to the link.

The most change is found in alternative 2. With a focus on AV-supportive policies, the traffic density will either increase or decrease for a positive or negative value. The effect of this change can have a high impact. Therefore, this determinant need to be monitored closely.

The model is not very sensitive for small increases or decreases in the link weights and for self-loops.

5.3. Conclusions on model results

The model results provide the most relevant and important determinants of a safe mutual interaction between VRUs and AVs to use in further research and pilots. The centrality of a determinants determines the importance in the system of interaction. Five determinants with the highest centrality are *safe crossing behaviour, VRU friendly road design, AV friendly road design, identification and recognition of AVs* and *intelligent infrastructure* are the most important determinants according to the model.

The model also computed the dynamic behaviour of the determinants of a safe mutual interaction between VRUs and AVs. Four model runs are performed for four scenarios. Each scenario is described by an exogenous determinant, which provides input for the system.

Sensitivity analysis analysed the effect of two relationships that the professionals assigned conflicting values. Little change is found, which indicate a robust model. The sensitivity analysis also showed that the model is in general pretty robust an insensitive for small value changes (+/- 10%).

6. Case: AV pilots in Amsterdam

This chapter applies the results from the methodology into a case. The practical case aims recommends on pilots that can be designed to test AVs in the urban environment. Extensive knowledge is gathered on the key determinants in interviews with four professionals. This information is used as background information for this chapter. Summaries and transcripts, together with the description of knowledge capture, are provided in Appendix – Interviews.

6.1. General description

Vehicles are developed in a gradually increasing level of automation towards autonomous driving, in which a vehicle is fully automated and does not require the supervision of a human. Before such autonomous vehicles are available for the consumer, a lot of tests with highly automated vehicles are needed to address practical and technical challenges.

There is a difference in the development path of automated vehicles between Europe and the United States (US). Europe focusses the development of cooperated vehicles. Cooperated vehicles can communicate with other vehicles, surrounding infrastructure or with a control centre. Such vehicles are not self-driving in essence, but can be supported in automation driving systems such as Adaptive Cruise Control (ACC), Lane Departure Warning (LDW) and platooning (CROW, 2014a). In the US, the focus is more on the development of robotic vehicles which have to ability to drive autonomously. These vehicles depend solely on their own technology for automated driving and collect data from the environment by using their own sensors such as radar, lidar and GPS. Examples of robotic cars are also found in the Netherland with for example the WEPods.

In the Netherlands, several pilots are currently executed or have been executed for highway chauffeur, truck platooning, automated collision avoidance and ITS systems (CONCORDA, 2017; CROW, 2014a). These pilots take place on a closed track or on highways and arterials. This research looks into the scenario where AVs have to interact with VRUs, thus on public roads with crossings and longitudinal VRU-traffic. Pilots with people movers such as the WEPod look into the interaction between the pod and VRUs. However, this vehicle does not make use of traffic rules, is in essence only programmed to drive a prefixed route and is programmed to stop in case an object blocks its path (de Craen, 2017). In the WEPod, a steward is present which supervises the process and is able to intervene if necessary. After a while, the steward is supposed to be replaced by remote supervision from a control centre. The example of the WEPod illustrates how small the current steps are in testing AVs. A field in which little or no pilots are executed in the Netherland is for level 3 and level 4 automation of passenger vehicles in the urban environment. This advisory focus on this type of AV with an interaction with VRUs.

6.1.1. Needs, objectives

There is a need for largescale testing of innovative concepts such as automated vehicles. This can support new options to steer, guide advice and inform on developments in automated driving for the City of Amsterdam, but also other stakeholders in the Netherlands and abroad (PPA, 2017). Amsterdam is considered an interesting metropolitan area for a largescale testing site, with a collaboration between multiple stakeholder such as City of Amsterdam, Practical Trial Amsterdam (PPA), Amsterdam Metropolitan and the Province of North Holland.

The overall objective global pilot project is to address the practical, organisational and technical challenges faced due to the additional layer of complexity introduced by connected and automated vehicles (CONCORDA, 2017). The overall objective is made fit for pilots with special attention on the interaction between AVs and VRUs with the following list op of objectives:

- To integrate, test and validate required technologies in support for the pre-deployment of automated vehicles, in light of the identification of gaps and recommended transition paths
- To test and simulate automated vehicles in real-life circumstances to better understand and assess impacts on traffic safety
- To log, monitor and share data derived from experiments and tests so other stakeholders can get an improved understanding of AVs
- To prepare the traffic system for mixed traffic in terms of automation

6.2. Activities

This paragraph elaborates briefly on the activities that should be performed in the organisation, preparation, operation and evaluation of the pilot.

Project management

The drivers and goals of the pilots are determined in the project management phase. The project plan elaborates upon the research questions and provides a detailed description on what to test, with how many vehicles, what (kind of) roads, when, how long etc. A planning is created to illustrate to duration of the project step towards the finished product. Desk analysis identifies safety- and environmental risks and propose preventive and mitigation measures.

Relevant stakeholders are identified and a pilot team is created. Stakeholder engagement ensures a single-minded purpose, shared goals and knowledge sharing. This results in an implementation plan. The implementation plan contains i.a. plans for coordination of all activities, plans for communication, guidelines and requirements. Also, an exemption has to be filed with the RWD for testing.

A pilot framework should include all of the products described above. This framework will be used in the pilot, but also enable testing the same pilot on other sites.

Pilot roll out preparation

This phase consists of an iterative approach to develop an interoperable network on the test side for the following three subjects: Technology, Services and Implementation (CONCORDA, 2017). This results in a set of profiles, specifications and standards for the pilot, which are shared by all participating parties. Next, an analysis should be performed on existing and relevant pilots and technologies. The set of profiles, specifications and standards for the pilot are assessed and compared to the relevant pilots and technologies. This prevents errors that have already been identified by other projects, but also ensures that the pilot is filling a research gap.

Finally, KPIs are identified that will be used to measure the performance of the pilot.

Technology integration

State of the art and proven technology will be used in the test vehicle(s) and on the test site. These technologies should be implemented in this phase prior the actual pilot. After the technology is integrated in the test vehicle(s) and on the test sites, initial testing should be performed on closed proven ground by the RDW (CROW, 2014b). The RDW gives their approval of the technology based on the performance on the closed track before the test vehicles are allowed on the public roads.

Pilot operation

The aspect of "why" is one of the main questions according to Methorst (Methorst, 2017). Results should therefore be monitored and documented with great detail within a pilot operation framework. This framework can be used on other test sites as well, to validate results and behaviour. This provides consistent evaluation procedures. KPI guidance ensures that all relevant results are documented.

Transparent communication is important for all stakeholders and road users on the test site.

Evaluation and possible iterations

A solid evaluation procedure contributes to the "Learning by Doing" philosophy. The pilot framework is evaluated and possible improvements are proposed. Quantitative data should help evaluate the effect on the system performance and traffic safety, but also qualitative data (experience of road operators, service providers, fleet operations and road users) is important data in the evaluation of the pilot. The above products are used in an impact assessment that assessed the technology of automated driving in the traffic system.

Knowledge sharing

The impact assessment leads to recommendations on regulations and policy, but also to recommendations on improvements of the pilot framework. The development of automated driving technologies could thrive when results and recommendations are openly shared to anyone who is interesting. This prevents mistakes and errors from happening twice, and validation of follow-up pilots can be created within the same framework. An exchange platform can help to share knowledge from individual studies or pilots, and make it available for authorities or OEMs. However, it is questionable if all participating stakeholders are willing to share the results openly, since they don't want other parties to use their knowledge without investing in the project.

6.3. Practical and technical challenges

This paragraph describes the practical (6.3.1) and technical challenges (6.3.2) that are expected to arise when designing and executing pilots on the system of interaction. If a city is interested in pilots on the mutual interaction between VRUs and AVs, the following practical and technological challenges are important according to the model and professionals.

6.3.1. Practical challenges

A lot of practical challenges arise in the development of automated driving systems. Based on the model results and interviews, the following practical challenges are identified.

Step by step

Today a handful of pilots on automated driving is executed in the Netherlands. As soon as a new pilot is planned or started, the media reports with great enthusiasm on the pilot. Headlines such as "Self-driving vehicles are allowed to go on the public roads" (*Zelfrijdende auto's mogen de openbare weg op*) (NOS, 2017) and "Brabant lets self-driving vehicles test on the public road" *(Brabant laat zelfrijdende auto's testen op de openbare weg)* (RTL, 2017) makes it look like self-driving vehicles can be seen any day now, although scientific research in chapter 0 showed that autonomous vehicles cannot be expected in the next couple of years.

The pilots that are currently being executed only test for a small fraction of the total system of automated driving (de Craen, 2017). It is therefore important to realise that AV pilots are expected to test the technology step by step. The technology should first be tested with a steward on board, that can intervene and take over control when necessary. After a while, the steward can be replaced with remote supervision from a control centre (Happee, 2017). The subsequent and final step is test autonomous vehicles, that are able to operate driving tasks without a human supervising or being able to take control.

Location

A location for testing in Amsterdam should be determined. It is not likely that car manufacturers will develop an AV that can only be used in one city (Happee, 2017). Therefore, the location should be such a general location that it can be representative for other locations in Amsterdam, the Netherlands and possible the whole world.

It is recommended to search for a location where vehicles have primacy (Methorst, 2017). VRUs already have developed an expected behaviour for manual driven vehicles on a road where vehicles have primacy. If AVs are introduced to these specific roads, the expected behaviour should be more or less the same. It should be researched if this hypothesis is true and if the expected behaviour is likely to change when VRUs can identify an AV as such.

Secondly, it is recommended to search for a location where pedestrians have to walk long distances (de Craen, 2017), e.g. where public transport has no or little coverage. An AV would have a functional advantage on a location where the travel time could be significantly reduced. An AV in such locations is not required to drive as fast as manual driven vehicles to still be a functional mode of transportation (Eenink, 2017). It is also possible to use dedicated test locations to perform pilots. Such test locations can be changed to a certain limit to resemble a real location. Virtual reality has the potential to test human behaviour in the system of interaction without being physically present on a real location (Happee, 2017).

Collaboration and knowledge sharing

As can be seen in the stakeholder analysis (section 4.1.3), a lot of stakeholders are interested in the development and introduction of AVs in the urban environment. Collaboration between stakeholders could reduce costs, improve knowledge sharing and eventually would speed up the process of development and introduction of AVs.

It would be best if all pilot results would be shared freely, so other stakeholders will not try to test the same research areas and stakeholders can learn from former researches. It is furthermore important to document and share the findings of all pilots publically {Methorst, 2017 #141}. Pedestrian data is poorly documented in the Netherlands (as it is the same in the rest of the world) according Methorst. It is therefore hard to quantify if safety measures have an effect on traffic safety of the pedestrian. It is essential to document the findings so future research can compare the results.

6.3.2. Technical challenges

A lot of technical challenges arise in the development of automated driving systems. Based on the model results and interviews, the following technical challenges are identified.

Appearance of AVs

It is not known on what the appearance of AVs should be. It can be argued that AVs need to be distinguishable as such, so other road users are able to develop a behavioural pattern. However, it can also be argued that no distinction between manual driven vehicles and AVs need to be made. Otherwise, abuse can be provoked where VRUs take advantage of for example automated braking systems.

Pilots can measure the differences in crossing behaviour between interactions with AVs with a characteristic appearance or AVs that cannot be identified as such.

Communication

Research into different communication measures between AVs and VRUs have to be executed. It is currently not known what kind of signals an AV should send, for example "I see you", "I am going first", "I am slowing down" etc.). Also, the best measure to send such signals are currently not known, for example lasers, lights, sounds, icons, projections etc. These communication measures should be clear so that other road users will not require additional training to understand the meaning of the message.

Road design

Different road dimensions and elements influence the driving behaviour of manual driven vehicles, driving behaviour of AVs and crossing behaviour of VRUs. At this moment, scientific data is present on the effect of different road dimensions and elements on traffic safety. Such scientific data is not present for the scenario in which AVs are also introduced to the public roads. Pilots with different road design can test the automated driving technologies for acceptable speeds and gap distances.

Also, the use of intelligent infrastructure systems such as ITS and C-ITS have the potential to improve traffic safety for both AVs and VRUs. Such systems are currently focussed on traffic management and aim for an efficient traffic system. Pilots should test the readiness and potential of such systems.

7. Conclusions

This research provides insights in the system of a safe mutual interaction between Vulnerable Road Users and Automated Vehicles in the urban environment. To do so, several sub questions are answered to identify determinants in this system of interaction. The sub questions answer the theoretical development of a Fuzzy Cognitive Mapping model, a model that combines fuzzy logic and cognitive mapping. The results of the theoretical research are furthermore applied in a case. This case aims to answer the main research question:

What are the practical and technical challenges faced due to the mutual interaction between vulnerable road users and automated vehicles?

The answer on the main research question is furthermore specified in an advice for the City of Amsterdam on AV pilots. An answer on the sub questions is first described. Lastly, an answer on the main research is provide in this chapter.

1. *What are the determinants of a safe mutual interaction between VRUs and AVs in the urban environment?*

The system of interaction can be described by determinants that influence each other and the target concept *Traffic safety*. Literature study is executed to both gain state-of-the-art knowledge on interactions in the system of interaction, but also to identify an initial set of determinants. Scoping provided the determinants that fall within the boundaries of the research. These determinants are the most relevant determinants that describe the system of interaction. A total of 19 determinants are found in the literature study. Another three determinants are introduced by the participants of the workshop. The following list itemizes the determinants of a safe mutual interaction between VRUs and AVs in the urban environment:

Target concept

- Traffic safety

Endogenous determinants (internal to the system)

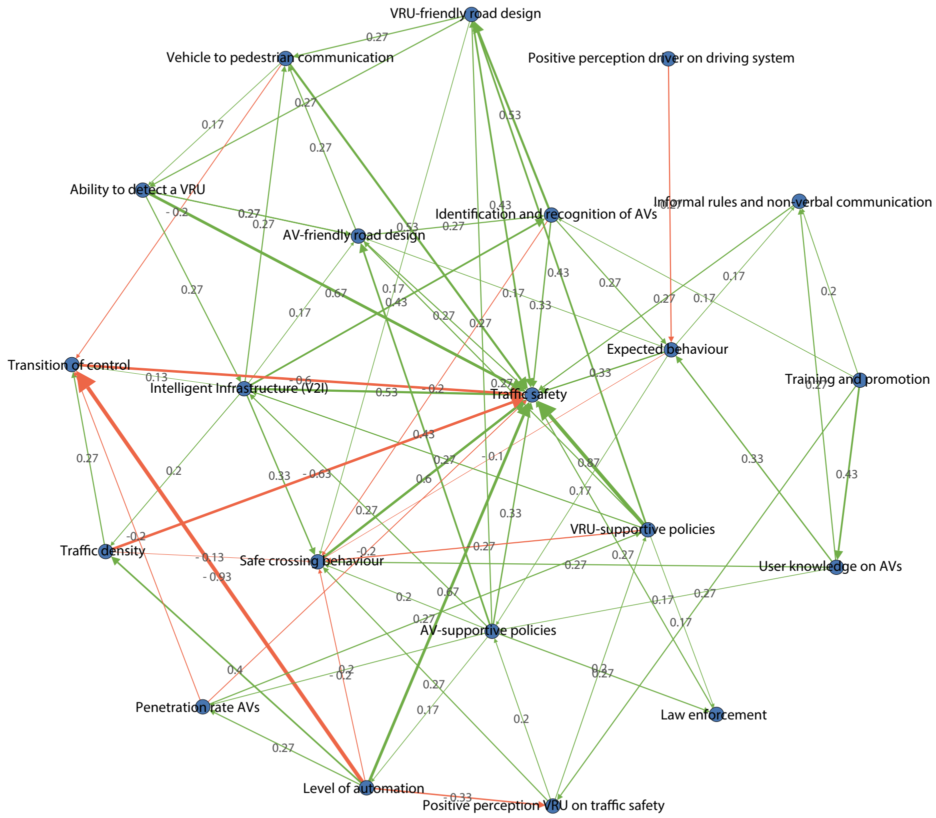
- Safe crossing behaviour
- VRU-friendly road design
- AV-friendly road design
- Training and promotion
- User knowledge on AVs
- Identification and recognition of AVs
- Expected behaviour
- Vehicle to Infrastructure communication
- Vehicle to Pedestrian communication
- Ability to detect a VRU
- Informal rules and non-verbal communication
- Transition of control
- Law enforcement
- Traffic density
- Positive perception driver on driving system
- Positive perception VRU on traffic safety
- Penetration rate AVs

Exogenous determinants (external to the system, inputs)

- Level of automation
- AV supportive policies
- VRU supportive policies

2. *How do the determinants of a safe mutual interaction between VRUs and AVs influence each other?*

The relationships between determinants is assigned by professionals in a participatory workshop. The set of initial determinants was handed to three groups of a total of 12 professionals. In one hour, they positioned the determinants on a poster and assigned relationships and weight between the determinants and the target concept by using the following project question: "*To what extent do AVs have a changing influence on the traffic safety of VRUs in the urban environment?"*. The detailed FCM model that is the product of the workshop and post-processing, shows how the determinants of a safe mutual interaction between VRUs and AVs influence each other. The relationships are best presented in a visual representation.



Positive relationship

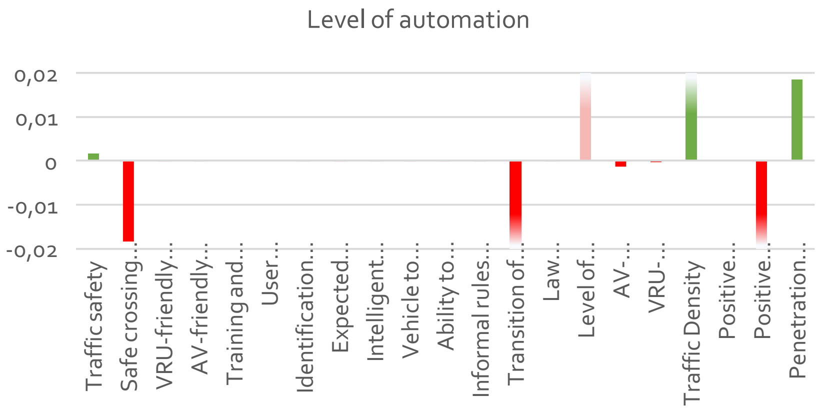
Negative relationship

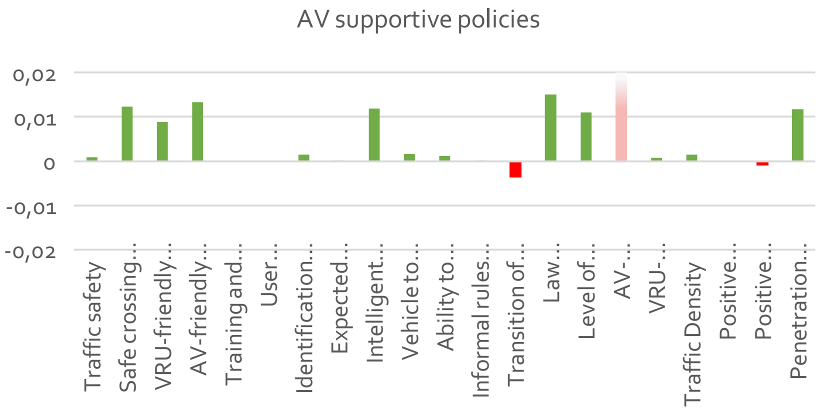
3. *How are determinants of a safe mutual interaction between VRUs and AVs expected to behave for future scenarios?*

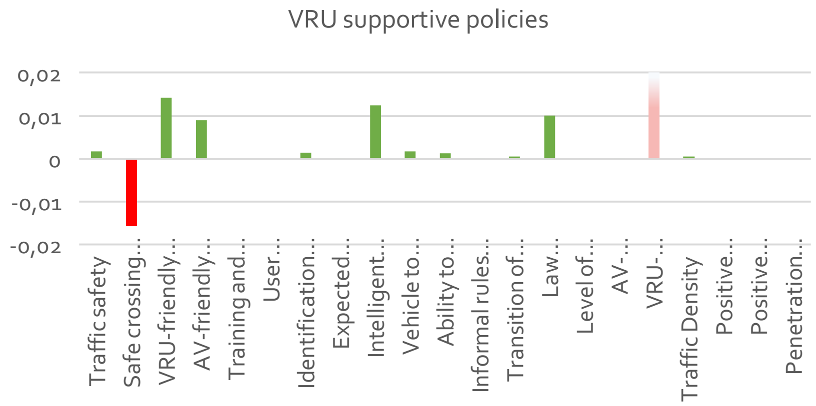
Computations on the detailed FCM model provide the dynamic behaviour of the determinants and provide indices on the structure of the system. The dynamic behaviour describes how determinants are expected to change for scenarios. A total of four scenarios is computed, namely for (1) level of automation, (2) AV supportive policies, (3) VRU supportive policies and (4) combination of the three exogenous determinants. The change in determinant value is for each scenario shown in the graphs on the page.

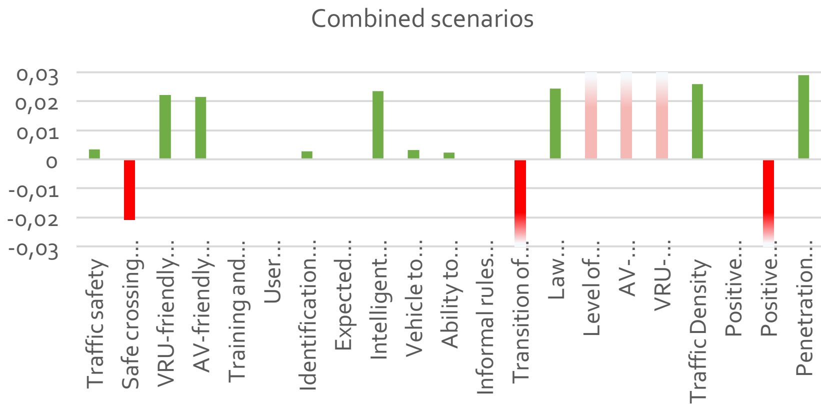
The change is classified by the following difference in value between the base scenario and the calculated scenario:

- (+/-) Δ 0,01 Strong change
- (+/-) Δ 0,001 Medium change
- (+/-) Δ 0,0001 Weak change
- (+/-) Δ 0,00001 Very weak change


Level of automation
0,02
0,01
0
-0,01
-0,02
Traffic safety
Safe crossing…
VRU-friendly…
AV-friendly…
Training and…
User…
Identification…
Expected…
Intelligent…
Vehicle to…
Ability to…
Informal rules…
Transition of…
Law…
Level of…
AV-…
VRU-…
Traffic Density
Positive…
Positive…
Penetration…


AV supportive policies
0,02
0,01
0
-0,01
-0,02
Traffic safety
Safe crossing…
VRU-friendly…
AV-friendly…
Training and…
User…
Identification…
Expected…
Intelligent…
Vehicle to…
Ability to…
Informal rules…
Transition of…
Law…
Level of…
AV-…
VRU-…
Traffic Density
Positive…
Positive…
Penetration…


VRU supportive policies
0,02
0,01
0
-0,01
-0,02
Traffic safety
Safe crossing…
VRU-friendly…
AV-friendly…
Training and…
User…
Identification…
Expected…
Intelligent…
Vehicle to…
Ability to…
Informal rules…
Transition of…
Law…
Level of…
AV-…
VRU-…
Traffic Density
Positive…
Positive…
Penetration…


Combined scenarios
0,03
0,02
0,01
0
-0,01
-0,02
-0,03
Traffic safety
Safe crossing…
VRU-friendly…
AV-friendly…
Training and…
User…
Identification…
Expected…
Intelligent…
Vehicle to…
Ability to…
Informal rules…
Transition of…
Law…
Level of…
AV-…
VRU-…
Traffic Density
Positive…
Positive…
Penetration…

4. *What are the most relevant and important determinants of a safe mutual interaction between VRUs and AVs to use in further research and pilots?*

The computations also provided indices on the structure of the model. The centrality describes the importance of a determinant in the system. Five key determinants with the highest centrality, excluding the target concept and exogenous determinants, are as followed:

- Intelligent infrastructure
- Safe crossing behaviour
- AV-friendly road design
- VRU-friendly road design
- Identification and recognition of AVs

These determinants are therefore considered most relevant and important.

What are the practical and technical challenges faced due to the mutual interaction between vulnerable road users and automated vehicles?

If a city is interested in pilots on the mutual interaction between VRUs and AVs, some practical and technological challenges are important according to the model and professionals.

Step by step. Headlines in news articles say that the technology for autonomous vehicles is just around the corner and that self-driving vehicles are being testes in pilots in the Netherlands at this moment. It is true that pilors are executed on automated driving systems, but the technology is far from autonomous. Pilots only research a small fraction of the entire system. It should therefore be noted that pilot goals should be small and realistic. A steward should be present in the first step of the process. Secondly, the supervision of the steward can be taken over by remote supervision of a control centre. Finally, the vehicle should be able to drive anonymously, without a human having to monitor or able to take over control.

Location. Car manufacterers are not likely to develop automated driving technologies that can only be used in one specific city. Therefore, a general location has to be chosen which can represents other locations in Amsterdam, the Netherlands and de rest of world. It is advices to use a location in which vehicles have primacy and walking distances are relatively long. If no location can be found that meets the requirements, vritual reality or a dedicated test track can be used to simualte reality.

Collaboration and knowledge sharing. Numerous stakeholders are actively involved in the development and introduction of AVs. A collaboration between stakeholders could reduce pilot costs, improve knowledge sharing and would eventually speed up the process of development and introduction of AVs. Results should be made public so other stakeholders can learn from former pilots and will not duplicate the same pilots.

Appearance of AVs. It is not known at this moment if AVs should appear different from manual driven vehicles or not. If an AV is distuingisable from manual driven vehicles, other road users can develop a behaviour pattern. However, it might also provoke abuse. Pilots can test crossing behaviour of VRUs for different appearances of AVs

Communication. Pilots have to be executed on the communication between VRUs and AVs. It is not known which messages an AV should communicate to other road users. Also, research into communication measures is limited and should therefore be tested in pilots.

Road design. Differences in road dimensions and elements causes different driving behaviour for manual driven vehicles and automated vehicles, but also for differences in crossing behaviour. Little or no scientific data is currently present on the effects of different road dimensions and elements in the scenario of automated driving. Also, the potential for traffic safety by using intelligent infrastructure systems such as ITS and C-ITS and AVs should be tested in a pilot.

8. Discussions and Recommendations

This chapter provides a discussion on the results and methodology. Recommendations are made directly after each subject.

FCM isn't a methodology that has proven itself in the field of transport planning at this moment. Although the methodology looks promising, it should be assessed if this method is a useful method for this research or similar cases. This chapter discusses remarkable results in this research (8.1) and the method (8.2) and finally provides an answer on the question if Fuzzy Cognitive Mapping is a useful method in the field of transport planning (8.3).

8.1. Results

This paragraph discusses and provide recommendations for further research or changes regarding uncertainties, assumptions, choices and/or remarkable results.

8.1.1. New introduced determinants

Three determinants were introduced by two participant groups during the workshop, namely *Positive perception driver on driving system*, *Positive perception VRU on traffic safety* and *Penetration rate AVs*. The other participant groups were not notified that new determinants are used by other groups. Therefore, they were not able to use these determinants in the FCM map.

Since only one participant group was able to assign relationships to these determinants, the value of the link would be divided by three after mathematically combining the maps. Therefore, the link weight in the detailed FCM model will be lower than the behaviour that the participant group was describing during the workshop. Therefore, the model would not accurately describe reality.

Recommendation
Knowing this afterwards, I would recommend future practitioners that use a workshop to directly introduce the new added determinants to other participant groups as well. It is possible that they do not believe the new determinant is relevant, and could therefore not use the determinant in the model. This results in a link value that resembles reality to a greater extent.

Further research on these determinants is at this moment recommended. These determinants might have a greater link weight in reality, although this is not necessarily the case. It would be best to redo the workshop with the same professions and include the new determinants in the initial set of determinants, although this suggestion is not considered feasible and efficient.

8.1.2. Post-processing without involvement participants

Jetter and Kok argue that post-processing without the involvement of the participants might result in the creation of a FCM model that no longer reflect the participants' knowledge of the system and its behaviour (A. J. Jetter & Kok, 2014). Due to the limit amount of time in the workshop, there was little involvement of professionals in this research. The only step in post-processing in which a professional provided his opinion was to delete short feedback loops. Pablo Nûnez Velasco participated in the workshop and gave his opinion on the most important relationship in this matter.

The detailed FCM model is highly dependent on the post-processing steps. Therefore, it can be said that involvement of professionals in this stage have a high impact on the detailed FCM model. This research only processed a minimum amount of data in order to keep the detailed FCM model as close as the results from the workshop as possible. Only the necessary changes are made for e.g. disregard of model boundaries, short feedback loops and definitional determinants.

Recommendation
When time is a limiting factor in a workshop, it can be expected that post-processing will be done by the modeller afterwards. I would recommend to only process the necessary elements, and leave as much as possible untouched. Therefore, the model would represent the results from the workshop at best.

However, if time is not a limiting factor in the workshop, I would recommend to perform the post-processing step together with the participant groups. After constructing the conceptual FCM models, the modeller should be able to identify any mistakes and flaws. It is therefore recommended that the modeller is familiar with such flaws and is able to identify these within a short time. The flaws have to be presented to the professionals, after which choices have to be made by the group.

If any further flaws would be found in a later stage, the professionals should be asked for their opinion. I would recommend a future practitioner to ask the professionals for their willingness to assist after the workshop, either through personal contact, email or another meeting with all participants.

8.1.3. Conflicts in combing the conceptual models

After mathematically combining the three conceptual FCM models, two relationships showed opposing values:

- *Expected behaviour – Safe crossing behaviour*
- *Level of automation – Traffic density*

Group A did not assign a relationship between the first set of determinants. Group B assigned a positive relationship with a weight of 0,5. Group C assigned a negative relationship of – 0,8. The second conflict describes the relationship between *level of automation* and *traffic density*. Group A assigned a negative relationship between these determinants with a weight of -0,2. Group B did found a relationship, but couldn't determine if this relationship was either positive or negative. Group C assigned a positive relationship of 1,0.

By mathematically combining the conceptual FCM models, a value would be the results that does not describe the behaviour that any of the groups described. For example, if group A described a strong positive relationship, group B described a weak negative relationship and group C did not think there was a relationship, the result would be a weak or medium relationship, which neither of the groups was describing.

Recommendation

I believe it is not automatically wrong to combine these conflict the way the methodology prescribes. The average value represents the average opinion of the participant groups. Therefore, the choice made in this research is not found to be wrong.

However, it would be interesting if this conflict was found during the workshop. In that case, the participant groups could have been asked for their opinion. A group discussion would determine the value that should be used in the model. If the participants cannot come to an agreement, further research is required. If further research does not provide answers, it should be accepted that the weight depends on the perspective and expertise of the professionals that are using the model.

8.1.4. Key determinants vs all determinants

Five determinants with the highest centrality, excluding the target concept and exogenous determinants, are chosen as most import in the system of interaction. Interviews have been executed to gain extensive knowledge on these key determinants. Other determinants no longer had a lot of focus, and would only be discussed in interviews when they are mentioned by the interviewee.

It can be argued that determinants that have a lower centrality can be of importance in the system of interaction. The dynamic behaviour showed that *Transition of control, law enforcement, traffic density, positive perception VRU on traffic safety* and *penetration rate AVs* each have a significant change in some scenario. Since the dynamic behaviour is only focussed on the difference of change, and not the end value, little can be said on the importance of these determinants.

Recommendation

I believe that, in order to prioritize research, a top 5 is justified. However, further research into the end value of determinants should be executed when assessing dynamic behaviour. Secondly, the centrality relies heavily on the relationships the professionals assigned. If a different set of professionals would have participated in the workshop, different centralities can be expected. Therefore, it cannot be said with certainty that the top 5 is also the top 5 of every professional in the knowledge domain. Prioritizing such research should therefore always be done with care.

8.1.5. Transition of control

Continuing on the previous section, the determinant of *transition of control* was not included in the top 5, although it should have been ranked 5th according to the centrality. This determinant gained a higher value after a late post-processing step, which was executed parallel to the interviews. The invites for interviews were already send, and due to a lack of time no additional professional is found to discuss the transition of control.

Recommendation

The results show that the determinant of *Transition of control* has a high influence in the system of interaction. Therefore, additional research is required on this determinant. I would recommend further research by executing an interview with a relevant professional and to translate the state-of-the-art knowledge into the pilots on AVs in Amsterdam.

8.2. Methodology

This paragraph discusses and provide recommendations for further research or changes regarding the methodology or choices that have been made in this thesis.

8.2.1. Target concept

The objective of this research was to gain insight in the system of a safe interaction between VRUs and AVs. This system of interaction has never before been researched and little is therefore known on determinants that describe the mutual interaction between VRUs and AVs. As incorporated within the objective and sub questions, this thesis is researching a safe interaction.

Traffic safety has been chosen as a target concept. A target concept is a receiver that will be influenced by other determinants without influencing other determinants itself. The target concept is determined in the project description and is used as a guidance throughout the whole research. The literature study focusses on finding determinants that are influence traffic safety. The resulting set of determinants is handed to professionals in the participatory workshop, in which the participants were asked *what extent AVs have a changing influence on the traffic safety of VRUs in the urban environment.*

By applying this focus on traffic safety, the strategies are to some extend executed on biased guidance. Perhaps determinants were not found in the literature study that would have an effect in the system of interaction that has nothing to do with safety. And by provided this biased guidance to participating groups in the workshop, little focus has been put on other (possibly relevant) aspect of the system.

I believe nevertheless that such guidance was essential for this approach in which the time to develop a FCM map during a workshop was limited. If the participants were asked to discuss and determine a target concept for themselves, it might have resulted in three totally different target concepts. This would have resulted in three FCM maps that have little or no similarities. Since the maps would no longer describe the same system, mathematically combining the maps would no longer result in a system that describes the mental maps of all participants.

Recommendation

Determining a target concept in an early stage applies scope and guides the strategies to develop a model. I recommend to determine a target concept when starting a literature study to apply focus. Also, by providing the target concept to the participants of a workshop, focus and guidance is provided and deviations will be kept to a minimum.

However, if the modeller wants to gain insights in different believes of stakeholder groups by using a workshop, and therefore is not combining the conceptual models, he is advised to let the participants decide on a target concept. This would represent the mental maps of a specific stakeholder group that has expertise in a certain area of the knowledge domain.

8.2.2. Combining conceptual FCM models

Continuing on the previous section, a discussion on the differences between combing the conceptual models from a workshop or using them individually is presented.

This research combined the conceptual FCM maps that three participant groups made in a workshop. It is however also possible to maintain the individual maps and process these into three individual detailed models. There are two main reasons why combining is chosen, namely (1) time limitations for the workshop and (2) representation of the average worldview of professionals.

The input from multiple professionals is required in the development of a FCM model. The workshop was scheduled after a meeting with 12 professionals on automated driving. The professionals were already present and would not have to invest too much time to participate in this research. I believe that I wouldn't have found 12 professionals that would be willing to invest 1 hour of their time in a workshop, let alone travel times towards the same location and aligning everyone's schedule. The goal therefore was to make the best use of as little time as possible.

I wanted to get a better understanding of the system as a whole, and thus as it is described by a variety of relevant professionals. For this research, I was not interested in opposing views on the system.

Recommendation

A negative result of a workshop with limited time is that there is a change that not all determinants are used and/or not all relevant relationships are identified. By dividing the total group of participants and developing three individual conceptual FCM maps, the change increases that a relevant determinant or relationship is assigned by one of the groups. This justifies mathematically combining the maps afterwards, since the most relevant or important components have been assigned. If a practitioner is looking for a map that describes the system without biased influences of stakeholder groups, I would recommend mathematically combining the conceptual FCM maps. Also, if a practitioner has a restriction of available time, I would recommend to combine the individual conceptual models into one conceptual model.

If a practitioner is looking for different worldviews between stakeholder groups, I would recommend to group the participants according to their expertise or knowledge area. This would result in maps that describe the system as the stakeholder group finds most interesting, and could therefore be used to indicate opposing worldviews and interests.

8.2.3.Black box

The mathematics behind the computation in the software of FCMappers are not known into detail and cannot be accessed. The developers of the software do not provide information on these calculations, and the user has to rely on their expertise by using the software. The outcome of the computation relies on the mathematics and squashing function. For this research, the software is believed to make the right computations. Not knowing what the model run does in detail makes the software a black box in which data is inputted and results are outputted.

Scientific research into the different types of squashing functions is limited, even though this has a big influence on the results. When using such as black box, two potential pitfalls are present, namely (1) the outcome does not provide what the professional was expecting. The professional is therefore likely to say that the model is wrong. Or (2) the outcome represents what the professionals was expecting. The professional is therefore likely to say that the model was of no use (Kok, 2017). By making the computations transparent, professionals can see the steps that have been made.

Recommendation

I recommend further research into the mathematics of this method and the impact different squashing functions have on the outcome. Until this research is performed, little can be said about the different ways of making the calculations and practitioners remain relying on the software provided by others.

8.2.4. How to assess structure and dynamic behaviour

The structure of the model is used in this research to determine the key determinants in the system of interaction. The dynamic behaviour is used to validate if the behaviour is plausible and if it represents reality. FCM captures qualitative data from professionals and translates this into semi-quantitative data. The semi-quantitative data, which represents a strength of a relationship, is therefore not expected to be very accurate.

Since this method relies mostly on the structure, and uses the dynamic behaviour mostly to assess if the model represents reality, I believe the right balance is chosen between these two model results for this specific research.

Recommendation

If a practitioner is mostly interested in the structure of a system, and into a lesser extent in the dynamic behaviour of the system, the applied balance used in this research will suffice. However, if a practitioner is more interesting in the dynamic behaviour, for example to assess future scenarios, I would recommend not to use the method of FCM and use a different planning method.

This method is found useful to find the structure of a system for which no or little scientific data is presents, such as the case for the still-evolving (and at the moment not used) technology of AVs.

8.2.5. Why component

Continuing on the recommendation of the previous section, the usefulness of the outcome of the dynamic behaviour can be argued. The usefulness of semi-quantitative data to address scenario analysis can be questioned. More importantly, I believe the method cannot be used to address "why" certain behaviour occurs.

The dynamic behaviour is based on the relationships that the professionals assigned between two determinants. If and only if the professionals provide a detailed description on why they choose the relationship and weight, the behaviour can be explained to some extent. However, in complex systems with numerous determinants and relationships, the behaviour is very hard to explain due to the presence of feedback loops. Especially if a lot of feedback loops are present in the system, an explanation for the behaviour cannot be accurately provided.

This researches tried to provide an explanation for certain behaviour and validates remarkable behaviour with professionals during an interview. However, the explanation of the behaviour relies heavily on assumptions and biased worldviews of the practitioner.

Recommendation

The explanation on the dynamic behaviour in this research might not be accurate enough to describe reality. Although an explanation is provided, it can be easily questioned by others with different opinions. If they believe a certain behaviour is not logical, they would say the model is wrong.

If the reasoning of the participant groups was documented during the workshop, a more substantiated explanation could have been provided. Nevertheless, due to the presence of feedback loops, these explanations could also be easily questioned by others. I would therefore recommend to use the dynamic behaviour as in indication and not to rely heavily on the outcomes.

Further research into the dynamic behaviour might result in a better understanding and potential improvement of the methodology, but I believe that other methods would be more useful to address future scenarios.

8.2.6. Time component

Time is ill-defined concept in the methodology. The method can be used to describe behaviour over time where direct effects can be compared to effects over time. Effects over time are caused by feedback loops or because a determinant is activated after a couple of iterations. The latter is possible when a determinant has more than one other determinants in between the link to the managed determinant.

Each iteration can represent a time step if properly constructed. A time step can represent one minute, one day or even years. Not all influences have the same time window (e.g. changes in nature have a longer time window compared to changes in infrastructure), which makes it hard to use time as an indicator in the method. By adding dummy variables, time delays can be built in the model. However, if time windows vary between minutes and years, the number of dummy variables would be huge.

This research did not make use of the time component in the methodology, Therefore, one iteration does not represent a time step. Only the steady state, in which the system has no longer changes in value, is addressed. The consequence of this is that only certain statements can be made for "long term" changes, although "long term" cannot be defined.

Recommendation

Time can be used in really simple FCM model with a minimum of determinants and with time windows that are not too far apart from each other. The direct and indirect effects can be measures for each step, and can therefore assist to say something on indirect effects that affects a determinant after it is affected by another in a previous step. Dummy variables can be used to deal with different time windows, but should be handled with care.

8.2.7. Adapted approach

Originally, three strategies can be applied to develop a FCM model (A. J. Jetter & Kok, 2014). In the strategy of literature study, the practitioner analyses documents. The content analysis can be used to gather information on cognitive maps from written documents such as scientific publications and technological reports. The second strategy is that the modeller surveys professionals, either in the form of questionnaires/ interviews or in the form of Delphi-studies, in which the opinion of multiple experts is asked during a workshop. In the last strategy, the modeller is the expert and develops the system by using his own knowledge. The latter strategy is considered ill-suited for a multiple-stakeholder study.

As Jetter and Kok (2014) suggest, a combination of the three strategies can be made. This research did not make use of the latter approach and used the first (interviews) and second (both interviews and workshop) strategy to develop a FCM model. The research starts with a literature study. The results of the literature study are used in the workshop. Lastly, the results from the workshop are discussed in the interviews. Similar approaches are not found in any scientific literature studies.

Recommendation

By applying the adapted approach, advantages can balance or mitigate disadvantages of other methods. I recommend future practitioners of the method to combine these strategies if they are looking for a complete model. If only a first glance at a problem or system is required, one of the strategies can be applied.

The strength of this approach is that the methodology can be applied with a limited effort from professionals. A workshop originally is advices to be executed over 1, 2 or even 3 days. I believe that if the strategy would require such a large amount of time, the strategy is no longer a functional one. By limiting the time for a workshop in this approach, the disadvantages had to be mitigated or balanced by other approaches. This however require more effort from the modeller. By determining the goals, objectives and desired outcome, the modeller should be able to choose for applying one or a combination of strategies.

8.3. Conclusion on the methodology

This paragraph provides a brief answer on the question if Fuzzy Cognitive Mapping is a useful method in the field of transport planning. For this research, the methodology is found to be useful. This research had to deal with limited availability of scientific data on AVs, but aimed to provide insights in a system that has never been researched on the level. The methodology was able to capture the qualitative data derives from professionals and translates this into semi-quantitative data. The structure and dynamic behaviour could therefore be computed.

I believe that the methodology was useful to identify the structure of the system of a safe mutual interaction between VRUs and AVs in the urban environment. However, the dynamic behaviour (the semi-quantitative data) is found not to be accurate. In this research, this inaccurate character is not found to be detrimental to the research due to the still-evolving technology of AVs. Future behaviour cannot be known into detail at this moment. The methodology therefore serves its purpose at this moment. However, as soon as pilots on AVs are executed on a large scale and quantitative data will be available, other methods are expected to prove themselves more useful compared to FCM modelling.

In conclusion, I believe that Fuzzy Cognitive Mapping can be of use in the field of transport planning, but mostly to address cases in which the impact of future technologies or transport modes. The structure of a system in transport or traffic can be identified by Fuzzy Cognitive Mapping, although a (more simple) causal loop diagram is expected to be able to capture the same structure. The advantage of fuzzy logic as an addition to causal loop diagrams is therefore argued. It can be useful for specific cases with a high level of uncertainty, but has many uncertainties and disadvantages for cases where more quantitative data is present.

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Appendixes

Appendix – Background information AVs

The technology for AVs is currently being developed, tested and systems for automation are gradually entering the traffic system. The technology has a large potential, but also new costs and problems arise. Litman (2016) provides a (non-exhaustive) list of potential benefits and costs:

Table 4: Benefits and costs of AVs (Litman, 2016)

Benefits	Costs
Reduced driver stress. Reduced the stress of driving and offer the opportunity to rest or work while travelling	**Increased costs**. Requires (costly) additional vehicles equipment and possibly roadway infrastructure
Reduced driver costs. Reduced costs for commercial drivers such as taxis	**Additional risks**. May introduce new risks or encourage other road users to take additional risks (offsetting behaviour)
Mobility for non-drivers. Provide independent mobility for non-driver such as children or elderly	**Security and Privacy concerns**. May be used for criminal or terroristic activities, is vulnerable for information abuse and might raise privacy concerns
Increased safety. Reduce accidents caused by human error and therefore crash costs and insurance premiums. Also reduces high-risk driving	**Induced vehicle travel and increased external cost**. Because of increase travel convenience and affordability, an increase in vehicle travel, costs for external parking and pollution can be expected
Increased road capacity, reduced costs. Potential for platooning (vehicle groups travelling close to each other), narrower roads, reduced intersection stops and reduce congestion	**Social equity concerns**. May have unfair impacts by reducing other modes' convenience and safety
More efficient parking, reduced costs. Drop of passengers and find a parking place. Studies found that on average 30% of the cars in congested downtown traffic were looking for a parking place (Shoup, 2011)	**Reduced employment and business activity**. Commercial drivers are no looking needed and a reduce in demand for car crash repairs
Increase fuel efficiency, reduce pollution. Efficient system that increases fuel efficiency and reduce the emissions	**Misplaced planning emphasis**. Focus in this technology might diverge communities from implementing other cost-effective transportation modes
Supports shared vehicles. Can facilitate car sharing, which provide various savings	

A long transition period towards full automation is likely, where non-automated, partly-automated and full-automated share the road network. This Appendix provides some basic background information on AVs, used definitions, possible scenarios and expected time horizons.

Defining vehicle automation

First of all, there is the distinction between automated driving and autonomous driving. Automated means "made to operate by machines or computers in order to reduce the work done by humans". Autonomous means "independent and having the power to make your own decisions" (Cambridge Dictionary, N.D.-a, N.D.-b). Therefore, a fully automated vehicle is considered to be an autonomous vehicle. Partly-automated vehicles are called AVs.

There are different levels of automation in vehicles. A broad accepted classification by the SAE identifies six levels of automation from no automation to full automation (SAE International, 2014). In level 0 to level 3, the human driver monitors the driving environment. In level 3 to level 6, the Automated Driving System monitors the driving environment. The next table shows the levels of automation from No Automation to Full Automation according to the SAE.

Level	Name	DDT*		DDT Fallback	ODD***
		Sustained lateral and longitudinal vehicle motion control	OEDR**		
Driver performs part of all the DDT					
0	No driving automation	Driver	Driver	Driver	n/a
1	Driver assistance	Driver and system	Driver	Driver	Limited
2	Partial driving assistance	System	Driver	Driver	Limited
Automated Driving System performs the entire DDT (while engaged)					
3	Conditional driving assistance	System	System	Fall-back ready user	Limited
4	High driving assistance	System	System	System	Limited
5	Full driving assistance	System	System	System	Unlimited

* DDT = Dynamic Driving Task
** OEDR = Object and Event Detection and Response
*** ODD = Operational Design Domain

Scenarios

Different perspectives on future scenario are taken by several authors. Tillema et al. base four scenarios on the level of automation that is reached and the willingness to share a vehicle (Figure 20):

- Scenario A. Multimodal and shared information

The technology for full automation is not (yet) applicable or the technology is not accepted by society. However, level 3 and level 4 automation are in practise and car sharing is commonly used. Societal impacts in this scenario are an increase in traffic safety, intensive use of public transport and a decrease in vehicles numbers.

- Scenario B. Mobility as a Service

The technology is advanced to full AVs and people are willing to share their rides. Mobility has become a service and autonomous vehicles are available anytime and anywhere. Societal impacts are a strong increase in traffic safety, new groups of passengers (elderly, handicapped etc.) make use of the system and cities are easily reachable.

- Scenario C. Letting go on highways

The technology has advanced to level 3 and 4. In crowded cities a human remains the driver. However, on highways and larger roads the automated system takes over. The technology contributes to traffic safety, cities are easily reachable and transition zones are created outside of the cities. In the last scenario

- Scenario D. Fully Automated Private Luxury

The technology has advanced to full automation, but people value their own vehicle. An increase in traffic safety is the result, but an increase in vehicle numbers is expected.

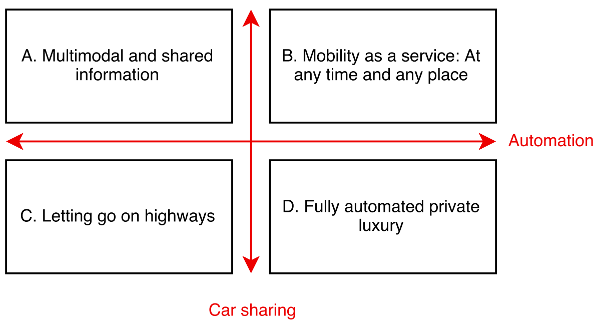


Figure 20: Scenarios based on Level of Automation and Car Sharing (Taede; Tillema et al., 2015)

MIlakis et al. (2015) determine scenarios from a different perspective, namely from the level of technological development and restrictive or supportive policies for AVs Figure 21.

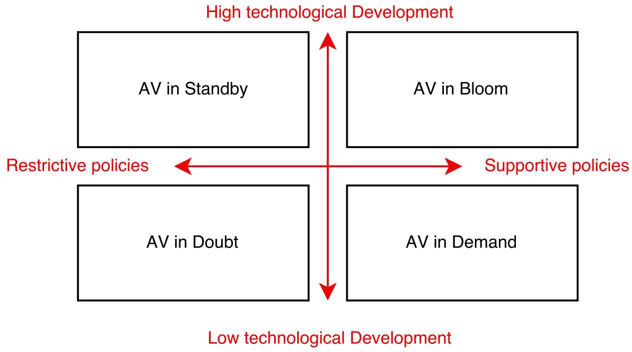


Figure 21: Scenarios based on technological development and policies (Milakis et al., 2015)

- AV in Standby

The fully automated and cooperative vehicles are expected in 2030. Although the technology is evolved, the technology is not yet fully used. This has mainly to do with a high regulation on AVs tests and inflexibility in legislations. Therefore, the use of AVs is restrained resulting in a mid-low demand and a modest economic growth.

- AV in Bloom

Both the technology is developed and laws and regulations support the use of AVs. Fully automated and cooperative vehicles are expected in 2025. Due to the positive attitude towards AVs, there is a strong demand and a high economic growth. Technological developments provide a clean system with limited environmental impact.

- AV in Doubt

Because of low technological developments and restrictive policies, a slow transition towards a low-carbon economy is the result. Fully AVs are expected in 2045 because there is limit legislation for integration of different levels of AVs. A low demand is the result of a negative customer attitude.

- AV in Demand

Policies support the AV, but technological developments have not been forthcoming. Customers are still not really interested and pollution is still a main issue in the transport sector. Fully automated and cooperative vehicles are expected in 20040.

As also is described in paragraph 1.1, authors expect the AV to be introduced between 2018 and 2060, varying for different levels of automation and different scenarios (BCG, 2016; ERTAC, 2017; Litman, 2016; Milakis et al., 2015; van Nes & Duivenvoorden, 2017).

Appendix – Flow Chart Methodology

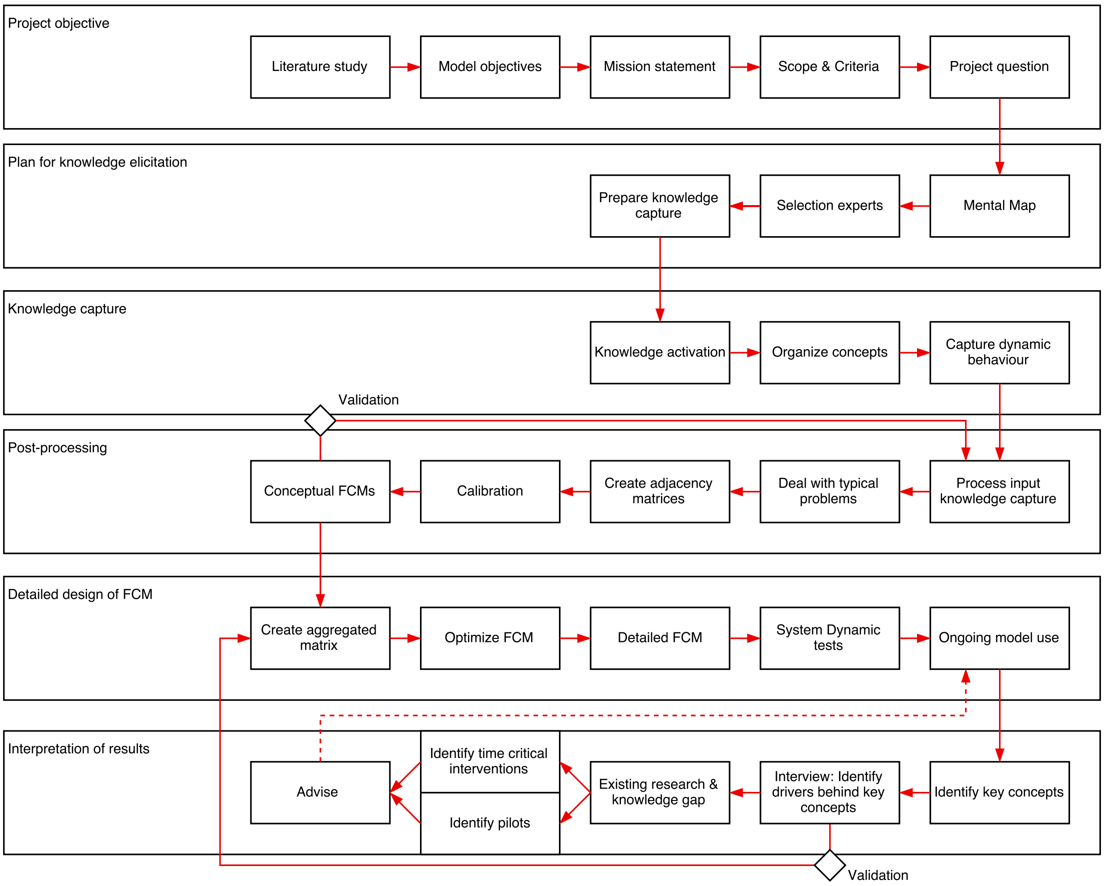


Figure 22: Detailed representation of Flow Chart

Appendix – Initial determinant descriptions

Description of initial determinants, that are determined after the literature review and provided to the participants in the workshop.

Target concept

Traffic safety

Traffic safety in a broad sense for all road users, such as pedestrians, cyclists, motorists and passengers. An increase in traffic safety results in a decreased chance of (severe) accidents or traffic deaths.

Endogenous determinants

Safe crossing behaviour

The crossing behaviour of pedestrians and cyclists on both designated crossing areas as for jaywalking. A high degree of Safe crossing behaviour means a decreased change on collision between VRUs and AVs.

VRU-friendly road design

Traffic safety and usability from the perspective of VRUs are determinative in the road design, such that this type of road user is able to use the road in its full potential.

AV-friendly road design

Traffic safety and usability from the perspective of AVs are determinative in the road design, such that this type of road user is able to use the road in its full potential.

Training and promotion

Road users are trained (e.g. during driving lessons) in the identification, recognition and expected behaviour of AVs. A traffic campaign is an example of promotion and provides knowledge and awareness. Both elements contribute to a better understanding of AVs.

User Knowledge on AVs

The knowledge of all road users, such as pedestrians, cyclists and motorists, about AVs. A high degree of user knowledge on AVs results in a better understanding of the intentions and expected behaviour of AVs.

Identification and recognition of AVs

Level of degree in which pedestrians, cyclists and motorists can identify, recognize and distinguish AVs from manual driven vehicles.

Expected Behaviour

The expected behaviour of (automated) vehicles, based on e.g. previous experience, road design, traffic rules etc. The expected behaviour is not always equal to the actual behaviour.

Vehicle to Infrastructure (V2I)

(Automated) vehicles communicate with the surrounding infrastructure trough wireless and/or visual communication. The communication contributes to a more efficient and safer traffic system.

Vehicle to Pedestrian communication

(Automated) vehicles communicate with pedestrians and cyclists through smartphone or handheld devices. The vehicle knows the exact location of a person, even though this person is out of sight (e.g. when behind a parked vehicle). Needless to say, the person has to make use of the technology that supports this determinant.

Ability to detect a vulnerable road user

The ability of an AV to detect a pedestrian and/or a cyclist. The detection depends on e.g. the accuracy of the detection system, road design, weather etc.

Informal Rules and non-verbal communication

Informal rules are followed in special situation where formal rules don't contribute to a solution. For example, in the case when an object blocks the road and road users have to cross a solid line to continue their way. Non-verbal communication consists of eye contact, body language and (small) gestures. Both elements describe difficult processes for automated driving systems.

Transition of Control
When the control of an AV has to be taken over by the driver, for example when the AV enters a road section that does not support automated driving systems or in emergency situations, it is expected that the driver suffers from a lowered concentration and alertness. This might result in accidents.

Law Enforcement
The degree of law enforcement, such as active of passive.

Exogenous determinants

Level of Automation
The level of automation of AVs, in unison with the six levels of automation described by SAE International (SAE International, 2014).

AV-supportive policies
All policies that supports and/or stimulates the usage of AVs. These policies aim to use the AV in its full potential.

VRU-supportive policies
All policies that supports and/or stimulates the traffic of VRUs. These policies aim to use the full potential of walking and cycling.

Formal traffic rules and regulations
The starting point of the *Wegenverkeerswet* is traffic safety and traffic flow, and the fact that no one causes any nuisance or danger on the road. It is likely that new rules and regulation are implemented with the introduction of AVs.

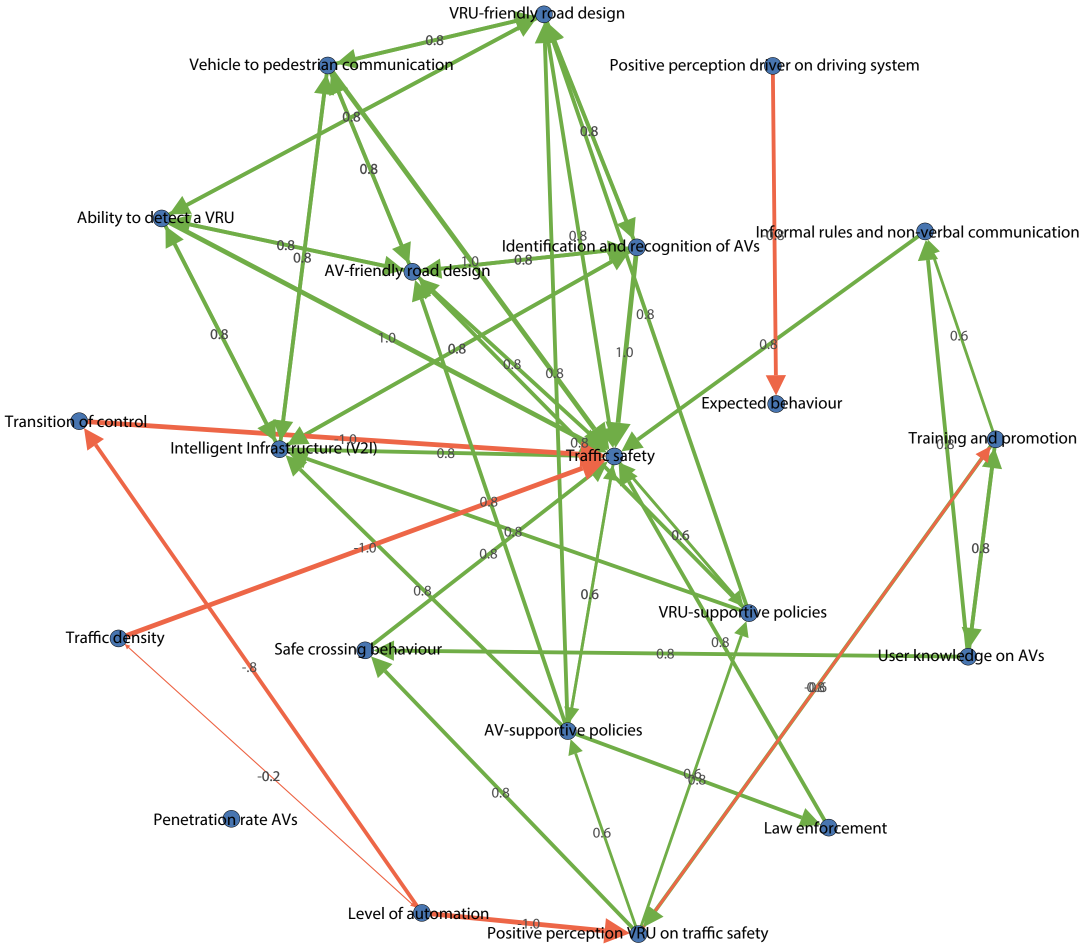
Traffic density
This determinant describes the average number of vehicles on one kilometre. This determinant is used to express an increase or decrease of the total number of vehicles.

Appendix – Participants workshop

Name	Company/Institution	Position	Group
Eric de Kievit	City of Amsterdam	Senior Advisor Mobility Research	C
Anne Blankert	City of Amsterdam	Senior Advisor Traffic Management	C
Barry Ubbels	City of Amsterdam	Transport Economic Expert	B
Johan Olsthoorn	City of Amsterdam	Researcher Mobility	B
Jorden Steenge	City of Amsterdam	Policy Advisor	A
Taede Tillema	KiM Netherlands Institute for Transport Policy Analysis	Senior Researcher	A
Kees-Willem Rademakers	Amsterdam University of Applied Sciences	Lecturer/researcher	A
Pablo Nunez Velasco	TU Delft	PhD Candidate	C
Lode Goossens	Vervoerregio Amsterdam	Project Leader Infrastructure	A
Tom Kuipers	AMS Institute	Programme Developer	A
Chris de Veer	Province of Noord-Holland	Strategic Policy Advisor	C
Pieter Bos	CROW / Radboud University Nijmegen	Graduate Student	B

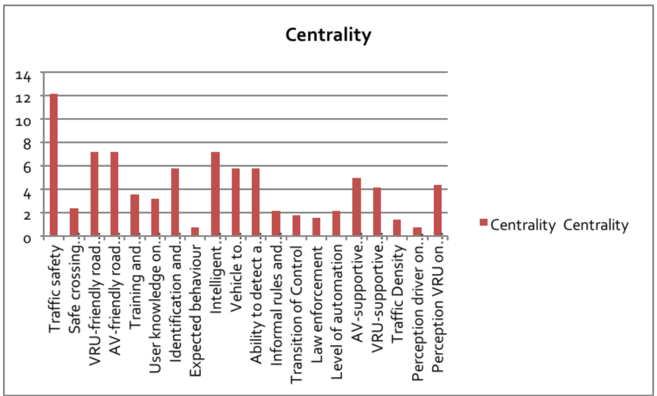
Appendix – Results participatory workshop

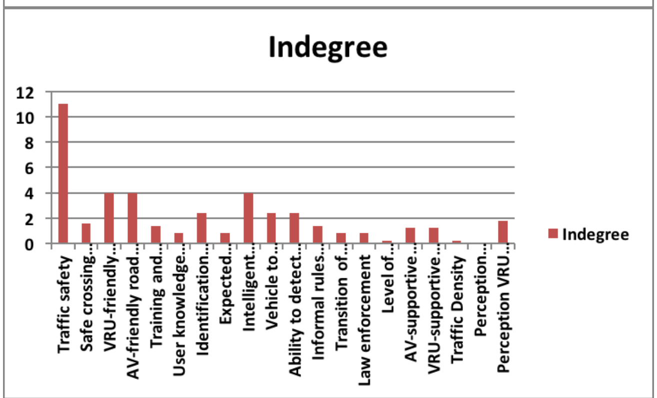
Group A

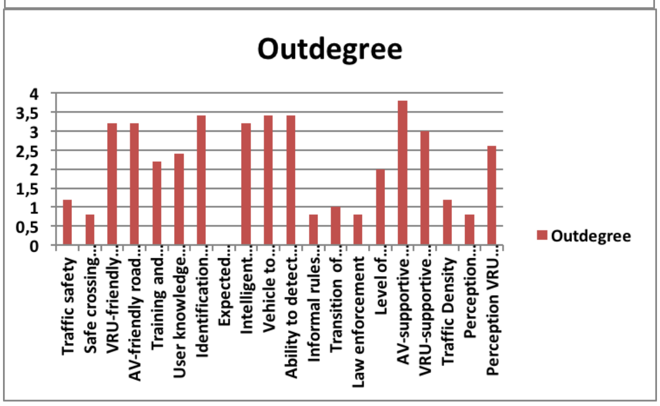


	A
Density	0,1375
Total # determinants	20
Total # connections	55
# Transmitters	1
# Receivers	1
# Ordinary	18
# Self-loops	0

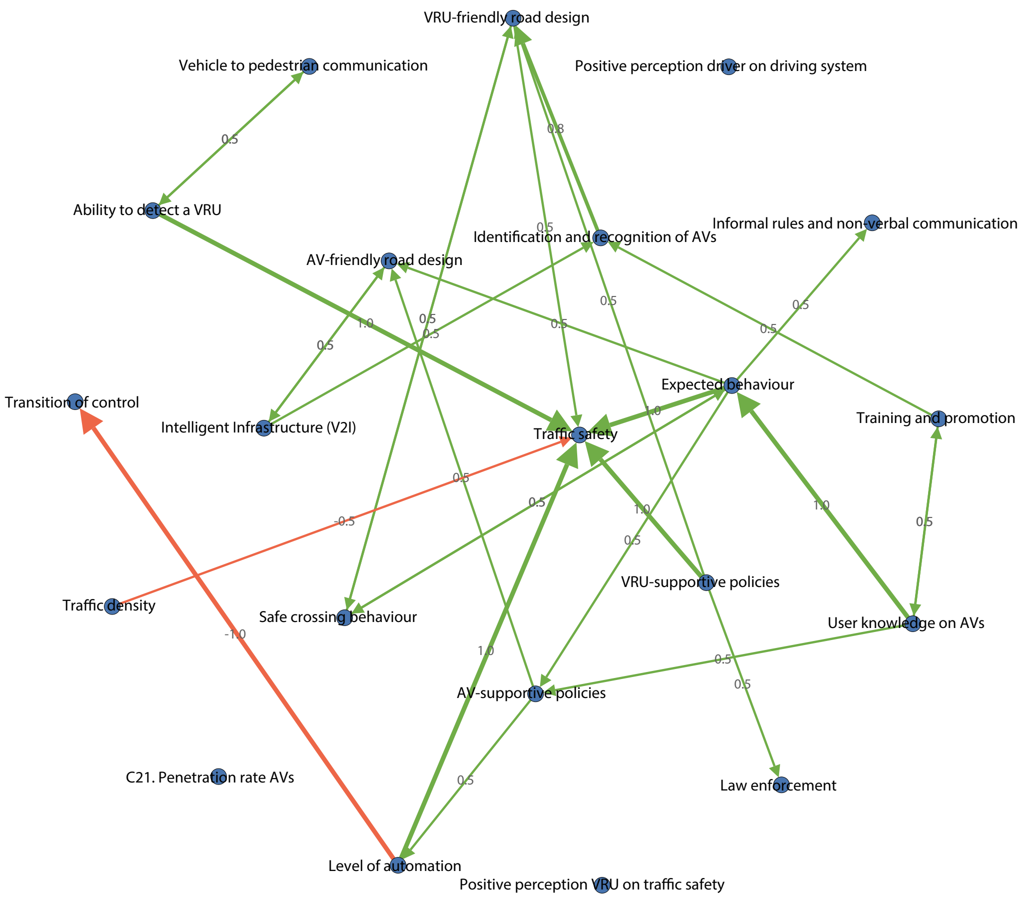
		Traffic safety	Safe crossing behaviour	VRU-friendly road design	AV-friendly road design	Training and promotion	User knowledge on Avs	Identification and recognition of Avs	Expected behaviour	Intelligent infrastructure (V2I)	Vehicle to pedestrian communication (V2P)	Ability to detect a VRU	Informal rules and non-verbal communication	Transition of Control	Law enforcement	Level of automation	AV-supportive policies	VRU-supportive policies	Traffic Density	Positive perception driver on driving system	Positive perception VRU on traffic safety	Penetration rate Avs
		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C19	C20	C21	C23
Traffic safety	C1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,6	0,6	0	0	0	0
Safe crossing behaviour	C2	0,80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VRU-friendly road design	C3	0,8	0	0	0	0	0	0,8	0	0	0,8	0,8	0	0	0	0	0	0	0	0	0	0
AV-friendly road design	C4	0,8	0	0	0	0	0	0,8	0	0	0,8	0,8	0	0	0	0	0	0	0	0	0	0
Training and promotion	C5	0	0	0	0	0	0,8	0	0	0	0	0	0,6	0	0	0	0	0	0	0	0,8	0
User knowledge on Avs	C6	0	0,8	0	0	0,8	0	0	0	0	0	0	0,8	0	0	0	0	0	0	0	0	0
Identification and recognition of Avs	C7	1	0	0,8	0,8	0	0	0	0	0,8	0	0	0	0	0	0	0	0	0	0	0	0
Expected behaviour	C8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Intelligent infrastructure (V2I)	C9	0,8	0	0	0	0	0	0,8	0	0	0,8	0,8	0	0	0	0	0	0	0	0	0	0
Vehicle to pedestrian communication (V2P)	C10	1	0	0,8	0,8	0	0	0	0	0,8	0	0	0	0	0	0	0	0	0	0	0	0
Ability to detect a VRU	C11	1	0	0,8	0,8	0	0	0	0	0,8	0	0	0	0	0	0	0	0	0	0	0	0
Informal rules and non-verbal communication	C12	0,8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Transition of Control	C13	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Law enforcement	C14	0,8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Level of automation	C15	0	0	0	0	0	0	0	0	0	0	0	0	-0,8	0	0	0	0	-0,2	0	-1	0
AV-supportive policies	C16	0,6	0	0,8	0,8	0	0	0	0	0,8	0	0	0	0	0,8	0	0	0	0	0	0	0
VRU-supportive policies	C17	0,6	0	0,8	0,8	0	0	0	0	0,8	0	0	0	0	0	0	0	0	0	0	0	0
Traffic Density	C19	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	-0,2	0	0	0	0	0	0
Perception driver on driving system	C20	0	0	0	0	0	0	0	-0,8	0	0	0	0	0	0	0	0	0	0	0	0	0
Perception VRU on traffic safety	C21	0	0,8	0	0	-0,6	0	0	0	0	0	0	0	0	0	0	0,6	0,6	0	0	0	0
Penetration rate Avs	C23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0





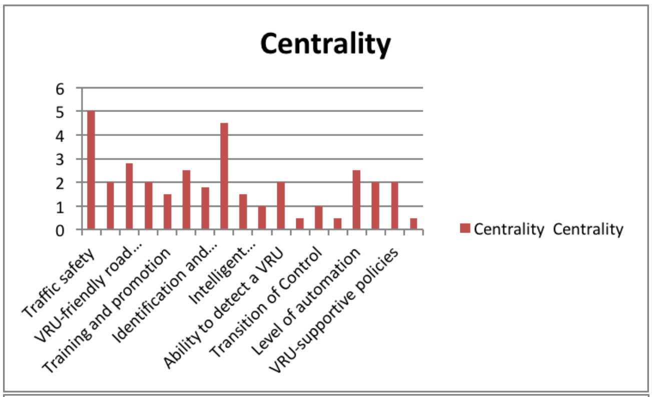


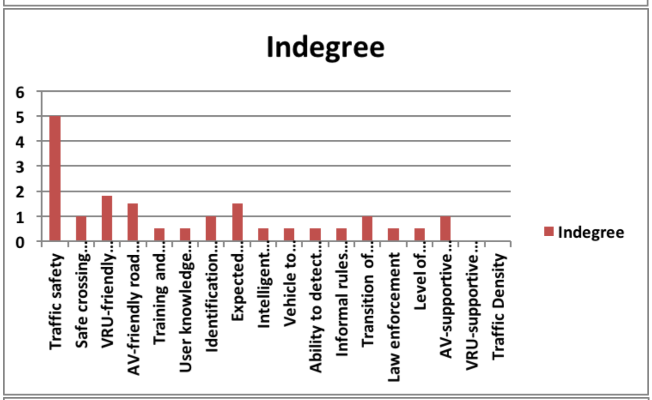
Group B

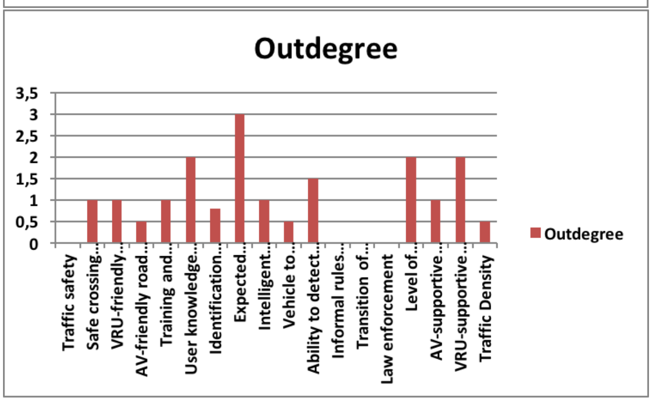


	B
Density	0,0895
Total # determinants	18
Total # connections	29
# Transmitters	2
# Receivers	4
# Ordinary	12
# Self-loops	0

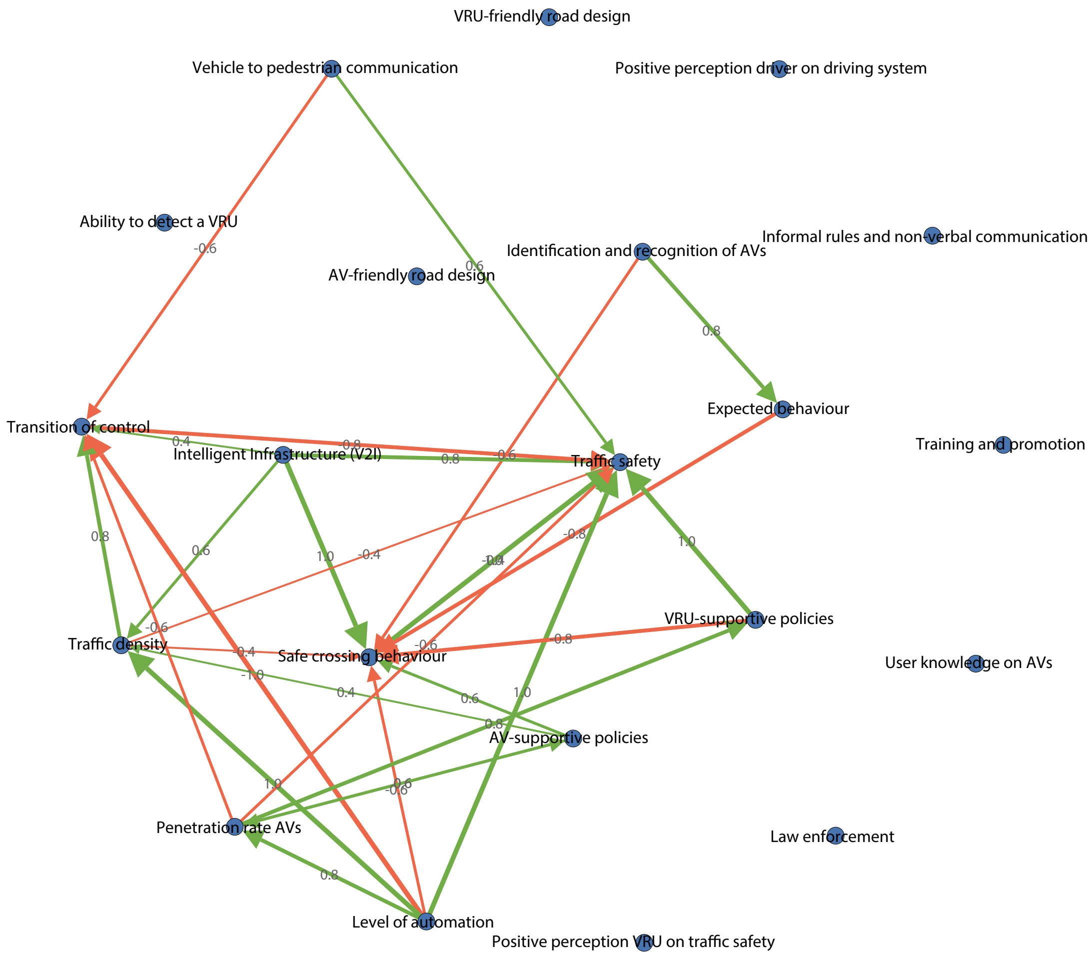
		Traffic safety	Safe crossing behaviour	VRU-friendly road design	AV-friendly road design	Training and promotion	User knowledge on Avs	Identification and recognition of Avs	Expected behaviour	Intelligent infrastructure (V2I)	Vehicle to pedestrian communication (V2P)	Ability to detect a VRU	Informal rules and non-verbal communication	Transition of Control	Law enforcement	Level of automation	AV-supportive policies	VRU-supportive policies	Traffic Density	Perception driver on driving system	Perception VRU on traffic safety	Penetration rate Avs
		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C19	C20	C21	C23
Traffic safety	C1	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Safe crossing behaviour	C2	**0**	**0**	**0,5**	**0**	**0**	**0**	**0**	**0,5**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
VRU-friendly road design	C3	**0,5**	**0,5**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
AV-friendly road design	C4	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0,5**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Training and promotion	C5	**0**	**0**	**0**	**0**	**0**	**0,5**	**0,5**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
User knowledge on Avs	C6	**0**	**0**	**0**	**0**	**0,5**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0,5**	**0**	**0**	**0**	**0**	**0**
Identification and recognition of Avs	C7	**0**	**0**	**0,8**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Expected behaviour	C8	**1**	**0,5**	**0**	**0,5**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0,5**	**0**	**0**	**0**	**0,5**	**0**	**0**	**0**	**0**	**0**
Intelligent infrastructure (V2I)	C9	**0**	**0**	**0**	**0,5**	**0**	**0**	**0,5**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Vehicle to pedestrian communication (V2P)	C10	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0,5**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Ability to detect a VRU	C11	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0,5**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Informal rules and non-verbal communication	C12	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Transition of Control	C13	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Law enforcement	C14	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Level of automation	C15	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**-1**	**0**	**0**	**0**	**0**	**?**	**0**	**0**	**0**
AV-supportive policies	C16	**0**	**0**	**0**	**0,5**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0,5**	**0**	**0**	**0**	**0**	**0**	**0**
VRU-supportive policies	C17	**1**	**0**	**0,5**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0,5**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Traffic Density	C19	**-0,5**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Perception driver on driving system	C20	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Perception VRU on traffic safety	C21	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Penetration rate Avs	C23	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**





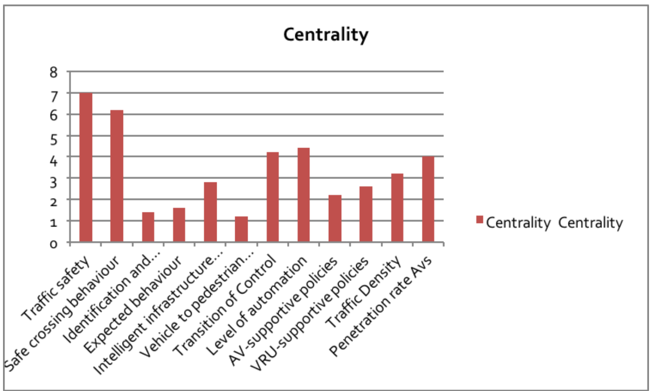


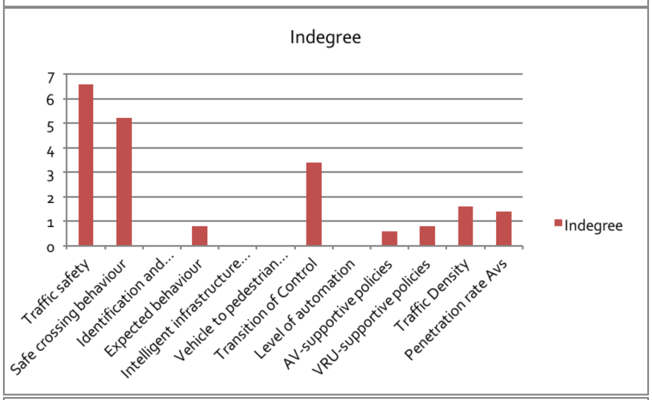
Group C

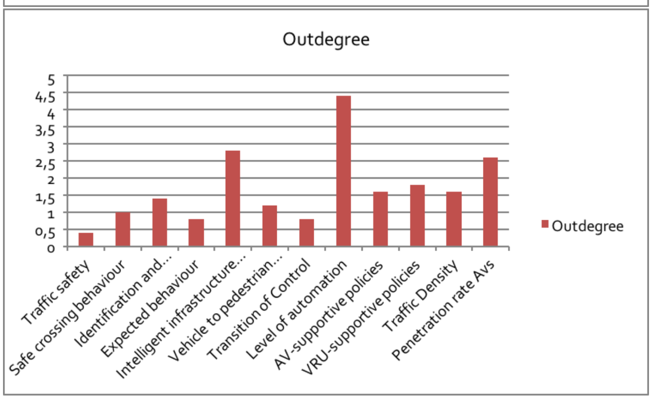


	C
Density	0,2014
Total # determinants	12
Total # connections	29
# Transmitters	4
# Receivers	0
# Ordinary	8
# Self-loops	0

		Traffic safety	Safe crossing behaviour	VRU-friendly road design	AV-friendly road design	Training and promotion	User knowledge on Avs	Identification and recognition of Avs	Expected behaviour	Intelligent infrastructure (V2I)	Vehicle to pedestrian communication (V2P)	Ability to detect a VRU	Informal rules and non-verbal communication	Transition of Control	Law enforcement	Level of automation	AV-supportive policies	VRU-supportive policies	Traffic Density	Perception driver on driving system	Perception VRU on traffic safety	Penetration rate Avs
		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C19	C20	C21	C23
Traffic safety	C1	0	-0,4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Safe crossing behaviour	C2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VRU-friendly road design	C3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AV-friendly road design	C4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Training and promotion	C5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
User knowledge on Avs	C6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Identification and recognition of Avs	C7	0	-0,6	0	0	0	0	0	0,8	0	0	0	0	0	0	0	0	0	0	0	0	0
Expected behaviour	C8	0	-0,8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Intelligent infrastructure (V2I)	C9	0,8	1	0	0	0	0	0	0	0	0	0	0	0,4	0	0	0	0	0,6	0	0	0
Vehicle to pedestrian communication (V2P)	C10	0,6	0	0	0	0	0	0	0	0	0	0	0	-0,6	0	0	0	0	0	0	0	0
Ability to detect a VRU	C11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Informal rules and non-verbal communication	C12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Transition of Control	C13	-0,8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Law enforcement	C14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Level of automation	C15	1	-0,6	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	1	0	0	0,8
AV-supportive policies	C16	0,4	0,6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,6
VRU-supportive policies	C17	1	-0,8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Traffic Density	C19	-0,4	-0,4	0	0	0	0	0	0	0	0	0	0	0,8	0	0	0	0	0	0	0	0
Perception driver on driving system	C20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perception VRU on traffic safety	C21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Penetration rate Avs	C23	-0,6	0	0	0	0	0	0	0	0	0	0	0	-0,6	0	0	0,6	0,8	0	0	0	0







Appendix – Combining conceptual FCM models

			Traffic safety	Safe crossing behaviour	VRU-friendly road design	AV-friendly road design	Training and promotion	User knowledge on Avs	Identification and recognition of Avs	Expected behaviour	Intelligent infrastructure (V2I)	Vehicle to pedestrian communication (V2P)	Ability to detect a VRU	Informal rules and non-verbal communication	Transition of Control	Law enforcement	Level of automation	AV-supportive policies	VRU-supportive policies	Traffic Density	Positive perception driver on driving system	Positive perception VRU on traffic safety	Penetration rate Avs
			C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C19	C20	C21	C23
Traffic safety		A	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,6	0,6	0,0	0,0	0,0	0,0
	C1	B	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		C	0,0	-0,4	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Safe crossing behaviour		A	0,8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	C2	B	0,0	0,0	0,5	0,0	0,0	0,0	0,0	0,5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		C	1,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
VRU-friendly road design		A	0,8	0,0	0,0	0,0	0,0	0,0	0,8	0,0	0,0	0,8	0,8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	C3	B	0,5	0,5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		C	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
AV-friendly road design		A	0,8	0,0	0,0	0,0	0,0	0,0	0,8	0,0	0,0	0,8	0,8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	C4	B	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		C	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Training and promotion		A	0,0	0,0	0,0	0,0	0,0	0,8	0,0	0,0	0,0	0,0	0,0	0,6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,8	0,0
	C5	B	0,0	0,0	0,0	0,0	0,0	0,5	0,5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		C	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
User knowledge on Avs		A	0,0	0,8	0,0	0,0	0,8	0,0	0,0	0,0	0,0	0,0	0,0	0,8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	C6	B	0,0	0,0	0,0	0,0	0,5	0,0	0,0	1,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,5	0,0	0,0	0,0	0,0	0,0
		C	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Identification and recognition of Avs		A	1,0	0,0	0,8	0,8	0,0	0,0	0,0	0,0	0,8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	C7	B	0,0	0,0	0,8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		C	0,0	-0,6	0,0	0,0	0,0	0,0	0,0	0,8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Expected behaviour		A	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	C8	B	1,0	0,5	0,0	0,5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,5	0,0	0,0	0,0	0,5	0,0	0,0	0,0	0,0	0,0
		C	0,0	-0,8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Intelligent infrastructure (V2I)		A	0,8	0,0	0,0	0,0	0,0	0,0	0,8	0,0	0,0	0,8	0,8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	C9	B	0,0	0,0	0,0	0,5	0,0	0,0	0,5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		C	0,8	1,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,4	0,0	0,0	0,0	0,0	0,6	0,0	0,0	0,0
Vehicle to pedestrian communication (V2P)		A	1,0	0,0	0,8	0,8	0,0	0,0	0,0	0,0	0,8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	C10	B	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		C	0,6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	-0,6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Ability to detect a VRU		A	1,0	0,0	0,8	0,8	0,0	0,0	0,0	0,0	0,8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	C11	B	1,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		C	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Informal rules and non-verbal communication		A	0,8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	C12	B	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		C	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Transition of Control		A	-1,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	C13	B	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		C	-0,8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Law enforcement		A	0,8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	C14	B	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		C	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Level of automation		A	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	-0,8	0,0	0,0	0,0	0,0	-0,2	0,0	-1,0	0,0
	C15	B	1,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	-1,0	0,0	0,0	0,0	0,0	?	0,0	0,0	0,0
		C	1,0	-0,6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	-1,0	0,0	0,0	0,0	0,0	1,0	0,0	0,0	0,8
AV-supportive policies		A	0,6	0,0	0,8	0,8	0,0	0,0	0,0	0,0	0,8	0,0	0,0	0,0	0,0	0,8	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	C16	B	0,0	0,0	0,0	0,5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,5	0,0	0,0	0,0	0,0	0,0	0,0
		C	0,4	0,6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,6
VRU-supportive policies		A	0,6	0,0	0,8	0,8	0,0	0,0	0,0	0,0	0,8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	C17	B	1,0	0,0	0,5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,5	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		C	1,0	-0,8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Traffic Density		A	-1,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	-0,2	0,0	0,0	0,0	0,0	0,0	0,0
	C19	B	-0,5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		C	-0,4	-0,4	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Positive perception driver on driving system		A	0,0	0,0	0,0	0,0	0,0	0,0	0,0	-0,8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	C20	B	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		C	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Positive perception VRU on traffic safety		A	0,0	0,8	0,0	0,0	-0,6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,6	0,6	0,0	0,0	0,0	0,0
	C21	B	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		C	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Penetration rate Avs		A	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	C23	B	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		C	-0,6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	-0,6	0,0	0,0	0,6	0,8	0,0	0,0	0,0	0,0

		Traffic safety	Safe crossing behaviour	VRU-friendly road design	AV-friendly road design	Training and promotion	User knowledge on Avs	Identification and recognition of Avs	Expected behaviour	Intelligent infrastructure (V2I)	Vehicle to pedestrian communication (V2P)	Ability to detect a VRU	Informal rules and non-verbal communication	Transition of Control	Law enforcement	Level of automation	AV-supportive policies	VRU-supportive policies	Traffic Density	Positive perception driver on driving system	Positive perception VRU on traffic safety	Penetration rate Avs
		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21
Traffic safety	C1		-0,13	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,20	0,20	0,00	0,00	0,00	0,00
Safe crossing behaviour	C2	0,60		0,17	0,00	0,00	0,00	0,00	0,17	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
VRU-friendly road design	C3	0,43	0,17		0,00	0,00	0,00	0,27	0,00	0,00	0,27	0,27	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
AV-friendly road design	C4	0,27	0,00	0,00		0,00	0,00	0,27	0,00	0,17	0,27	0,27	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Training and promotion	C5	0,00	0,00	0,00	0,00		0,43	0,17	0,00	0,00	0,00	0,00	0,20	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,27	0,00
User knowledge on Avs	C6	0,00	0,27	0,00	0,00	0,43		0,00	0,33	0,00	0,00	0,00	0,27	0,00	0,00	0,00	0,17	0,00	0,00	0,00	0,00	0,00
Identification and recognition of Avs	C7	0,33	-0,20	0,53	0,27	0,00	0,00		0,27	0,27	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Expected behaviour	C8	0,33	-0,10	0,00	0,17	0,00	0,00	0,00		0,00	0,00	0,00	0,17	0,00	0,00	0,00	0,17	0,00	0,00	0,00	0,00	0,00
Intelligent infrastructure (V2I)	C9	0,53	0,33	0,00	0,17	0,00	0,00	0,43	0,00		0,27	0,27	0,00	0,13	0,00	0,00	0,00	0,00	0,20	0,00	0,00	0,00
Vehicle to pedestrian communication (V2P)	C10	0,53	0,00	0,27	0,27	0,00	0,00	0,00	0,00	0,27		0,17	0,00	-0,20	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Ability to detect a VRU	C11	0,67	0,00	0,27	0,27	0,00	0,00	0,00	0,00	0,27	0,17		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Informal rules and non-verbal communication	C12	0,27	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Transition of Control	C13	-0,60	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Law enforcement	C14	0,27	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00		0,00	0,00	0,00	0,00	0,00	0,00	0,00
Level of automation	C15	0,67	-0,20	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,93	0,00		0,00	0,00	0,40	0,00	-0,33	0,27
AV-supportive policies	C16	0,33	0,20	0,27	0,43	0,00	0,00	0,00	0,00	0,27	0,00	0,00	0,00	0,00	0,27	0,17		0,00	0,00	0,00	0,00	0,20
VRU-supportive policies	C17	0,87	-0,27	0,43	0,27	0,00	0,00	0,00	0,00	0,27	0,00	0,00	0,00	0,00	0,17	0,00	0,00		0,00	0,00	0,00	0,00
Traffic Density	C18	-0,63	-0,13	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,27	0,00	-0,07	0,00	0,00		0,00	0,00	0,00
Perception driver on driving system	C19	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,27	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00		0,00	0,00
Perception VRU on traffic safety	C20	0,00	0,27	0,00	0,00	-0,20	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,20	0,20	0,00	0,00		0,00
Penetration rate Avs	C21	-0,20	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,20	0,00	0,00	0,20	0,27	0,00	0,00	0,00	

Appendix – Post-processing

The three initial maps have to be combined into one conceptual FCM model that represents the view of all participating professionals. The initial maps that professionals constructed during the workshop need to be adjusted before computation and meaningful model interpretations can be made (A. J. Jetter & Kok, 2014). Determinants with disregard of the model boundaries, definitional or overly detailed links and diagnostics variables should be deleted. The modeller can also choose to add links if necessary.

Table 5: Adjustments to initial (group) maps

Map	What	Action	Comment
A	Determinant Image/Politics	Remove determinant and corresponding links	Disregard of model boundaries
All	Determinant C18. Formal traffic rules and regulations	Include determinant in C14. Law enforcement	All professionals use C18. as a step towards C14 without any other links in or out. Therefore, this can be combined
A	Link C21 – C16 Link C21 – C17	Make positive relation	Participants misinterpreted the behaviour of the link
A	Determinant C20. Perception driver on abilities driving system	Rename: C20. Positive perception driver on abilities driving system	The determinant need to describe the behaviour (either positive or negative)
A	Determinant C21. Perception VRU on traffic system	Rename: C21. Positive perception VRU on traffic system	The determinant need to describe the behaviour (either positive or negative)
A	Link C12 – C1	Make positive relation	Participants misinterpreted the behaviour of the link
A	C5 – C21	Assign weight 0,8	Based on other groups
A	C21 – C5	Assign weight -0,6	Based on other groups
B	Link C1 – C15	Remove link	Other participant groups found no relation
B	Link C7 – C3	Assign weight 0,8	Adopt the same weight as group A
B	Link C8 – C13	Remove link	Other participant groups found no relation
B	Link C13 – C8	Remove link	Other participant groups found no relation
B	Link C15 – C1	Assign weight 1,0	Adopt the same weight as group C
C	Link C19 – C1	Assign weight -0,4	Based on other groups

		Traffic safety	Safe crossing behaviour	VRU-friendly road design	AV-friendly road design	Training and promotion	User knowledge on Avs	Identification and recognition of Avs	Expected behaviour	Intelligent infrastructure (V2I)	Vehicle to pedestrian communication (V2P)	Ability to detect a VRU	Informal rules and non-verbal communication	Transition of Control	Law enforcement	Level of automation	AV-supportive policies	VRU-supportive policies	Traffic Density	Positive perception driver on driving system	Positive perception VRU on traffic safety	Penetration rate Avs
		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21
Traffic safety	C1		-0,13	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,20	0,20	0,00	0,00	0,00	0,00
Safe crossing behaviour	C2	0,60		0,17	0,00	0,00	0,00	0,00	0,17	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
VRU-friendly road design	C3	0,43	0,17		0,00	0,00	0,00	0,27	0,00	0,00	0,27	0,27	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
AV-friendly road design	C4	0,27	0,00	0,00		0,00	0,00	0,27	0,00	0,17	0,27	0,27	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Training and promotion	C5	0,00	0,00	0,00	0,00		0,43	0,17	0,00	0,00	0,00	0,00	0,20	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,27	0,00
User knowledge on Avs	C6	0,00	0,27	0,00	0,00	0,43		0,00	0,33	0,00	0,00	0,00	0,27	0,00	0,00	0,00	0,17	0,00	0,00	0,00	0,00	0,00
Identification and recognition of Avs	C7	0,33	-0,20	0,53	0,27	0,00	0,00		0,27	0,27	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Expected behaviour	C8	0,33	-0,10	0,00	0,17	0,00	0,00	0,00		0,00	0,00	0,00	0,17	0,00	0,00	0,00	0,17	0,00	0,00	0,00	0,00	0,00
Intelligent infrastructure (V2I)	C9	0,53	0,33	0,00	0,17	0,00	0,00	0,43	0,00		0,27	0,27	0,00	0,13	0,00	0,00	0,00	0,00	0,20	0,00	0,00	0,00
Vehicle to pedestrian communication (V2P)	C10	0,53	0,00	0,27	0,27	0,00	0,00	0,00	0,00	0,27		0,17	0,00	-0,20	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Ability to detect a VRU	C11	0,67	0,00	0,27	0,27	0,00	0,00	0,00	0,00	0,27	0,17		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Informal rules and non-verbal communication	C12	0,27	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Transition of Control	C13	-0,60	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Law enforcement	C14	0,27	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00		0,00	0,00	0,00	0,00	0,00	0,00	0,00
Level of automation	C15	0,67	-0,20	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,93	0,00		0,00	0,00	0,40	0,00	-0,33	0,27
AV-supportive policies	C16	0,33	0,20	0,27	0,43	0,00	0,00	0,00	0,00	0,27	0,00	0,00	0,00	0,00	0,27	0,17		0,00	0,00	0,00	0,00	0,20
VRU-supportive policies	C17	0,87	-0,27	0,43	0,27	0,00	0,00	0,00	0,00	0,27	0,00	0,00	0,00	0,00	0,17	0,00	0,00		0,00	0,00	0,00	0,00
Traffic Density	C18	-0,63	-0,13	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,27	0,00	-0,07	0,00	0,00		0,00	0,00	0,00
Perception driver on driving system	C19	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,27	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00		0,00	0,00
Perception VRU on traffic safety	C20	0,00	0,27	0,00	0,00	-0,20	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,20	0,20	0,00	0,00		0,00
Penetration rate Avs	C21	-0,20	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,20	0,00	0,00	0,20	0,27	0,00	0,00	0,00	

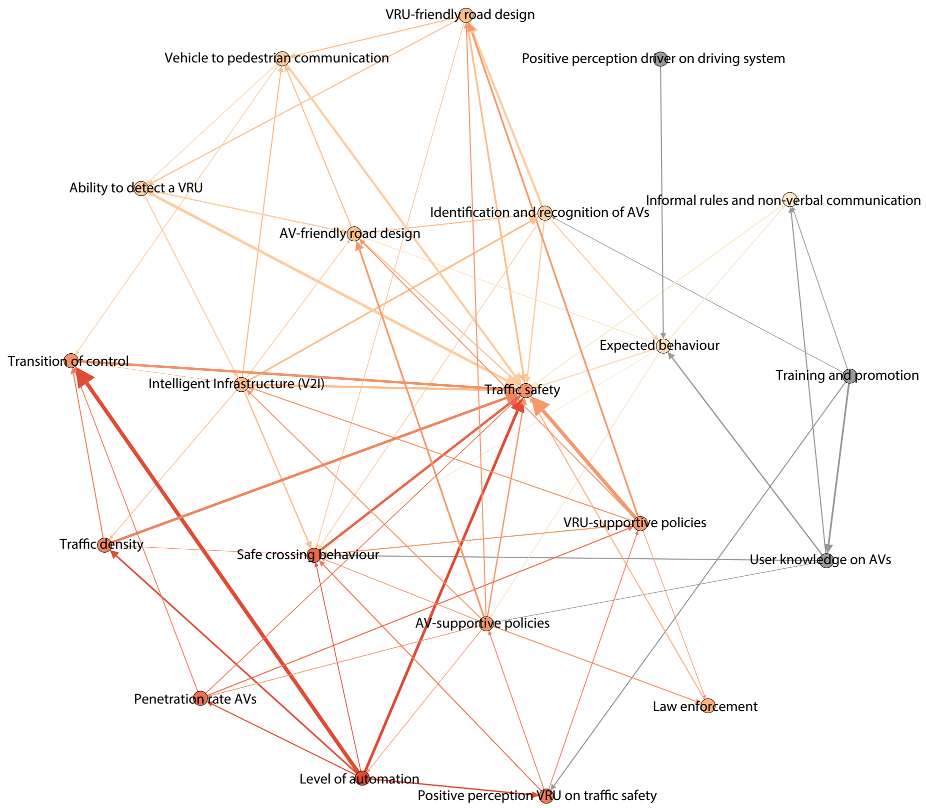
Figure 23: Short feedback loops in the adjacency matrix

Table 6: Post-processing Combined matrix

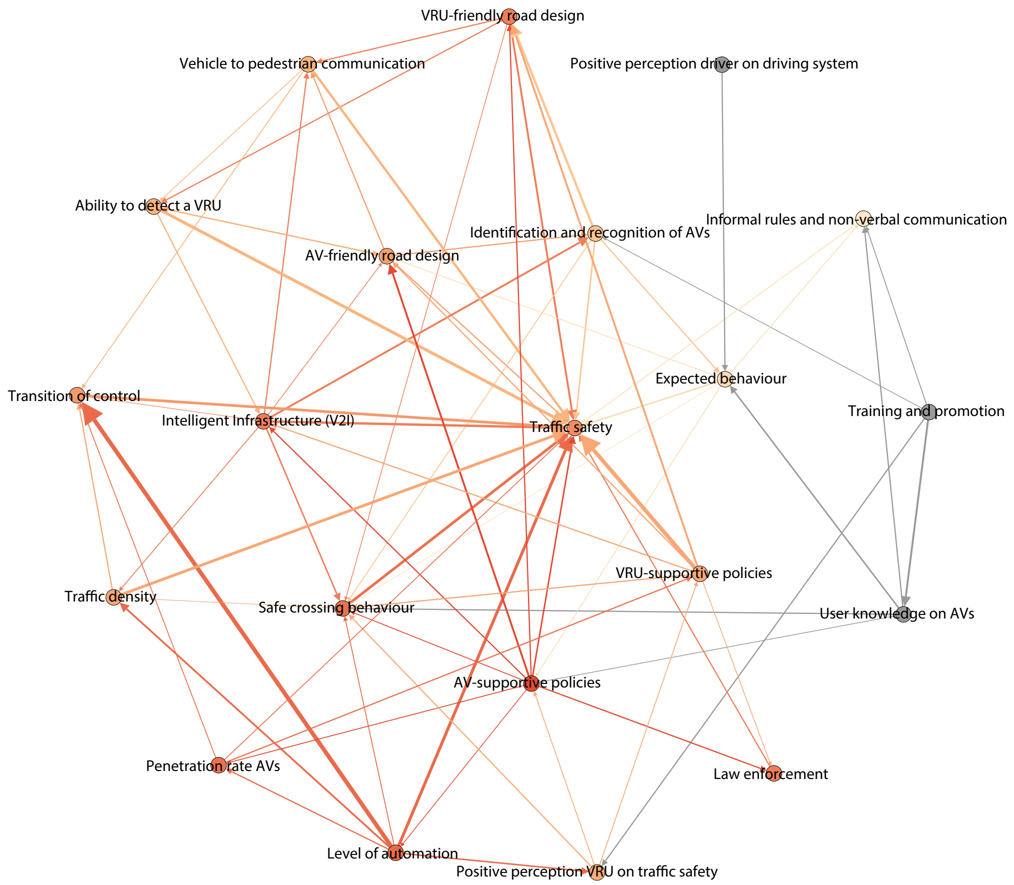
#	Link 1	Link 2	Choice	Comment
1	~~C1 – C2~~	C2 – C1	Majority of groups	1 vs 2
2	~~C1 – C16~~	C16 – C1	Majority of groups	1 vs 2
3	~~C1 – C17~~	C17 – C1	Majority of groups	1 vs 3
4	~~C2 – C3~~	C3 – C2	Professional's choice	Research has shown that road design affects behaviour. The other way around is more difficult and has a larger time frame
5	~~C2 – C8~~	C8 – C2	Majority of groups	1 vs 2
6	~~C3 – C7~~	C7 – C3	Majority of groups	1 vs 2
7	C3 – C10	~~C10 – C3~~	Professional's choice	Link 2 doesn't sound logical; road design should influence V2P
8	C3 – C11	~~C11 – C3~~	Professional's choice	Link 2 doesn't sound logical; road design should influence ability to detect
9	C4 – C7	~~C7 – C4~~	Professional's choice	AV road design can indicate an AV to other road users, e.g. on a dedicated lane.
10	~~C4 – C9~~	C9 – C4	Professional's choice	The better V2I there is, the friendlier road design is for AVs
11	C4 – C10	~~C10 – C4~~	Professional's choice	Road design should be leading in this system
12	~~C4 – C11~~	C11 – C4	Professional's choice	If a VRU is not visible, the road design has to be changed
13	C5 – C6	~~C6 – C5~~	Professional's choice	Link 2 is contradictory and doesn't seem logical
14	C5 – C20	~~C20 – C5~~	Professional's choice	Link 1 makes more sense
15	~~C7 – C9~~	C9 – C7	Majority of groups	1 vs 2
16	C9 – C10	~~C10 – C9~~	Professional's choice	V2I can contribute more to V2P than the other way around
17	~~C9 – C11~~	C11 – C9	Professional's choice	Both are applicable, but at this moment link 2 is found more important. This might change over time
18	C10 – C11	~~C11 – C10~~	Professional's choice	Both are applicable, but at this moment link 2 is found more important. This might change over time
19	~~C18 – C15~~	C15 – C18	Majority of groups	1 vs 3
20	~~C21 – C16~~	C16 – C21	Professional's choice	If AV policies are not right, the penetration rate of AVs will not be sufficient enough to force a transition

Appendix – Heat maps scenarios

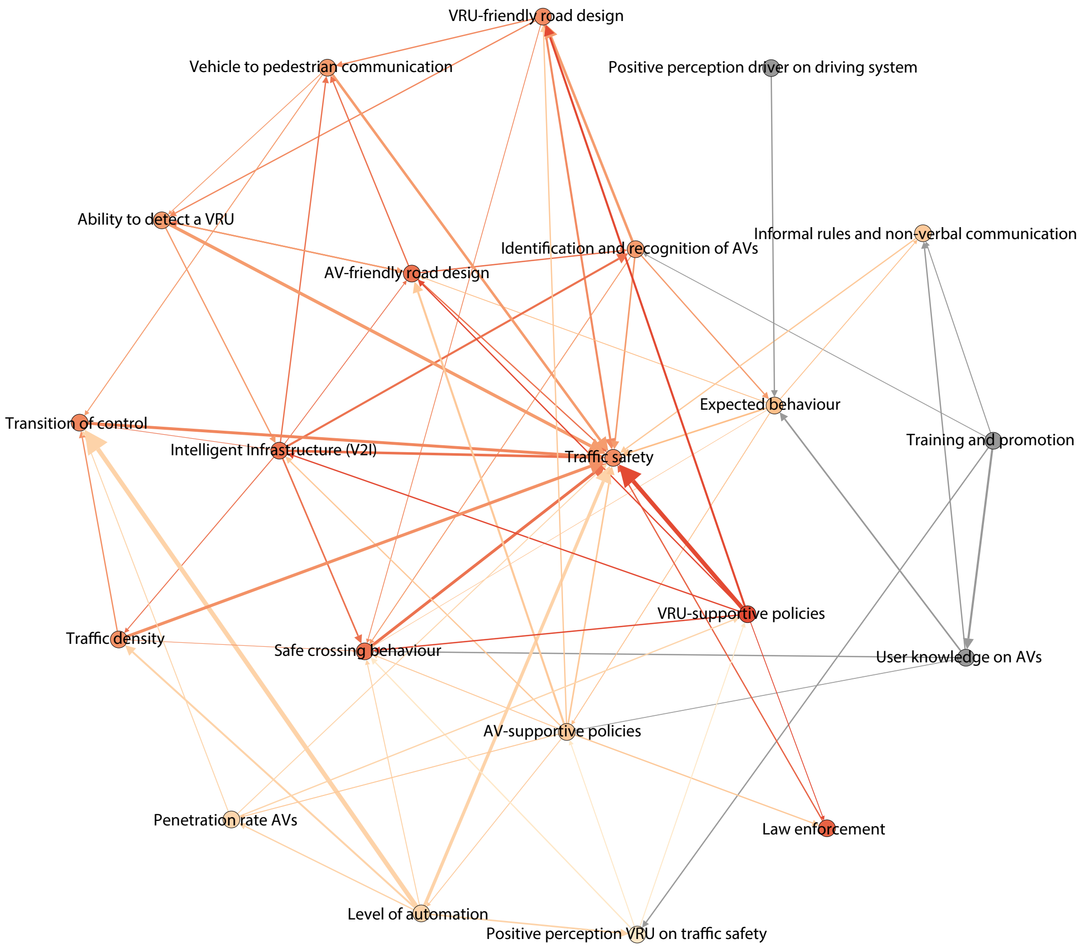
Level of automation



AV supportive policies



VRU supportive policies



Appendix – Interviews

The last step in the adapted FCM approach is executing the interviews. In the interview, the professional is asked to validate remarkable results from the model structure and dynamic behaviour of key determinants. Furthermore, the professionals are asked for state-of-the-art knowledge on a specific key determinant. This knowledge is used to get an improved understanding of the key determinants and to identify relevant research gaps. The first section describes the objective and selection of professionals. The second section summarizes the most relevant and important findings from the interviews.

Knowledge capture

This section describes the plan for knowledge elicitation of the interviews. First, the objective is determined. After that, a selection is made for relevant professionals that are interviewed.

The interviews are designed to fulfil three objectives, namely:

1. Extensive research into key determinants
2. Validation on assumptions made by the participants of the workshop
3. Validation on the model results

The second and third objective are only discussed with the professional if the assumption(s) or result(s) fall within their field of expertise.

The interviews are executed in an exploratory or semi-structured manner to capture a wide range of the specific determinant. Relevant subjects are found and translated into open question before the interview took place. This list of subjects and questions is used during the interview for guidance and to prevent the interviewee from going into irrelevant subjects.

Selection of professionals

The professionals for the interview are chosen because they have an above average knowledge of (at least) one of the key determinants, are objective and are motivated to participate in the process of interviewing and validation. On top of these requirements, a set of criteria is created. Each professional meet at least one of the criteria, and professionals that meet more criteria are favoured in the selection procedure.

Criteria:

1. Expertise in traffic safety;
2. Expertise in AVs
3. Expertise in autonomous vehicles
4. Expertise in policy making
5. Expertise in human behaviour in the traffic system

The list of professionals that participated in the interviews in presented in Table 7.

Table 7: Professional selection

Person	Company	Criteria					Key Determinant			
		1	2	3	4	5	Safe crossing behaviour	AV/VRU road design	Identification and recognition of AVs	Intelligent Infrastructure (V2I)
Rob Methorst	SWOV									
Saskia de Craen	SWOV									
Riender Happee	TU Delft									
Rob Eenink	SWOV									

The professionals were send an email with a request for an interview. The introduction of the email briefly the research, the subject and why this research is being performed. The professional is explained that the interview is used to validate results and to gain extensive information on one or two specific key determinants. The reason that this professional is contacted is also described in the introduction.

To safeguard the objectivity, no further information is given to the professional other that the key determinant that will be the subject of the interview. The professional is explained that the interview will take up 30 to 60 minutes. The professional is asked for permission to record the interview and to use their name in the report. If desired, the professional is documented anonymously. Lastly, the professional is instructed that the results of the interview will be send to them for validation before they are used in the report. The interviews were executed in Dutch, which is the native language of both the interviewer as the interviewees. The relevant findings are summarized, translated into English and send for validation to the interviewee.

Appendix – Interview Dr. Ir. Riender Happee

Riender Happee is an associate professor and programme manager Automotive at Delft University of Technology at the faculty Mechanical, Maritime and Materials Engineering (3ME) and at the faculty Civil Engineering and Geosciences (CEG). Happee plays an active role in projects such as '*Dutch AV Initiative (DAVI)*', '*WEPods autonomous driving in the province of Gelderland*' (coordinator / contract partner), '*Safe interaction of AVs with VRUs* (*SafeVRU)* (coordinator) and '*Human factors of Automated Driving (HFAuto)* (coordinator). Happee is interviewed on the concept of *identification and recognition of AVs.*

First of all, the expected appearance of AVs is not known in detail at this moment. Since the technology is currently being developed, questions on this matter remain (partly) unclear. Happee is willing to speculate on the topic.

It is known that eye contact is important in the interaction between VRUs and (drivers of) vehicles. However, there are situations present where no eye contact is made in the interaction. In the dark, a pedestrian or cyclist have trouble seeing the driving of a vehicle even though the driver is able to see them. Non-verbal communication is in that scenario not present or limited, but do not automatically result in a dangerous situation. It can therefore be said that a safe interaction between VRUs and vehicles can also take place without non-verbal communication. It is therefore questionable if the AV need to be recognized as such. The WEPod is deliberately designed with a different, modern look. Other road users can develop expectation patterns if they recognize the vehicles as self-driving. However, making a vehicle easily distinguishable from manual driven vehicles might provoke abuse. Making the AV recognizable has its advantages and disadvantages. These advantages and disadvantages can be researched.

As an example, the self-driving vehicles in Capelle aan de Ijssel where occasionally blocked by youngsters. An operator in the (external) control room communicated with the youngsters that they had to give way to the vehicle. Eventually, the police were sent to the youngsters and their parents, which stopped the problem. Such a control room makes it possible to remove the steward from the service. This remote supervision doesn't have a primary safety task, so the AV can be operated without the control room paying constant attention. When the vehicle registers an irregularity, the control room can send someone to take care of things or take over control from a distance. In that case, AVs can be a functional transport service on road sections where cyclists and pedestrians are present.

Crossing behaviour depends on context, road typology, culture etc. In all these different contexts, AVs are introduced in the near future. It is therefore necessary to develop requirements for AVs specified for certain areas. Research into crossing behaviour in the current traffic system, thus without AVs, is the first step towards understanding the crossing behaviour when AVs are introduced. Some locations even need to be avoided on certain times, for example when a lot of pedestrians and cyclist make use of the same road section. If the AV has to interact with a lot of pedestrians, it is likely that this vehicle is standing still a lot of the time. Take the Kalverstraat as an extreme example. If you ask someone to drive through this street, he will eventually get through it. A self-driving vehicle is expected to stand still most of the time and can only continue its drive when de street is free of pedestrians. It is likely that the assigned areas and time slots for automated driving are limited. Autonomous driving in a personal vehicle is therefore functionally not very interesting in the city centre, but in a taxi-service the decrease in travel speed might be acceptable. A dedicated track is always a solution, but expensive and not always desired.

We know that we have to deal with these cases and that we have to communicate with VRUs in order for the AV to drive more assertive and closer to the pedestrians and cyclists. It might also be desirable that other road users learn that they have to give way to AVs. For example, when pedestrians are crossing a bus lane, they don't expect the bus driver to give way to them. The pedestrian has developed an expectation pattern that the bus has priority on the bus lane and that he has to drive on schedule. Therefore, the pedestrian is more cautious and will most likely don't jaywalk. This type of expectation patterns has to be developed for the AVs and are at this moment unknown. The developers of the technology are responsible, together with the government, for the choice on how conservative of aggressive the vehicles are programmed. The reliability of the technology needs to be proven step by step.

Emergency brake systems already exists that react to pedestrians. This system can to some extent distinguish pedestrians from cyclists and vehicles. These systems are not 100% safe, but with the combination of a human driver they contribute to traffic safety. This technology is currently being developed to gain a better level of detection and intent recognition. As soon as the technology is at its desired level, strategies will be developed for the AVs for assertive driving while making use of different ways of communication (light signals, sound effects, projections etc). What the features of the vehicles should look like is the responsibility of the developer, but legislations are needed from the government (or RDW).

One of the most important aspects in the communication between VRUs and ZVs is if the vehicle is going to stop for the VRU or not. A human is capable to estimate the time to collision, but find it harder to detect if a vehicle is decelerating of accelerating. It is therefore hard to estimate if the vehicle is going to stop or not. Since this is the case for manual driving, it is expected that the same limitations are applied in the interaction with AVs. If the AV is communicating that it is going to stop, the pedestrian can cross the road in an earlier stage. This is a possible gain in time and acceptation. How this communication should be executed has yet to be researched. The pedestrians should not have to be trained to know what AVs mean with different signals. Happee believes that the system should be designed in the most easy and intuitive way as possible, so that other road users can interact with the AV without extra training or promotion. The responsibility for this lies with the developer and legislator.

A Virtual Reality (VR) lab exists in Munchen, where traffic safety and acceptation is tested for AVs. Similar tests will be performed at the TU Delft where on-road test facilities and a VR lab are developed. WEpods are currently tested and improved at the TU Delft campus. The City of Amsterdam might request experiments to be performed in Delft, to support introduction of automated driving (shuttles) in Amsterdam. The City of Amsterdam should therefore analyse and select a route in Amsterdam where AVs can be operated in an attractive manner. A pilot has to be implemented to learn about the specific challenges of the selected location, and to create local (Amsterdam) public awareness. Note that a steward is required in the beginning of the pilot, and investments will be needed to operate and evaluate such pilots.

Appendix – Transcript interview Dr. Ir. Riender Happee

Delft, 24-05-2017. Faculty Mechanical, Maritime and Materials Engineering (3ME). Ref: (Happee, 2017)

HH. Beschikt u over de kennis over hoe AVs eruit moeten komen te zien?

RH. Dat moet nog besloten worden. De vragen liggen echt nog open, wat hebben we nodig om het oogcontact te vervangen door een nieuwe communicatie, moet het zelfrijdend voertuig altijd als zodanig herkenbaar zijn? Die vragen, daar is nog geen keihard antwoord op. Ik wil er wel wat op speculeren.

RH. Wat we weten is dat oogcontact heel belangrijk is. We weten ook dat er regelmatig interacties zijn waarbij we geen oogcontact hebben. Dat betekent dat in elk geval in het donker dat je als voetganger niet de bestuurder ziet en dat de bestuurder jouw wel altijd ziet. Maar niet even goed als wanneer het bij licht is. Dat betekent dat er dat wel wat non-verbale communicatie is, dat je ziet wat iemands loopbeweging is, kijkbeweging, dat is er allemaal wel en dat speelt ook zeker een rol, maar toch weten we ook echt ook dat zonder ook wel kan.

RH. En moeten we nog zien te kwantificeren door daar onderzoek naar te doen hoe mensen oversteken zonder dat er automatisering in het spel is. Hoe dat gaat en ook hoe variabel dat is. We weten dat uit allerlei studie het oversteekgedrag van mensen heel erg anders is afhankelijk van context, soort weg, de infrastructuur, het land. Mensen steken gewoon in sommige landen over van er moet maar plaats voor mij komen en afhankelijk van de urgentie. In die wereld moeten wij straks de zelfrijdende auto's introduceren, waarbij ik toch denk dat daarbij mogelijk is dat je het gedrag van mensen dat je daar andere eisen aan kunt stellen.

RH. Wat we in eerste instantie als ontwerp filosofie hebben bij bijvoorbeeld de WEPods is Rijd zo voorzichtig mogelijk met als uiterste consequentie dat je dus langer onderweg bent. Minder risico neemt, langzamer rijdt. Dat je zelfs op bepaalde tijden bepaalde plekken mijdt omdat je weet dat het verkeer daar met name de aanwezigheid van voetgangers zo groot is dat je stil komt te staan.

RH. Je kunt een beetje als limiet Kalverstraat nemen, als je iemand vraagt om met een auto door de kalverstraat heen te rijden, je maakt dat even wettelijk mogelijk, dan gaat hij erdoorheen komen. Een taxichauffeur zou misschien de claxon gebruiken, misschien niet en komt erdoorheen. Die zelfrijdende auto zal heel lang stil blijven staan. Pas als de straat weer leeg is daardoorheen gaan. En dat is wat nu niet doen en tegelijkertijd weten we ook dat we daar iets mee moeten doen. Dat we dan toch communicatie kunnen gaan gebruiken om gecontroleerd wat dichterbij de andere weggebruikers te kunnen komen in tijd en snelheid en ook wat assertiever kunnen zijn. Maar nogmaals het kan ook zijn dat er toch de andere weggebruikers moeten gaan leren dat ze die auto wel de ruimte moeten geven.

HH. Dat is ook een van de variabelen die uit mijn onderzoek naar voren kwam. Stel zelfrijdende auto's zouden er nu komen, dan moeten we weten wat we ervan kunnen verwachten, maar ook hoe wij daarmee kunnen communiceren.

RH. Een bus op een busbaan, als jij daar met een auto even wil keren ofzo, of oversteken als voetganger, verwacht je dat die voor jou stopt?

HH. Hij zal stoppen, maar hij zal dat niet met liefde doen

RH. Die buschauffeur gaat ervanuit, bij een bus heb je eigenlijk een verwachtingspatroon dat met name op zo'n busbaan, dat is zijn plek en hij moet op schema rijden dus hij stopt liever niet. En je hebt een andere situatie dat de voetgangers woonwijk gecombineerd met een zebra en als voetganger wil oversteken en er komt een auto aan die keurig met 30 km/h rijdt, dan verwacht je wel dat hij stopt. Dus de verwachtingen zijn daar al heel verschillend in.

RH. Die zullen dus nog voor de zelfrijdende voertuigen een vorm krijgen

HH. Ook dat is een resultaat na identificatie en herkenning, uit het model wat is opgebouwd door de experts, dat je als voetganger kunt zien of het een manueel bestuurde auto of zelfrijdende auto is, dan ga je daaruit inderdaad het verwacht gedrag op aanpassen.

RH. Wij kunnen dus ook als ontwerper van zelfrijdende voertuigen, als overheid die ze toelaat, daar een keuze in maken. Gaan wij inderdaad kiezen voor zelfrijdende voertuigen die zo conservatief zijn dat ze in bepaalde gebieden erg langzaam functioneren of gaan we dat niet doen. Dat zijn gewoon keuzes. En we moeten stap voor stap de betrouwbaarheid van de techniek aantonen want er zijn nu al gewoon auto's die emergency brake hebben als reactie op voetgangers. Die kunnen voetganger en fietser van elkaar onderscheiden, snelheid inschatten en op basis daarvan besluiten om te stoppen. Nou dat soort systemen zijn er nog niet 100% veilig, maar je zult zien als er al een bestuurder is dat deze een heel goeie aanvulling zijn op de verkeersveiligheid.

RH. Die zijn we aan het door ontwikkelen tot een veel beter detectieniveau en intent recognition niveau. Als we dat bereiken gaan we ook die regel strategieën op het voertuig toepassen op zoek naar veilige, maar toch enigszins assertieve interactie gebruik makende van communicatie. Dat zijn lichtsignalen, geluid, smiley op het voertuig, zebra die ervoor wordt geprojecteerd, dat zijn allemaal dingen waarvan wij verwachten dat ze veiligheid en voorspelbaarheid verbeteren.

RH. Dan kom je ook nog bij acceptatie. Willen we deze voertuigen op de weg hebben? Ik denk dat dat wel gaat gebeuren, ook wel vrij snel.

HH. Ook al zodra fietsers en voetgangers in het plaatje komen?

RH. Het is echt vreselijk lastig, maar ik denk wel dat we het gaan doen, alleen maar dat betekent niet dat je op een voldersgracht een voetganger gaat inhalen met zoveel marge. Je gaat wat meer afstand houden en je gaat wat langzamer rijden, dat betekent dus ook dat je dat die mate van automatisering niet heel aantrekkelijk is om in je gewone auto te hebben. Daar heb je eigenlijk niets aan. Dus dat wil je niet.

RH. Je gaat langzamer rijden, je gaat de extreme drukte vermijden dus dan kom je op een beperkt gebied van wegen en tijden waar je rijdt. Afgezonderde infrastructuur kan daar een deel vanuit maken. Dat betekent dat je echt geautomatiseerd rijden in de stad in je auto is functioneel niet heel interessant, maar als je door een driverless taxi vervoerd wordt over een korte afstand dan is die 20km.h misschien weer wel acceptabel. Stel je wordt van het station naar de TU Delft gebracht met 20km.h naar je hotel, of iets langzamer, dan is dat oké. Dus ik verwacht dat het wel gebeurd, alleen dus niet op de manier dat meteen de auto uit alle planning valt.

HH. Dus bijvoorbeeld in gebieden als de Damrak, daar zullen deze systemen nog niet snel komen

RH. Stel dat je werkt op een traject van 3km, waarop je een heel klein stukje Damrak hebt, dan denk je dat die gewoon daar met een boog omheen gaat rijden?

HH. Ik denk niet dat hij daar überhaupt moet komen. Als ik zo'n auto kan onderscheiden van een normale auto, en ik heb haast, dan zal ik oversteken.

RH. Dat moeten we dus mogelijk veranderen, maar dan heb je ook nog dus met de WEPods zijn we nu zo ver dat we permissie hebben om te rijden met steward. De volgende mijlpaal is om de techniek zo te verbeteren dat dit zonder steward kan en dan doen we dat natuurlijk nog steeds eerst op die rustige Wageningen campus.

RH. Dus eerste stap is steward eruit, maar wat we dan nog wel hebben is een controle room en die kan dan natuurlijk als je echt een clubje voetgangers tegenkomt, die kan dan ook met de microfoon en de luidspreker op het voertuig met die jongen zeggen van: Ga eens even weg, anders stuur ik de politie op jullie af. Dat kan allemaal gaan gebeuren. Dan heb je remote supervision. Dit die heeft geen primaire veiligheidsfunctie, voertuig moet gewoon ook als die controle room niet oplet moet de voertuig dat veilig kunnen bewandelen, maar als hij in een situatie staat waarin assistentie nodig is kan hij de control room daar iemand naar toe sturen voor reparatie of wat dan ook, of die kan dan ook op afstand beslissingen nemen als, er gebeurt iets, de sensor detecteren iets in de weg, is het een gat, je kunt met de camera's de omgeving monitoren. Dus dat kan ook een rol gaan spelen en daar kan je dus die ene deadlock situatie wel degelijk even mee doorlopen. Ook als je een traject hebt met een stukje met voetgangers die heel langzaam rijdt, dan kan je nog steeds een functioneel transport hebben. Dat is in alle publiek transportvormen van driverless is dat nu nog aan de hand. Is natuurlijk ook bij trein en bus, trein – metro is er natuurlijk ook altijd iets van een controlroom. Snelweg heeft ook een controlroom. Dus die moet je niet vergeten.

HH. Betreft weersomstandigheden, kunnen we altijd die zelfrijdende auto goed zien. Ik was benieuwd of er onderscheid gemaakt gaat worden tussen zelfrijdende voertuigen of manueel bestuurde voertuigen, worden die hetzelfde ontworpen of niet, kunt u daar al iets over zeggen?

RH. Met de WEPods wilden we graag er anders uitzien We hebben ook overwogen om een personenauto om te bouwen, of een state of the art busje om te bouwen. We vonden het toch prettig om een andere moderne look en feel te hebben en toen hebben we ook wel aan de veiligheid gedacht. Dus ik denk dat het in het bouwen van de verschillende verwachtingpatronen van verschillende soorten voertuigen gewoon helpt om dat hele voertuig al herkend wordt als dit is gewoon een zelfrijdend voertuig. Of je dan bij voertuigen die je bij verschillende manieren gebruikt kan worden dat je iets zet voorop als in: Ik ben zelfrijdend. Dat is allemaal mogelijk.

RH. Als je het wel aangeeft, lok je een beetje misbruik uit. Dat misbruik zal ook ontstaan met jongens die ervoor springen om te kijken hoe het werkt. Dat is ook echt gebeurd met de 2getthere voertuigen wat bij Capelle rijdt. Daar zijn in het begin ook schooljongens voor gaan staan om eens te kijken. Daar zijn ook control room op een gegeven moment hebben die politie naar de jongens en ouders gestuurd en dat is ook weer daarmee gestopt, dus dat kunnen we allemaal wel weer hanteren. Maar dat gaat allemaal wel weer gebeuren.

HH. Dat kom in het model ook naar voren. Als we de zelfrijdende voertuigen krijgen, zal er steeds meer handhaving plaats moeten vinden.

RH. Dat is ook zo, maar dat hoeft helemaal niet een heel groot probleem te worden. Dat zal wel.

HH. Het ontwerp van de auto's, ligt dat nog heel erg in de handen van de fabrikant?

RH. De WEPods, daar ben ik eindverantwoordelijke voor geweest, dat zijn natuurlijk de fabrikanten, de busmaatschappijen zijn daar straks in bepalend. Dus dat zal een marktwerking zijn.

HH. Heel kort weer terug naar de zelfrijdende auto zal misschien moeten communiceren met: Ik heb je gezien of niet gezien…

RH. Wat nuttig is, is om te communiceren: Ik ga voor je stoppen. Want als mens, als voetganger ben je niet zo gevoelig voor je kan wel zien hoe groot iets is hoe ver weg ongeveer, hoe hard het naar je toekomt. Zelfs die twee dingen kun je niet zo heel goed schatten, maar visueel uit de optical flow kun je met name de time to collission schatten. Dus over hoeveel seconden is die bij je. Wat je dus niet goed kunt waarnemen, dus time to collision is een combinatie van snelheid en afstand. Wat je niet goed kunt waarnemen is of dat voertuig aan het remmen is. Dus betekent dat je als voetganger niet goed ziet, remt deze auto voor mij of niet. Dat is nu het probleem bij manual driving, dat zal met zelfdrijdende voertuigen ook aan de hand zijn. Als je als voertuig aangeeft; Ik ga voor jou stoppen, dan betekent dat dat je als voetganger eerder weet van

Oh ik kan nu oversteken. Dat je niet wacht tot die stil staat. Dus dat is een mogelijk tijdswinst en acceptatiewinst. Met name het signaal van: Ik ga niet voor jou stoppen! Kan heel nuttig zijn.

HH. En dat zal met lichten gebeuren, geluidssignalen etc.

RH. Dat gaan we dus onderzoeken, hoe je dat duidelijk kan doen. Licht, geluid, teken op de bumber, tekentje ergens onder, op de voorruit, letters, projectie. Er zijn heel veel mogelijkheden.

HH. Hoe worden de mensen getraind daarin om die tekens te herkennen? Of zijn dat zulke algemene tekens om te kunnen herkennen?

RH. De hele filosofie met zelfrijdende auto's is: We moeten het zo goed maken en zo makkelijk dat gebruikers en ander weggebruikers er zonder training mee overweg kunnen. Dat is het streven. 20 jaar geleden was het nog heel veel (..) automated highway systems, een nieuwe snelweg met aparte rijbanen voor zelfrijdende voertuigen. Op dat gebied is het erg stil op dit moment, dat blijft natuurlijk wel een mogelijkheid. Dat zal ook nog steeds weleens ergens gaan gebeuren. Maar de main stream is gewoon Mixed traffic, dus je maakt de systemen zo goed en intuïtief dat iedereen ermee overweg kan, dat is het streven.

RH. Er zijn strategieën dat je heel conservatief bent, maakt dat wel dat je niet tot ingevallen lijdt.

HH. Dus de verantwoordelijkheid van het zo makkelijk mogelijk maken van zelfrijdende auto, die ligt dus bij de ontwikkelaar? Het is niet de taak aan de gemeente, die hoeven geen reclame te maken etc.

RH. Ja. En de wetgever, want die moet ze natuurlijk toe laten.

HH. Als allerlaatste vraag heb ik dan nog, ik wil proberen dit soort dingen te vertalen naar een advies voor de gemeente Amsterdam, waar denkt u dat een partij als de Gemeente Amsterdam onderzoek naar moet doen in die zelfrijdende auto's, en dan voornamelijk gericht op identificatie en herkenning. Is er iets dat u zegt, daar wordt nu onderzoek in gedaan, hier zitten nog de gaten in het onderzoek etc.

RH. Wat we kunnen doen is een plek identificeren waar ze zouden willen beginnen. Die plek moet echt in Amsterdam zijn, gewoon een functie functioneel project, ze hebben natuurlijk dat leuke ideetje met het gehandicapten ervoer op IJburg. Ze moeten gewoon iets kiezen en niet stopzetten. Hoeven ze niet meteen dat te gaan doen, maar echt kijken naar he wat is de waarde daarvan, wat zijn de veiligheid en acceptatievragen, en dan moet je voordat je daar meteen gaat rijden, moet je kijken wat zijn nou de manieren waarop we die veiligheid en acceptatievragen kunnen beantwoorden. En dan kan het zijn dat ze die bijvoorbeeld vertalen naar een simulatiestudie die ze bijvoorbeeld aan ons vragen om te doen.

RH. In München hebben we al een VR lab, daar kun je als voetganger een auto tegenkomen. Dat wat ik jou net vertelde, dat onderzoek met de lamp voorop de auto en kijkt of de voetganger er beter door. Dat gaan we daar eerst onderzoeken en dan gaan we dat in het VR lab onderzoeken. Zowel gericht op veiligheid als acceptatie. Voel je je veilig? Dat kun je daar onderzoeken. Dat kun je ook hier straks op de campus in Delft onderzoeken. Alleen dan moet je dat dus doen met het idee van Ik wil in Amsterdam die en die straat, daar wil ik dat gaan doen op die en die tijd en verkeersdrukte. En die instrumenten die je daar of hier op de Mekelweg inzet die kan je helemaal afstemmen op die visie van Amsterdam, wat zij nu willen. Maar je kan ook zeggen, we maken die analyse, dus een desk analyse. Kunnen wij dit wel gewoon gaan doen. Dan kan het ook zijn dat de gemeente Amsterdam zegt: We kiezen een traject waarbij we WEPod-achtig voertuigen erbij betrekken en we gaan gewoon rijden. Met steward. Met steward, dat heb je goed gehoord?

HH. Ja, en anders heb ik het opgenomen. Wat ik begreep over IJburg is dat de fabrikant zei: De techniek is er, we kunnen en de Gemeente Amsterdam wilde eerst testen. Die andere partij had daar geen geld voor over dus daar is het op spaak gelopen.

RH. Dat wist ik al voordat al die meetings gehouden waren. Aan de andere kant, als je nu zegt als Amsterdam: Wij willen echt stappen maken en leren, dan moet je het dus wel gewoon gaan doen. Je moet IJburg dus niet doen voor IJburg, maar je moet IJburg doen omdat je ergens moet beginnen, omdat je denkt dat IJburg een goeie plek is om te leren. En dan kan je, dan kost dat dus wat meer geld, maar dan moet je dat dus niet proberen te financieren uit alleen maar uit die behoefte van dat projectje. We hebben dit gekozen als Pilot, en we gaan proberen.

RH. Maar ik weet dus zelf echt niet of die zelfrijdende auto herkenbaar moet zijn.

Appendix – Interview Dr. S. de Craen

Saskia de Craen is a specialist in self-driving vehicles at SWOV. De Craen is involved in risk assessment of newly requested pilots regarding self-driving vehicles in the Netherlands.

Minister Schultz van Haegen has the ambition that the Netherlands plays an active role in the development and testing of AVs. A lot of tests and pilots are therefore drawn to the Netherlands, which is also noticeable by an increase in local initiatives. In general, such tests are not allowed to be performed on public roads. The RDW has the responsibility to give exemption for such tests and pilots. SWOV is asked to look into safety aspects of every request for exemption. The result of this assessment is a list with risks and corresponding weights and an advice for the RDW.

There is a great variety in AVs. It is therefore important to make clear what we are discussing in each scenario (e.g. distinction between people movers and automated passenger vehicles or platooning truck). In contrast to popular believe, people movers such as the WEPod are in essence dumb compared to human drivers. They do not follow basic traffic rules (e.g. yield for traffic from the right). The WEPod is merely scanning the environment for objects. If an object comes within the safety margins, the vehicle makes a stop. Naturally, this is not how people move around in traffic. A different development can be seen in passenger vehicles. Even if these vehicles will be able to cope with all traffic rules in the (near) future, they will have trouble dealing with exemptions and special circumstances. The trend today is that simple driving tasks are taken over by vehicle technology. This trend will be expanded over time. It will require a lot of time and developments before a passenger vehicle is able to drive in the inner city and can deal with for example different types of intersections.

A small number of pilots for automated passenger vehicles have crossed the desk of de Craen. These pilots focused on self-driving functions such as autopilot on the highway. The media makes us believe that the pilots are more advanced and complex then they are in reality. Craen hopes that the technology will be developed where human interference is no longer required. If the driver still need to pay attention to the road, the technology will not necessary be an improvement. A first step toward autonomous driving might be to assign specific areas for AVs or possible dedicated lanes. For example, in rural area's the technology is interesting. A self-driving vehicle can replace an expensive bus that carries a small number of passengers. The technology promise an interesting business case in such areas. Such interesting areas can also be found in the city of Amsterdam, in those locations where the number of pedestrians and cyclists is limited. An area where people have to walk long distances can be a viable case study.

Every new party that wants to start a new pilot wants to be innovative. Thus far, the steps in the progress are small. Craen's advice for new pilots is to start small. This will most likely not lead to headliners in the papers, but is important for any further development of self-driving technology.

Appendix – Transcript interview Dr. S. de Craen

01-06-2017, Den Haag, SWOV. Ref: (de Craen, 2017)

SC. Je kunt niet spreken over DE zelfrijdende auto, er zit verschil tussen people movers en de geautomatiseerd personenauto's.

SC. Ik ben zelf geen onderzoeker. Allerlei pilots en proeven komen er in Nederland, de minister wil dat Nederland een testland wordt. Daarmee zijn veel onderzoeken naar Nederland gehaald en zie je veel lokale initiatieven. Het moet allemaal veilig, het RDW geeft hier ontheffingen voor af. Soms mag een voertuig namelijk niet zomaar de weg op, zoals een people mover (WEPod) en soms gaan ze dingen doen die niet helemaal mogen. De projectleider kan dan een ontheffing krijgen van de RDW, SWOV is gevraagd om bij elke ontheffing mee te kijken naar de veiligheidsaspecten. We schrijven een advies op een bepaalde proef, heel concreet, hoe de veiligheidsrisico's zoveel mogelijk beperkt kunnen worden. We doen geen uitspraak over Dit is veilig, Dit is niet veilig, maar we geven een lijst met risico's en bijbehorende gewichten, wat wij ervan vinden en oplossingen.

SC. RDW neemt dit risicodossier mee in het ontwerp. Diegene die de pilot uitvoeren zien over het algemeen geen risico's.

HH. Veel voorkomende risico's?

SC. Hangt van de proef af. Met PM zien we een groot probleem; deze houdt zich niet aan de verkeersregels. Hij geeft geen voorrang, hij kan niet zien of iemand voorrang heeft. Hij gaat daar dus niet voor stoppen. WEPods die rijden gewoon en als iemand ervoor springt, dan stopt hij. Hij stop dus eigenlijk voor alles wat binnen de veiligheidsmarge komt. Dit is niet hoe wij in het verkeer ons bewegen

SC. Het zijn dus eigenlijk hele domme karretjes. Zelf mensen die ermee werken denken dat hij voorrang verleent.

HH. De auto's waar ze mee aan het rijden zijn in Amerika, die kennen de voorrangsregels toch wel?

SC. Die kennen volgens mij ook niet

SC. Belangrijk dat je onderscheid maakt tussen PM en ZVs. De WEPods zeggen in eerste instantie: We gaan zelfstandig rijden. Maar het zijn vrij domme voertuigjes vergeleken met de mens. Een andere ontwikkeling is de personenwagen; zelfs al kunnen die omgaan met de verkeersregels, dan kunnen ze nog niet omgaan met de uitzonderingen.

SC. De meest simpele taken van een bestuurder gaan we nu overnemen, en die gaan we steeds verder uitbreiden. Voordat een voertuig in de stad kan rijden en kan omgaan met verschillende type kruisingen, dan ben je nog een heel eind verder.

HH. Pilots die nu worden aangevraagd, zijn die alleen voor PM of ook al voor personenwagens?

SC. Wel gehad, niet veel. Wat we gehad hebben is met zelfrijdende functies. (autopilot aan op de snelweg). Iedereen wil de eerste zijn, wedloop aan de gang. Media pakken dit klakkeloos op. Als je nu aankomt met een zelfrijdend voertuigje in een bepaald gebied, dan ben je al niet meer nieuw. Daar moet dus weer iets bij wat ze niet gaan waarmaken.

SC. De ontwikkeling van de zelfrijdende personen gaat er wel komen, wat ik hoop is dat we afgaan van de autopilot waar mensen nog moeten ingrijpen. Stukje snelweg, waarschijnlijk met dedicated lanes, waarop de ZV helemaal zelfstandig kan rijden. Op het moment dat ik moet blijven opletten, dan rijd ik liever zelf. Ik denk dat daar de toekomst wel ligt, op delen van de snelweg waar je als het ware een dutje kan doen, en in zie toekomst in de people movers. Hier moeten goede locaties voor worden gekozen en eventueel dedicated lanes.

HH. Wat zou voor de Gemeente Amsterdam nuttig kunnen zijn om een pilot op in te richten?

SC. Begrijpelijk dat voorgaande pilots geen doorgang hebben gevonden, omdat iedereen dat stapje extra wil doen en vernieuwend wil zijn. Ik weet niet wat voor stap extra ze kunnen doen, want de stappen tot dusverre zijn nog niet zo groot. WEPod, in werkelijkheid is het een speeltje waarbij de stewards nog he grootste deel manueel moeten rijden.

SC. In plattelandsgebieden is de technologie interessant, een bus is te duur als er slechts enkele mensen willen meerijden. Een zelfrijdend voertuigje kan daar handig zijn. In Appelscha, reden de auto's fietsers van de weg. Ze hebben dit opgelost door stewards toe te voegen en langs het fietspad stonden verkeersregelaars. Daar gaat je business case.

SC. Wat zou Amsterdam kunnen doen: Klein beginnen. Dan haal je de kranten natuurlijk niet, want dan zeggen ze dat ze al in Ede Wageningen rijden.

HH. Ik kan dit natuurlijk wel meenemen in het advies

SC. In Westerbork kan het bijvoorbeeld echt werken. Je kunt daar een hele route aflopen en dan stop je in het bos, dan worden mensen opgehaald door een dieselbus. Als je daar een people mover brengt, dan kun je daar een film afspelen, soort attractie. Daar kan het nou echt werken. Weinig fietsers en voetgangers, zijn er wel, maar echt op de openbare weg. Deze moet je dus waarschuwen.

SC. People mover kan ook alleen in een voetgangersgebied, daar zou je ook naar kunnen kijken. Dat gebeurt al elders in de wereld. Shared space omgeving zou kunnen.

SC. Heel ontprettig, er reed eens eentje op me af, maar je ziet niet waar hij heen wil. Dus ik ging uit de weg, maar hij reed ook mijn kant weer op.

SC. WEpod moet eerst de regels kennen, voordat hij gaat aangeven wat hij gaat doen

SC. 1/80e van de plannen van de WEPod zijn pas uitgevoerd, wat al veel is gezien de ambities

SC. Nu ook bezig met een pilot in Eemshaven, goed gebied om te beginnen. Rustig gebied, toch openbare weg.

SC. Als je een locatie zoekt, kijk dan naar plekken waar mensen lange stukken moeten lopen. Het vervoer gaat namelijk niet heel snel.

Appendix – Interview Ir. R. Eenink

Rob Eenink is a specialist in intelligent transport systems and traffic safety at SWOV. He plays an active role as project leader in notional and European projects such as PROLOGUE and UDRIVE. Relevant aspects in Intelligent Transport Systems and AVs are discussed in this explorative interview.

50% of the vehicle kilometers are made on highways. Naturally, people that drive a lot are expected to drive a lot on highways. It could be very interesting if these drivers can perform other activities than driving, such as working or sleeping. Eenink believes that the technology will support this transition in driving tasks in foreseeable time. However, operating a self-driving vehicle in the urban environment will be a challenge. It is of importance for the municipality of Amsterdam to determine if AVs can be introduced in a safe manner on the existing road network. It is not likely that a car manufacturer will develop an AV that is designed for a limited number of cities. AVs should be able to operate in every city in the world. A potential C-ITS system has to have a great standard, which automatically leads to legal challenges. Automated driving and ITS systems in public transport seems easier to achieve. The municipality is able to steer towards self-driving vehicles in this sector.

It is interesting to see that traffic safety of individual road traffic is much worse compared to when you are being driven (aircrafts, busses, trams, trains etc.) The reason is that we set higher demands when we rely on others for our safety. This is also the case for automated driving. When this technology is not 100% safe, even though if it is 10 times safer, the company that developed the software will be held accountable. Eenink believes that self-driving vehicles will not have a substantial contribution in the upcoming 25 years in the urban environment, but can be interesting for highways or rural areas.

Can ITS contribute to a safe introduction of AVs? ITS (nowadays) relates more to traffic rather than vehicle technologies (ADAS, advanced driver assistance systems). The safety measures in a vehicle are mainly within the vehicle itself instead of with interacting with the environment. Passive safety measures such as airbags and seatbelts have drastically decreased the change of death in a collision. Active safety measures intervene before a collision takes place. ABS (not effective) and ESC (very effective) are examples of such technologies.

ADAS such as Adaptive Cruise Control and Lane Departure Warning Systems aren't very effective for safety, and not suitable for urban environments. Autonomous Emergency Braking, however, can contribute to traffic safety in the city. This system can detect objects around the vehicle. If the driver cannot react in time, the vehicle will automatically brake. Smart cameras can detect and make a distinction between cyclists, pedestrians, lamp posts etc. The system can even determine if the vehicle will collide with an object and give warning to the driver or dodge the object.

Can such cameras be used in the infrastructure to detect for example VRUs that are behind a different object? The challenge of V2X is that car manufacturers would have to depend on the road authority or a different stakeholder. This is not the expertise of Rob Eenink. He can imagine this would result in challenges for the municipality of Amsterdam as well. The municipality would be responsible for any malfunctions. A simple example of how difficult this can be, is a map with speed limits. It will be challenge even for a developed country as the Netherlands to create a system who knows the speed limit on every existing road. One mistake might result in a collision. Car manufacturers are therefore probably more focused on stand-alone systems. The philosophy is that the AV can interact with the world as it is and should be able to drive in areas without ITS. It might however be possible that the municipality of Amsterdam provides certain information to car manufacturers for the development of automated driving systems, but a disclaimer is expected so that the municipality is not going to be accountable for any mistakes. It is therefore questionable if car manufacturers will use this information.

Appendix – Transcript interview Ir. R. Eenink

02-06-2017, Den Haag, SWOV. Ref: (Eenink, 2017)

RE. Bij SWOV sinds 1999, nooit als onderzoeker. Gekomen als afdelingshoofd (wisselde afdelingen). Toen ik net kwam bij SWOV was 1 thema Telematica. Dat thema overgenomen, verder geen verstand van, wel natuurkunde gestudeerd dus enige affiniteit met techniek.

RE. De helft van onze kilometers maken op de autosnelweg. Mensen die veel rijden, rijden veel op de autosnelweg. Als je dan kunt werken i.p.v. autorijden, dan kan dit interessant zijn. Dat zie ik op afzienbare termijn gebeuren, maar in een stad, dat is echt nog wel een stukje verder.

RE. Tamelijk nonsens dat Amsterdam zich er druk over maakt.

HH. Ze willen natuurlijk meedoen in het spelletje. Ze hebben geen concrete ambitie om zelfrijdende voertuigen in de stad te verwelkomen, maar ze willen vooral zichzelf voorbereiden op een eventuele veilige introductie van ZVs.

RE. Dan moet je voornamelijk gaan kijken naar wat de auto kan en of dit veilig op jouw wegennet kan. Ik kan me niet zo goed voorstellen dat een autofabrikant een zelfrijdende auto maakt voor een beperkt aantal steden in de wereld. Hooguit zou je daar een tijdje een pilot kunnen doen omdat steden dit wat makkelijker faciliteren, maar ZVs moeten in alle steden kunnen opereren. Dat vind ik ook met die coöperatieve systemen, dan moet er wel een hele goede standaard komen, enorm juridisch spektakel, maar dat is wel van wezenlijk belang bij de nieuwe ontwikkeling

RE. Het wordt misschien wat anders als het een vorm van openbaar vervoer is, de Gemeente kan daar wat meer invloed op uitoefenen, maar ook dan zal je wel een dedicated lane moeten hebben. Dan zie ik een zelfrijdende tram eerder gebeuren.

RE. Dan heb je nog alle andere ontwikkelingen die op weg zijn naar zelfrijdende auto's, zoals zelfrijdend op de snelweg (bijsturen, ACC etc). Deze functies heb je al. Dat is in die zin niet zo spannend. Ik denk niet dat als het niet veiliger is, of niet net zo veilig is, dat het er komt.

RE. Wat opvallend is als je naar verkeer en vervoer kijkt, dan is het veiligheidsniveau van het vrije wegverkeer ongelooflijk veel slechter dan als je zelf vervoerd wordt, dat geldt voor vliegtuigen, bussen, tram, trein, alles. Dat komt denk ik als wij het overgeven, als iemand anders voor ons moet zorgen, dan stellen wij veel hogere eisen. Prioriteit die de NS aan spoorveiligheid stelt is natuurlijk enorm, daarom is het ook zo veilig. Als jij dan in een auto zit die jou vervoerd, dan ga je ervanuit dat dit veilig is. Op het moment dat dit niet zo is, ook al ben je 10x veiliger dan als je zelf had gestuurd, dan gaat toch dat bedrijf aansprakelijk gesteld worden. Als dit voorkomt of als je in de krant komt, dan weet ik niet of die nog wel zoveel auto's verkoopt.

RE. Ik denk zeker dat ZVs er komen en dat ik dat ook nog wel meemaak, maar het gaat geen substantiële bijdrage leveren de komende 25 jaar. Tenminste niet in de stad, misschien wel op de snelweg of op het platteland.

HH. Glazen bol, stel dat deze er zouden komen over tientallen jaren, kan ITS bijdragen aan het hele systeem met zelfrijdend? Is het iets waar de Gemeente Amsterdam nu al op moet gaan letten?

RE. ITS gaat eigenlijk veel meer over verkeer en weg dan wat er in een auto zit. Ik begrijp dat het jou voornamelijk vanuit de auto geredeneerd is. Verkeerslichten zijn er niet voor de verkeersveiligheid, maar voor de bereikbaarheid. Als je kijkt naar kruisingen met VRI, die zijn niet veiliger dan zonder VRI. Al die systemen die in auto's komen, als je kijkt naar het veiligheidsniveau van auto's, risico dat je komt te overlijden in de auto is de afgelopen 40/50 jaar gigantisch gedaald. Heeft heel veel te maken met veiligheidsniveau van het voertuig zelf. Dat heeft in eerste instantie te maken met passieve veiligheidssystemen, gordel, kooiconstructie, airbags, wegligging. Deze trend wordt ook doorgezet, omdat er steeds meer actieve systemen in komen die al ingrijpen voordat het ongeval heeft plaatsgevonden.

RE. ABS is zo'n voorbeeld, maar electronic stability control is ook zo'n voorbeeld. Elandtest, Baby Benz (Mercedes A-klasse), test met plots uitwijken. Mercedes sloeg om. Systeem meet hoe hard je wielen draaien en hoe je stuur staat. Dan weet hij dat als alles goed gaat, dat weet hij of dat klopt of niet. Als daar een verschil in zit, dan ben je bezig in een slip te raken. Dat kan hij meten en dan kan hij onafhankelijk die wielen remmen zodat dat hersteld wordt. Dat kun je niet met het rempedaal. Dat heeft enorm effect op de verkeersveiligheid bij het van de weg raken. Succesvol voorbeeld, maar er zijn meer voorbeelden van dergelijke systemen verschenen. Allemaal dingen die voorkomen dat als er een botsing plaats kan vinden dat de snelheid in ieder geval veel lager ligt.

RE. Die ontwikkeling gaat door, heel veel van die systemen die je nodig hebt om zelf te rijden zoals ACC en Lane Departure Warning System, die worden verbeterd. Dat gaat ervoor zorgen dat mensen veiliger gaan rijden. Ik denk dat dat in de stad ook gaat gebeuren en ik denk dat systemen als autonomous emergency brake het meest interessant is. Die auto's meten wie er om hen heen zit, te snel dichtbij raken, krijg je een piepje, kun je niet meer reageren dan reageert het voertuig voor je.

RE. Je hebt tegenwoordig ook smart camera's (UDRIVE). Die kan objecten herkennen en onderscheiden (fietser/voetganger/lantaarnpaal). Die kan berekenen wanneer iets kritisch wordt en een waarschuwing geven en misschien zelfs wel uitwijken. Dit gaat heel veel opleveren voor voetgangers en fietsers.

HH. Zou het een voordeel kunnen zijn als de auto kan communiceren met camera's die in de stad hangen en die weten dat er achter een busje een voetganger loopt.

RE. Daar zijn volgens mij wel proeven mee (V2X), maar daar zijn wij niet heel erg bij betrokken. Het lastige daarvan lijkt me ook dat zo'n autofabrikant afhankelijk is van een wegbeheerder hetzij een andere autofabrikant. Dat wordt voor de overheid ook ingewikkeld. Stel jij weet als GemAmsterdam dat jij verantwoordelijk bent hoe jouw wegen in elkaar zitten en dat jij dus ook verantwoordelijk wordt voor dergelijke systemen. Als dat systeem niet werkt, dan ben jij verantwoordelijk als Gemeente.

RE. Het lijkt me buitengewoon lastige zaken. Google is bijvoorbeeld bezig met standalone. Dit is de wereld zoals hij is, daar ga ik me niet van afhankelijk stellen. Mijn auto moet veilig zelf kunnen rijden. Voor steden kan dat wel interessant zijn zodat ze een beetje kunnen sturen. Vanuit die optiek kan dat wel interessant zijn om toch een deal te willen maken met autofabrikanten. Ik weet niet of dat op dit moment aan de orde is.

RE. Zoiets simpels als een kaart met snelheidslimieten. Een redelijk ontwikkelt land als Nederland gaat dit al niet eens voor elkaar krijgen. Wat ga je doen als je een 30km/h weg hebt, maar dit staat niet goed op de kaart en de auto gaat 50 rijden en hij rijdt een kind aan, wie is er dan verantwoordelijk. Dan hebben we het alleen nog maar over limieten, niet over wegopenbrekingen o.i.d. De FIA heeft RAP, Road Assessment procedure. Die zijn ook bezig met Roads That Cars Can Read. Hoe de weg eruit ziet is van belang voor bijvoorbeeld lane departure warning system om een que te hebben of deze auto van de weg raakt. Hij moet dus weten welke belijning er is, hij ziet die belijnen en ten opzichte daarvan bepaalt hij of je een waarschuwing krijgt. Als die belijning er niet is, of even niet goed is, wat dan? Hoe wil je regelen dat alle wegen al hetzelfde uitzien, dat gaat je nooit lukken.

RE. Als je nou kijkt, waarom zou Amsterdam dit nou willen? Ik denk dat als de zelfrijdende auto's er in 1x zijn (dus verre toekomst), dan gaat het om autovods en autobots. Soort taxi (dus alleenvervoerder) danwel eentje die zegt hij in de buurt is maar meerdere mensen vervoerd. Daar zijn analyses op losgelaten over het vervoer in de stad. Wat mij opvalt is dat geen van beide scenario's er meer kilometers worden gemaakt dan in de huidige situatie. Het voordeel is dat je minder auto's nodig hebt en ze hoeven niet in je straat te staan.

RE. Ik kan me voorstellen dat gemeente Amsterdam bepaalde zaken ter beschikking wil stellen, maar tegelijkertijd zal er een grote disclaimer op gezet worden. Dan is het de grote vraag wat autofabrikanten daarmee doen. Dan krijgen ze informatie waarvan ze niet 100% zeker weten dat deze klopt. Dan moeten ze in ieder geval een terugvaloptie hebben.

RE. De Gemeente Amsterdam kan zich uitspreken tegen bepaalde landelijke regels (vb. Snorfietsen op de rijbanen, whatsapp verbieden). Steden kunnen dat doen, ik kan me voorstellen dat dit best mogelijkheden biedt.

Appendix – Interview Rob Methorst

It can be easily said that there is a knowledge gap in the knowledge domain of pedestrians. Little data and knowledge is collected and we experience a lack in research. The focus, both economic and research, on cyclists is 5 to 10 times higher compared to the focus on pedestrians. The focus for motorised vehicles is around 80 to 3000 times as high. Even public transport is a decreasing field of attention for research. After privatising the public transport sector, this knowledge field is almost completely collapsed. One of the main problems in pedestrian research is that everyone thinks they know how the system works, but they cannot substantiate the claims with data. Research into pedestrians is currently very specific, but general crossing behaviour as a risk is not often researched. You can even say that there is a blind spot in this knowledge domain.

In terms of traffic safety, a traffic accident is only an accident when a moving vehicle is involved. 60 to 70% of the pedestrian and cyclist accidents are one-sided, thus fall accidents. For pedestrians, no data is present or at the right place: local authorities. The number of fall casualties is four times higher compared to traffic accident casualties. 75% of the traffic injuries concern crossing accidents. The remaining 25% of traffic accident casualties concern longitudinal accidents. These numbers are badly registered, since liability often doesn't play a role. Even though the police are required to be present when someone is seriously injured, registering is often not a priority. The police often only file a registration set when legal consequences are present or when there is doubt about liability. For one-sided accidents, the liability is always clear. Therefore, the registration set is often not filed. Since cyclists and pedestrians are almost by definition not liable in an accident, there is less reason to file a registration set.

A lot of factors contribute to the distortion of reality when it comes to pedestrian safety data. The validity of the data is coming into dispute because of decentralisation. Municipalities are responsible for taking care of pedestrians and cyclists. Central government still has system responsibility for the system, since they are the only one that are authorized to create and change laws. Municipalities sometimes take up the responsibility to do research in certain domains of which they are not responsible. The results of this research are often not shared with other municipalities. There have been some pilots and tests in the past on pedestrians. The results of these are put into databases but are hard to be found on the internet. The biggest problems relating to the unavailability of data is an institutional problem. Negative results on pilots and research are logically undesirable. Failures or undesirable results are often not documented. In conclusion, you can say that the root problem in pedestrian research is an unavailability of adequate and valid data. It is very important that any future research into pedestrians is carefully observed and documented. Several municipalities are aware of the flaws in the registration of pedestrian data. Cities such as Amsterdam, Rotterdam and Utrecht are making observations, but these researches are often selective and mostly focussed on the city centre area. However, most of the traffic by foot can be found outside of the city centre.

Pedestrians are just like human beings. Also, the average pedestrian does not exist. Great differences are noticeable in e.g. age and gender. A healthy adolescent pedestrian is on average highly manoeuvrable in contrary to elderly and children. Children are not as manoeuvrable as you might think. There are focussed on only one task. When a kid is running for example, it will only look forward and disregard its surroundings. Elderly receive less stimuli. Also, the ability to react in time decreases gradually. Crossing behaviour will also differ between pedestrian groups. Youngsters are more likely to make disadvantage of AVs if they know that such a vehicle is programmed to stop for any obstacle in their path. Elderly are expected to less show this behaviour. Children however will mimic the behaviour from their parents. A self-driving vehicle is expected not to able to make a distinction between humans according to skills. The system cannot look into the mental state of a pedestrians and determine the expected behaviour.

It can be useful for the City of Amsterdam to design a pilot in which interaction between pedestrians and vehicles is observed. The next step in the research will use this information and can look into the interaction between pedestrians and AVs. Methorst believes that the City of Amsterdam should not perform such test individually, but in collaboration with other cities such as Rotterdam, Utrecht and The Hague. The top four cities combined would have a higher budget for such researches, which will most likely lead to better results. If they choose to collaborate on such pilots, they should keep in mind that they should not focus solely on the city centre. Normally, such research is focussed on city centres due to economical motivations. For Amsterdam, this is particularly driven by tourism, while Rotterdam is more driven by shopping and leisure related benefits. The city centre has to be liveable because this had economic consequences. If all four of the largest municipalities choose to do research on surrounding neighbourhoods, they have to keep in mind that the research takes place in a larger area. Since there is little experience in such research, the pilots will be largely pioneering.

If the model uses AV supportive policies as a scenario, *safe crossing behaviour* can be expected to change negatively. Methorst believes that this can be explained by a false sense of safety. Pedestrians will change their behaviour on expectations. For example, if you know that there is a 85% change a driver commitment to stop at a zebra crossing, it becomes more likely that one crosses without hesitation. On the other hand, if a driver doesn't encounter pedestrians on 85% of the zebra crossings, he will be less alert on pedestrians at any upcoming zebra crossings. The utility of the measure (zebra crossing) will diminish in that case. If you observe behaviour in a pilot, it is expected to lead to further questions on why such behaviour occurs.

Safety systems towards autonomous vehicles contribute a lot to traffic safety as long as these systems does not diminish the driving exercises of a human. When human drivers rely on such safety systems, they will no longer be capable to react adequate. The risk homeostasis theory by Gerard Wilde illustrates the counter-effect of safety measures. according to this theory, people accept a certain risk level. If they have the feeling that the system is safer, they will take more risks. This means that safety measures are likely to be compensated by taking more risk. However, they have to be aware of the safety measure. If they cannot tell if a vehicle uses the safety systems, the taken risk is probably not increased. In reality Wilde's theory can explain a little risk compensation, but never fully applies. It is however true that safety measures seldom produce the expected result and impact. This can help explain the model behaviour where safe crossing behaviour is expected to change negatively when the level of automation is increased.

Methorst thinks that AVs have most potential on roads where vehicles have primacy. These roads are mostly highways and access roads, where people expect the vehicle to have primacy. On access roads, where motorised vehicles do not have primacy, longitudinal pedestrian traffic will be an important factor in the interaction between pedestrians and vehicles. Especially when the vehicles are designed to brake for any obstacles in their way, pedestrians will make use of the road if the sidewalks are not accessible or walkable. This can already be seen in the city centre of Amsterdam. The sidewalks are too narrow, overcrowded and clotted, forcing pedestrians move to the streets. AVs will have great difficulties manoeuvring trough these streets. Difficulties can also be expected on roads with a 50km/h speed limit, but with a shops and other functional buildings, the so called grey roads. A lot of pedestrians can be expected in such areas. Autonomous vehicles can operate on such roads on dedicated lanes. That is where a crucial problem arises: one of the biggest conflicts between AVs and pedestrians arises when there is severe spatial competition.

Appendix – Transcript interview Rob Methorst

06-06-2017, Voorschoten. Ref: (Methorst, 2017)

RM. Als je het over voetgangers hebt dan kun je rustig spreken over een kennisachterstand. De fiets heeft sinds de jaren 90 onder invloed van masterplan Fiets zowel fysiek als qua kennis een boost gehad. Voetgangers zijn altijd achtergebleven. Er worden geen gegevens over verzameld, er wordt geen kennis over verzameld, er wordt geen onderzoek naar gedaan.

RM. Als je kijkt naar hoe de verhoudingen liggen kun je zeggen dat de fiets 5 tot 10x zoveel aandacht opeist als de voetganger. De auto tussen de 80 en 3000x. Zo zit het economisch, maar ook qua kennis en onderzoek.

RM. Horizon 2020 heeft als enige aandachtspunt Technologie. De rest telt echt niet mee. Zelfs openbaar vervoer valt tegenwoordig grotendeels af omdat het voorheen toch een sterk overheidsveld was, maar omdat het geprivatiseerd is, is dat als kennisveld eigenlijk helemaal ingestort.

RM. Het grote probleem bij voetgangers is dat iedereen denkt dat hij het weet, maar als je vraagt: Waar staat het? Dan zal je er niets over vinden. Dat is echt zo hard. De onderzoeken die er naar voetgangers gedaan worden zijn of geweldig smal (heel erg in de diepte): de loopsnelheid op een oversteekplaats, het reageren op bepaalde vormen van verkeerslichten. Dat soort zaken wordt onderzocht. Oversteken als generiek probleem? Ho maar. De mobiliteit van voetgangers? Er zijn niet eens gegevens over beschikbaar, zelf de OVIM (wat mobiliteit moet beschrijven) doet dat marginaal. Nou kun je niet zeggen dat is een fout van iemand, dat wil ik niet beweren, ik wil wel zeggen dat het een blinde vlek is.

RM. Als je aan iemand vraagt: Hoe ben je aan iets gekomen? Dan zal hij nooit zeggen dat hij een deel te voet is gekomen. Dat moet je eruit trekken. Als je naar de vragenlijsten van de OVIM kijkt, dan zie je dat er niet specifiek naar voetgangers wordt gevraagd. Je mag het opnoemen, het wordt als mogelijkheid gegeven, maar je weet hoe dergelijke vragenlijsten ingevuld worden. Mensen staan onder tijdsdruk en hebben er niet eens zo gek veel zin in. Dat komt gewoon niet aan de orde, dat beeld van lopen is dat het van deur tot deur is, maar als je preciezer gaat kijken dan zie je dat lopen 4 functies heeft; (1) deur tot deur, (2) voor en na transport, (3) circulatie (wandelen, shoppen, hond uitlaten, post wegbrengen) en (4) verblijven (wachten en spelen). Van wachten en spelen is geen statistiek. Recreatief wandelen wordt ook niet beschreven, want dit valt zelfs buiten de definitie. Het is een verplaatsing van meer dan 2 uur, dus geen mobiliteit.

RM. Bij verkeersveiligheid is het zo dan een verkeersongeval alleen maar een ongeval is als er een rijdend voertuig bij betrokken is. Bij fietsers weet je dat 60 tot 70% enkelzijdig zijn, oftewel valongevallen. Bij voetgangers is dat ook zo, maar deze vallen buiten de definitie met als gevolg dat als er al cijfers zijn, ze in ieder geval niet op de juiste plek te vinden zijn bij de Gemeente die daarover zou moeten beschikken.

RM. Dit is geen tirade, dit zijn gewoon feiten.

HH. Blij dat u dit aangeeft. Ik moet dit straks vertalen naar een advies voor de Gemeente Amsterdam waarop zei pilots moeten inrichten. Als u nu al aangeeft dat er een enorme blinde vlek zit op voetgangers, en in mijn model komt naar voren dat de stakeholders veilig oversteekgedrag belangrijk vinden, dan kan ik zeggen dat het belangrijk is dat zij daarnaar gaan kijken.

RM. Als je kijkt naar het aantal letselslachtoffers, dan praat ik over het aantal ziekenhuis slachtoffers, niet over schrammen en buien, die komen niet in de politie registratie. Het zijn 4x zoveel slachtoffers van valongevallen als van verkeersongevallen. En ¾ van de verkeersongevallen zijn oversteekongevallen. Van de verkeersongevallen zijn oversteekongevallen een dominante klasse. Het overige deel zijn langs ongevallen.

RM. Van de fiets- en voetgangersongevallen weten we dat ze onder geregistreerd worden. Als je de onderzoeken mag geloven, dan komen voetgangers beter in de registratie voor dan fiets. Dat geldt wel voor doden, maar voor andere aanrijdingen geldt dat echt niet. Aanrijdingen met fiets komen helemaal niet in de registratie, want daar komt geen politie bij.

HH. Want die hebben ook een lage snelheid, dus die zullen waarschijnlijk ook niet vaak naar het ziekenhuis moeten denk ik?

RM. Daar verkijk jij je op. Door de vergrijzing neemt de kwetsbaarheid van mensen enorm toe. Bij de valongevallen is ook de oudere dominant. Dat gaat echt over grote aantallen.

HH. Waarom wordt het niet geregistreerd?

RM. Bij een auto is er sprake van schade, als er sprake van schade is dan roep je de politie erbij. De politie moet erbij komen als er iemand ernstig gewond is, maar in werkelijkheid is dat niet zo. Dat gebeurt alleen maar als de politie er de tijd voor heeft, dat is natuurlijk bijna nooit, en ten tweede als er een hele dringende aanleiding is. De ambulance zal er nog wel bij komen, en de politie komt er vaak nog wel bij, maar het enige wat ze doen is regelen. En noteren doen ze niet meer. Waar haal je dan je kennis vandaan?

RM. Het probleem is dus, ALS de politie er al bij betrokken is, dan is het nog maar de vraag of ze er een registratie set van opmaken. Dat doen ze alleen maar als er juridische consequenties aan zitten, als er twijfel is over wie er aansprakelijk is. Bij enkelvoudige valongevallen is altijd duidelijk wie er aansprakelijk is, hoef je eigenlijk niet te registreren. Je ziet dat ook bij enkelvoudige auto-ongevallen, bij het van de weg afraken en dergelijke, die ook heel ernstig kunnen zijn, rond 25% van de ongevallen, worden ook veel slechter geregistreerd dan ongevallen met botsingen, want daar moet een registratie set van opgemaakt worden. Als de aansprakelijkheid 100% duidelijk is, dan is er geen reden om dit te doen.

RM. Omdat het juridische regime ook zo is dat voetgangers en fietsers bijna per definitie in hun recht staan, is er ook geen reden om daar een registratie set van op te maken. Alleen als die voetganger of fietser duidelijk in overtreding is, en buiten de groep kinderen, ouderen of gehandicapten valt, dan zal er een registratie set opgemaakt worden. Als je kijkt naar de cijfers zie je dat adolescenten t/m 55gers overgeregistreerd zijn ten opzichte van ouderen en kinderen. Voor kinderen is het namelijk duidelijk, er is geen enkele reden voor de politie om daar een set van op te maken, behalve dat het verplicht is. Maar er zijn wel meer dingen verplicht.

RM. Er zitten heel wat mechanismen erachter dat ervoor zorgt dat het beeld dat wij hebben van de werkelijkheid door de cijfers, dat dit niet klopt met de werkelijkheid. De validiteit van de cijfers komt in het geding en dat speelt dan met name bij gemeenten die door decentralisatie de verantwoordelijkheid hebben gekregen voor al dat soort dingen. Voor fietser en voetganger zijn zij volgens het rijk aan zet. Ik vind dat ook voorbijgaan aan iets, dat er twee soorten verantwoordelijkheden zijn, namelijk resultaatverantwoordelijkheid en systeemverantwoordelijkheid. Systeemverantwoordelijkheid heeft het rijk (en de politie) wel degelijk. De Gemeente heeft deze verantwoordelijk ook voor zoverre het hun systeem is, maar niet voor wat er buiten hun bevoegdheid/macht ligt. Bij het rijk ligt dit helemaal anders want de enige die wetgeving mag bepalen is het rijk. De enige die in staat is om onderzoek te programmeren is het rijk, niet de gemeente. Ze nemen wel een taak, maar voor hun eigen grondgebied. Kennisuitwisseling is op dit vlak niet hun zorg. Dat kun je ook niet op hun bord leggen.

RM. Net zoals je bij nationale overheden niet op hun bord kan leggen dat ze verantwoordelijk zijn voor het internationale afspraken. Dat ze het doen is mooi meegenomen, maar je kunt het niet op hun bord leggen. Internationale coördinatie van onderzoek, daar hebben we Europa voor. En door al dit soort mechanismen zie je dat kennis over voetgangers echt gewoon heel erg achterloopt bij andere terreinen en eigenlijk gewoon nul is.

HH. Ik heb natuurlijk wel wat ingelezen over wat er nou allemaal achter zit, dan heb je wel wat minimaal onderzoek bijvoorbeeld over gap acceptance, en het viel me al op dat er ten eerste weinig onderzoek is en het onderzoek wat er is op extreme punten gedaan zoals in India bijvoorbeeld. Echt onderzoek was minimaal.

RM. Het is er wel, alleen dit is binnenkamers gebleven. Kennisplein is dermate complex dat je daar echt niks vindt. Vroeger was het zo (j10 jaar geleden) dat je op internet bijna alle publicatie zo kon vinden. Die waren rechtstreeks te vinden in pdf, tegenwoordig moet je die benaderen via een database. Google kan niet via databases zoeken. Dus die publicaties die er wel zitten, die kun je niet vinden. Die kun je alleen maar vinden als je op de website zelf ernaar gaat zoeken, of als ze ergens als referentie zijn aangegeven. Google zoekt voor wetenschappelijke publicaties wel in databases met Scolar. Die zoekt standaard een aantal databases na. Maar daarbij heb je dan weer het probleem dat dit vooral artikelen zijn en bijna geen boeken. Ook daar heb je een database probleem.

RM. Er is dus wel wat, ik kan je best een aantal publicaties aan de hand geven, maar de praktijk is dat het gewoon heel lastig is.

HH. Wat bent u dan bijvoorbeeld op dit moment aan het doen?

RM. Ik heb heel veel van die dingen verzameld. Ik probeer een beschrijving van het hele veld te geven. Mijn proefschrift gaat over de ene kant wat is het probleem, wat voor omvang heeft het en wat zijn in grote lijnen de oorzaken, de factoren die een rol spelen, wat kun je eraan doen. Aan de andere kant, hoe is dat institutioneel geregeld. En dit laatste is verreweg het grootste probleem. De problemen die ik hier noemde, zijn eigenlijk allemaal institutionele problemen, het is slecht georganiseerd. Of niet georganiseerd.

RM. Mislukte onderzoeken en negatieve uitkomsten zijn ongewenst. Veel mislukt vooronderzoek in de farmaceutische industrie wordt niet gepubliceerd, ook niet als ze betaald hebben. Dat gebeurt met andere dingen ook, dat wil je helemaal niet. Dat speelt een rol.

RM. Bij de voetgangers ligt de basis dat de meest elementaire gegevens er niet zijn, of niet/verkeerd ontsloten.

HH. Dan kan het dus van wezenlijk belang zijn dat ik tegen de gemeente Amsterdam zeg; Ga proeven doen met zelfrijdende voertuigen en voetgangers, en registreer het allemaal goed.

RM. Observeer het echt, dat is de enige manier voorlopig

HH. Ik weet toevallig dat er aan de TU Delft wat proeven zijn gedaan met hoe voetgangers gaan reageren op zelfrijdende voertuigen. We zitten echt nog maar aan het begin, we weten er nog zo weinig van.

RM. Niks.

HH. Kunt u in de glazen bol kijken en zeggen wat u ervan verwacht?

RM. Voetgangers zijn net mensen. Gedrag wat je bij andere modaliteiten ziet, zul je bij voetgangers ook zien, maar vaak in extremen. Bij fiets is men nog van zekere mate bewust dat men aan het verkeer deelneemt, hoewel dat ook heel wat minder is dan in de auto. Al dat geapp enz dat haal je in de auto, als je een beetje verantwoordelijk bent, haal je dat niet in je hoofd. Op de fiets kan dat wel. Dat wordt niet helemaal serieus genomen. Rijden door rood, die verkeerslichten zijn er niet voor mij. Dat zou je een automobilist niet zo snel zien, die zijn er wel, maar dat zijn de idioten. Het zijn doodnormale mensen die dat doen. Tegen de richting hier rijden, op het fietspad, dat is zo normaal geworden. Als je er wat van zegt krijg je een klap voor je kop. Bij de voetganger is het zelfs regel. De voetganger moet in twee richtingen gebruik kunnen maken van het trottoir.

HH. Een rood stoplicht negeer ik als voetganger eerder dan op de fiets, al helemaal vergelijken met de auto.

RM. Nou moet ik er ook gelijk bij zeggen, in de auto is het zicht op wat er om je heen gebeurd aanmerkelijk minder is dat op de fiets. Ter voet is het nog beter. Plus dat je met de fiets nog altijd rekening moet houden met massa en snelheid, dat je niet gemakkelijk stil komt te staan. Als voetganger ben je buitengewoon wendbaar, tenminste de gezonde voetganger.

RM. Bij ouderen ligt dat anders, bij kinderen ligt dat ook anders. Kinderen zijn helemaal niet zo wendbaar. Dat lijkt wel zo, maar dat is niet zo. Kinderen zijn maar met 1 ding bezig. Als een kind aan het hardlopen is, dan is hij alleen maar aan het hardlopen. Dan is hij daarmee bezig, multitasking is geen goed punt voor een kind. Die kijkt alleen maar voor zich uit. De aandacht eromheen is dus weg. Dat is bij andere voetgangers beter. Jongeren kunnen meerdere prikkels beheersen, bij ouderen is dat niet zo. Als je ouder wordt komen er minder prikkels binnen en is het zo dat de mogelijkheid om daar goed op te reageren dus ook afneemt. Je hebt minder kracht, bent al gauw minder flexibel. Dat gaat heel gradueel.

HH. Zit er een correlatie tussen wijken waar vergrijzing optreedt, is daar een aanzienlijk deel hoger dat mensen in de problemen komen?

RM. Dat zou kunnen, dat weet ik niet. Dat ligt voor de hand dat dat zo is, maar daar heb ik geen gegevens over, daar heeft niemand gegevens over. Als er gegevens over voetgangers zijn, voetgangersongevallen, dan zal je die vooral vinden bij veiligheid NL en LMR. Het LMR is tegenwoordig via het CBS, dus daar kun je slecht bij. Vooral voor kleine gebieden kun je deze cijfers niet inzien. Dat speelt bij veiligheid NL minder een rol, maar dat is een steekproef. LMR is een registratie, dus in principe alle mensen die opgenomen worden in het ziekenhuis komen erin, maar bij het LIS gaat het over een beperkt aantal ziekenhuizen, dus je kunt wel een ophoging van niveau, maar inzicht in lokale omstandigheden wordt een ander verhaal.

HH. De wens om dat allemaal beter te registreren, dat zit er absoluut nog niet in of komt dat al mondjesmaat op gang?

RM. Er zijn wel gemeenten die zelf tellen en meten. Rotterdam en Amsterdam en Utrecht tellen wel, maar wel selectief en eigenlijk alleen maar in het centrum, terwijl je logisch kunt nagaan dat de meeste lopen niet in het centrum maar buiten het centrum plaats vinden. Daar wonen de meeste mensen. Daar vinden de meeste verplaatsingen plaats. De grootste concentratie vindt plaats in het centrum. Als het over observatie gaat, zal je het meeste zien in het centrum. Dat wil niet zeggen dat daar de grootste expositie zit. De grootste expositie zit echt buiten het centrum. De meeste voetverplaatsingen. Hier zal je dus niet zo gauw onderzoek en observaties over hebben. Zeker als dan onderzoek plaatsvindt, daar slecht aandacht aan besteed. Als je het aan het CBS vraagt, dan zeggen ze dat natuurlijk dat ze het goed doen, terwijl de steekproef nog maar een 5^{e} deel is van wat hij 10 jaar geleden was.

RM. Dat is een groot gemis. Dat betekent dat je bij alle dingen je over lopen en verplaatsen zegt, dat je dar altijd een vraagteken bij moet zetten. Altijd de vraag over hoe valide is de bron die ik heb voor mijn vraag.

HH. Als ze dan een pilot gaan inrichten, misschien moeten we dan kijken hoe voetgangers überhaupt met voertuigen in Amsterdam omgaat en hoe dit gedrag eventueel zal veranderingen als voertuigen zelfrijdend wordt in bepaalde mate. Veilig oversteekgedrag kwam als één van de belangrijkste concepten naar voren. De Gem Amsterdam wil weten welke pilots ze moeten opzetten, op welke vakgebieden ze nu moeten gaan inzetten. Dit kan een hele goeie uitkomst bieden.

RM. Dat denk ik. Ik denk ook dat de Gemeente Amsterdam dit niet alleen kan. In dit geval is het veel handiger als ze het samen met de drie andere grote gemeenten gaan doen. Dan kun je veel meer massa krijgen en kun je ook veel beter onderzoek doen.

HH. Hoe ziet u dat voor u?

RM. De gemeenten hebben een bepaald budget, als je dat gecoördineerd doet kun je veel betere resultaten krijgen. Ik kan wel honderd redenen bedenken waarom ze dit niet willen doen. Het is hun verantwoordelijkheid niet. Alle grote steden willen vernieuwend zijn.

RM. Utrecht is #1, Amsterdam #2, Rotterdam #3 en Den Haag #4 als het over voetgangers gaat, intensiviteit. Amsterdam doet het ook echt goed, doen echt hun best. Daar ligt het echt niet aan.

HH. Waarop doen ze hun best?

RM. Sterk centrumgericht. De reden is economisch. In Amsterdam is dat toerisme, in Rotterdam is dat winkelend publiek. Het centrum moet leefbaar zijn omdat dit economische consequenties heeft. Dat is heel cru de reden. In Amsterdam is er aandacht voor voetgangers omdat de toeristen klagen, niet omdat er zoveel ongevallen gebeuren. In Utrecht is het ook economisch, maar daar zit wat sterker een sociale component in. In Utrecht wordt wel nagedacht over het kijken naar de wijken, maar daar ondervinden ze nu ook grote problemen mee. Is veel meer verspreid, dus hoe pak je dat aan. Omdat het over een groter gebied gaat, gaat het natuurlijk ook over meer geld. Hoe je dat dan, waar ga je dan op letten? Dan is het voor een belangrijk gedeelte pionieren.

HH. Je zou dus zelfs een proef of pilot kunnen inrichten in een bepaald gebied, maar dan kun je nog steeds niks zeggen over de hele stad vanwege cultuurverschillen.

RM. De motieven verschillen, cultuur deels. Motieven verschillen, als jij loopt om te winkelen doe je dat anders dan als je loopt om van A naar B te gaan. Als je ergens doelbewust ergens loopt, dan doe je dit een stuk sneller dan als je gaat winkelen. Dan ben je niet zozeer met verplaatsen bezig, dan ben je met verkopen bezig. Dat is een noodzakelijk kwaad. Dat is niet deelnemen aan het verkeer. Als je je echt verplaatst, komt dat er nog wel bij.

HH. Ik verwacht ook niet dat de ZVs, in ieder geval de komende tientallen jaren, in de buurt van de dam of kalverstraat bijvoorbeeld gaan rijden. Het winkelend publiek zal in beperkte mate aanwezig zijn. Waar ik nu aan zit te denken is een gebied waarin veel loopverkeer is, waar bijvoorbeeld beperkt openbaar vervoer is, om daar bijvoorbeeld een shuttledienst of people mover te introduceren. Het moeilijke voor die apparaten is om te gaan met fietsers en voetgangers.

RM. Wat ik denk dat gaat gebeuren, voetgangers zijn vooral op hun eigen belang uit. Als die voertuigen toch stoppen, dan zullen wij er gewoon voorlangs gaan. Dat zullen ouderen niet doen, maar kinderen wel. Die volgen hun ouders, die geven het voorbeeld.

HH. Of zou het ook kunnen zijn omdat jongere mensen meer vertrouwen hebben in de technologie?

RM. Ook, die denken er gewoon minder over na. Die hebben ook meer mogelijkheid om als het fout gaat er nog iets aan te doen. Kinderen hebben dat niet, en ouderen ebben die mogelijkheid ook niet. Die ouderen zijn overmatig voorzichtig.

HH. Uit mijn model komt bijvoorbeeld, als wij inzetten op zelfrijdende voertuigen, dan gaat het veilig oversteekgedrag naar beneden, dat wordt negatiever. Ik dacht, dat kan verklaard worden doordat mensen een vals gevoel van veiligheid krijgen. Mensen denken dat die auto's sowieso stop, maar misschien is het geen zelfrijdende auto maar een manueel bestuurde auto die misschien langzamer reageert. Daarom dacht ik, dit kan verklaard worden. Wat is uw mening daarover?

RM. Daar zit wel wat in. Als je weet dat die dingen toch wel stoppen, of de kans dat ze stoppen groter is dan dat hij nu is, dan zullen mensen hun gedrag daarop bepalen. Je kunt het vergelijken met vorm van gewoontegedrag. Als je weet dat 85% van bepaald gedrag optreedt, dus als 85% van de auto's stoppen voor een zebra, dan steek je dus zo over. Aan de andere kant, als de automobilist 85% van de zebra's geen voetganger ziet, zal hij daar ook niet voor stoppen. Als er wel vele zebra's zijn, maar weinig overstekers, dan verdwijnt het nut van het signaal.

RM. Onder de 30 km zijn automobilisten eigenlijk niet in staat om voorrang te verlenen aan voetgangers, de enige manier om zebra's veilig te maken is om ervoor te zorgen dat daar 30 km gereden. Dan kunnen ze op tijd stoppen, is hun zichthoek groot genoeg. Als je 50 rijdt dan kan iemand wel aanstalten maken, maar ben jij misschien nog niet in staat om op tijd te stoppen.

RM. Ik denk dat je met heel veel vraagtekens komt te zitten. Je kunt wel dingen observeren, maar waardoor dat komt dat zal je apart uit moeten zoeken.

HH. Wat zou bij uitstek een goede proef kunnen zijn voor de gemeente Amsterdam met name met zelfrijdende voertuigen.

RM. Zelfrijdende auto's op de snelweg, dat lukt wel. Op het moment dat er gekrioeld wordt, wordt het wel erg moeilijk. De verschillen in houding, perspectief zijn zo groot dat dat problemen oplevert. Er zijn heel veel mensen die denken dat zelfrijdend een panacee is, een oplossing voor alles. Er zullen minder auto's rijden bijvoorbeeld, maar dat geloof ik al helemaal niet. Ik denk eerder dat er meer komen. De bezettingsgraad van auto's zal eerder naar beneden dan naar boven gaan. Als iedereen met de zelfrijdende auto kan, dan is er weinig reden om dat met iemand anders samen te doen.

HH. Zal je dan ook eerder de zelfrijdende auto pakken dan de fiets?

RM. Er zijn meerdere redenen om met een fiets te gaan, dat is niet alleen een veiligheidsreden. Zelfs een zelfrijdende auto moet nog naar je toekomen. Die moet beschikbaar zijn, daar zit ook tijd in. Hij moet geparkeerd worden, moet ergens kunnen stoppen. Voor en na transport voor een ZV zal, zeker als het drukker wordt, een toenemend probleem worden. Daar heeft de fiets veel minder last van. Ook wel toenemend, maar minder dan de zelfrijdende auto. Dat betekent dat een fiets, zeker op de kortere afstanden, en in een compacte omgeving, nog altijd in het voordeel is. Plus, een veel hogere mate va flexibiliteit. Eer je de zelfrijdende auto hebt, die zal heus niet om de hoek staan, die moet naar je toe komen, daar gaat het toch op neerkomen. Zoveel ruimte is er niet.

HH. Er wordt nu gesproken over dat deze ruimte buiten de stad gezocht wordt.

RM. Dat wordt dus een middel dat geschikt wordt bij verplaatsingen van boven de 2km, onder de 2km, dat is de meerderheid van de verplaatsingen, blijft de fiets gewoon heel aantrekkelijk. Onder de 1km wordt lopen veel aantrekkelijker, omdat de fiets ook niet overal gestald kan worden. Dat wordt langzaam maar zeker minder aanvaardbaar. Met meer ZVs heb je ook meer parkeerproblemen. Het gaat dus toch meer ruimte gebruiken, de vraag is waar hij deze ruimte gaat gebruiken. Mensen zeggen wel, dat is vooral buiten de stad. Nee dat is niet buiten de stad, want binnen de stad zijn de bestemmingen. Daar moet hij in ieder geval kunnen stoppen.

HH. Stel langsparkeren zou wegvallen in het uiterste geval (volledig autonoom), dan heb je voldoende ruimte om kort te parkeren.

RM. Jawel, maar het is ook zo dat die flexibele ruimte ook nog steeds ruimte is. Als je ook een fiets hebt en ZV zul je op een andere manier moeten parkeren dan een normale auto. In een parkeergarage kon dit nog weleens lastig wezen, of het moet volledig geautomatiseerd zijn. Het vraagt dus om andere soorten voorzieningen. Die zijn er voorlopig niet. De eerstkomende 20 tot 30 jaar heb je systemen naar elkaar.

HH. Dat is precies waar ik in mijn onderzoek rekening mee houd, met de mixed level. Niet eens zelfrijdend, maar geautomatiseerde voertuigen, alles wat ertussenin zit. Autonome voertuigen houd ik nog buiten beschouwing. De vraag is of dat überhaupt in de binnenstad kan komen.

RM. In bepaalde steden zal het eerder mogelijk zijn, in andere steden niet. In oude compacte steden zoals Delft, Amsterdam centrum, Leiden centrum, daar is het moeilijk. Den Haag is het al makkelijker, Rotterdam is relatief makkelijk. Utrecht is ook een groot probleem. Steden met een compact centrum, daar gaat dat niet lukken. Daar raak je ze gewoon niet kwijt. Je hebt dus een rijdend probleem, je hebt ook een stationeel probleem. Ze moeten ergens neergezet worden. Als er meer auto's komen heb je meer parkeerplekken nodig. Je kunt wel zeggen dat ze meer worden gebruikt, maar ik denk dat ze van 5% van de tijd naar 10% gaan. Dat is op zich al veel beter, maar nog steeds niet echt goed. Het gemiddelde aantal kilometers van een auto nu 12.000 tot 14.000 is, zal dat oplopen naar ongeveer 30, maar ik verwacht niet dat dat naar

100.000 gaat. Het wordt niet taxi niveau hoor. Taxi's zullen verdwijnen en openbaar vervoer zoals we het nu kennen zal ook verdwijnen.

RM. Openbaar vervoer kan alleen maar van kern naar kern, alleen maar met zware stromen. Dat zal blijven, daar wordt een ZV te duur voor. ZVs op het platteland zou nu al een oplossing kunnen zijn, daar zie je nu ook het grote voordeel. Als het echt zelfrijdend is zal je daar echt voordeel zien. Dan zal je je nog wel moeten afvragen of het niet een vorm van voor en na transport wordt. Als je de grote afstand toch met andere middelen aflegt.

RE. Nu moet ik er wel bijzeggen dat het merendeel van de verplaatsingen korte afstanden zijn. Ook in rurale gebieden is het zo dat bestemmingen, die zijn noodzakelijkerwijs verder weg, dat zijn heel gewone bestemmingen; om inkopen te doen, medische bestemmingen, recreatieve bestemmingen en woon-werk. Dat zijn regelmatige verplaatsingen die je wel kunt organiseren. Incidentele verplaatsingen is een ander ding, maar die zijn ook allemaal op relatief korte afstand. Daar zal het openbaar vervoer geen grote rol in gaan spelen. Langere verplaatsingen, iedereen denkt altijd dat het daar om gaat, dat is niet zo. Het aantal verplaatsingen boven de 15km, dat percentage is heel klein.

RM. Men denkt het liefst in grote termen, dus internationaal. Vakantieverplaatsingen zijn veel belangrijker, zet veel meer zoden aan de dijk. Dat heeft emotioneel een veel sterkere betekenis dan een verplaatsing naar het centrum. Als je het totaalaantal kilometers ziet dat gereden wordt, dan zijn dit allemaal kleine afstanden. De ZV kan daar een rol in spelen, maar niet in stedelijke gebieden. Ik denk toch dat dat echt een probleem wordt.

HH. Ik zie de systemen die naar de zelfrijdende auto ontwikkeld worden zoals ACC en EBS, dat zijn goede systemen om de verkeersveiligheid te verbeteren.

RM. Voor zover dat niet ten koste gaat van de oefening van de mens. Als mensen op de voorzieningen vertrouwen, zijn ze niet meer in staat adequaat te reageren. Als ze weten dat ze auto toch wel remt, dan hoef je daar toch ook geen auto voor te hebben daarvoor?

RM. Er zijn meer mensen die worden opgenomen voor een valongeval als voetganger dan mensen er worden opgenomen als slachtoffer van een auto-ongeval. Dat beeld wat mensen hebben dat klopt echt niet. "In een auto zitten is gevaarlijk, lopen is volkomen ongevaarlijk". Collectief klopt dit dus niet. Individueel kan dit heel ander liggen. Mensen tussen de 25 en 65/70 jaar lopen een relatief laag risico, die hebben weinig ongevallen. Die hebben ook relatief weinig letsel. Vanaf 55 loopt dat op, de ongevalskans loopt niet op. Letselkans loop wel op, ongevalskans loopt niet op. They are not risky, but at risk. Zelfs 75+ers hebben minder ongevallen per persoon per kilometer als 18 tot 25 jarigen. Dat scheelt een factor 3.

HH. Dat komt dan misschien doordat zij voorzichtiger zijn, maar ALS het fout gaat, dan kunnen ze dit niet goed opvangen.

RM. De ouderen zijn dus helemaal niet het probleem. Ze komen het meest in het ziekenhuis, maar dat kom niet omdat ze gevaarlijk gedrag hebben, dat komt doordat ze er minder goed tegen kunnen. Dat is wat je bij de zelfrijdende auto ook hebt, die kan heel erg slecht onderscheid maken naar vaardigheden van mensen. Hij kan niet in de kop kijken, kan ook niet in de fysieke zelfs mentale gesteldheid kijken. Hij kan wel een individu vinden, hij kan wel een mens vinden, maar hij kan misschien onderscheid maken tussen klein mens en groot mens. Ik vraag me af of hij onderscheid kan maken tussen kind en klein mens. Misschien is het mogelijk om daar nog wat van te vinden. Maar het verschil tussen een oudere en een niet zo oudere (80 vs 25) is een hemelsbreed verschil. Dat kunnen ze er niet uit halen.

HH. Dan zal hij dus van het meest ongunstige uit moeten gaan.

RM. Dat heeft weer een tegeneffect. Ken je de …-theorie van Wilder? Mensen hebben een soort aanvaard risiconiveau, dat is theorie. Mensen aanvaarden een bepaald risico, als ze het gevoel hebben dat het veiliger is, dan nemen ze meer risico. Dat betekent dat als je die dingen veilig gaat maken, dat mensen die weg compenseren, ze gaan zich onveiliger gedragen. 1 mits en een maar, ze moeten het wel weten dat het een veiligheidsmaatregel is. Als ze niet weten dat dit een veiligheidsmaatregel is, dan zou dat effect dus theoretisch niet omhoog gaan. Dat is niet wat Wilders zegt, hij zegt dat een veiligheidsregel maakt en dat dat gewoon wordt weg gecompenseerd. Ik denk dat dat voor een deel wordt weg gecompenseerd. Ik kan niet zeggen in welk percentage, denk dat dit heel erg van de groep afhangt hoe dit gaat (attitude, risico acceptatie, risico perceptie. Het zijn heel veel factoren die een rol spelen). Maar dat er een effect is, is duidelijk. Dus als je dingen veiliger maakt, moet je erop rekenen dat het effect nooit zo groot is als dat je denkt dat het zou zijn.

HH. Dat is heel goed. Wat uit het model komt als we inzetten op automatische systemen, dat het oversteekgedrag negatief beïnvloed wordt. Dat kan dus door die theorie verklaard kunnen worden.

RM. Dat kan, dat kan ook betekenen dat mensen erop gaan rekenen dat het zo is. Dan ga je er wat losser mee om. Je zult een groot verschil tussen groepen hebben. Je kunt dat niet generiek zeggen als die ZV ook geen onderscheid naar mensen kan maken. Als hij alleen maar een mens kan herkennen, dan heeft dit verschrikkelijk weinig zin.

RM. Wat je nu ook gewoon krijgt; als een voetganger ervoor komt, dat hij automatisch stopt. In een stad komt hij dan gewoon niet meer van zijn plaats. Dit gaat hij dan natuurlijk gewoon niet doen. Er zal iets tussenin komen, gaan algoritmes komen wanneer je dat wel kan doen. Als dat heel sterk groepsafhankelijk is, dan heb je wel een groot probleem.

RM. Amsterdam heeft shared space bij het IJ, daar gaar juichende verhalen over. Maar ga me nou maar eens vertellen hoeveel ouderen daar lopen en hoeveel kinderen daar lopen. Weinig. Die voelen zich daar zeer onveilig. Die gaan daar dus niet heen. Dit is een gok, maar ik weet wel dat dit in Haren zo is. Daar is dit het geval met shared space. Blinden en mensen die moeilijker lopen gaan niet meer naar het centrum van Haren toe. Die gaan naar een wijkcentrum of die laten zich brengen. Die vinden het veel te link. Al die auto's die daar vrij rondrijden, en fietsers niet te vergeten.

RM. Dat onderscheid maken kan dus nog een probleem worden. Hoe ga je rekening houden met die grote verscheidenheid aan mensen.

HH. Ik denk dat dat meer de taak is van de ontwikkelaar van de technologie dan..

RM. Dat is een theoretisch obstakel.

HH. Hoe kan de gemeente Amsterdam daarmee omspringen.

RM. Die kan dat niet veranderen.

HH. Dat is de reden waarom ik het eruit heb gelaten. Ik zoek juist naar concepten die veranderbaar zijn.

RM. Dan moet je je toch beperken tot die wegen waar die auto toch primaat heeft, dan zijn de 50km wegen (doorgaande wegen). De wegen die geregeld zijn, waar de auto dus als rijdend verkeer het primaat heeft en waar mensen verwachten dat de auto primaat heeft. Ontsluitingswegen of doorgaande wegen in SWOV termen.

RM. Je hebt naast oversteekgedrag natuurlijk ook langsgedrag. Dat gaat dan met name om gebieden waar het denkbaar is dat mensen op straat gaan lopen, daar zullen ze dan ook echt meer op straat gaan lopen. Daar zit misschien nog wel een grotere variatie in dan in het oversteekgedrag. Dat weten we niet, maar ik heb het vermoeden dat dat effect nog weleens groter kan zijn. Als je denkt dat die auto's toch wel rekening met je houden, waarom zou je niet gewoon op de weg kunnen lopen. Als het voetgangersareaal zo slecht blijft als het nu is, en de fiets in toenemende mate het voor zichzelf opeist, ga je dat ook krijgen. Als dan de dreiging van de auto afneemt, gaan mensen op straat lopen. Dat zie je nu al gebeuren in het centrum van Amsterdam. Dan weten ze, als de auto aankomt, dan stopt hij maar.

RM. Op de grachten moeten ze wel. Tegen de gevels staan fietsen, het trottoir wordt daardoor helemaal gebruikt, dus de kleine stukjes waar je wel kunt lopen doe je niet meer, want dan loop je op en af. Dan loop je gewoon op straat. Als je weet dat die auto's toch wel op je reageren, waarom zou je dan nog op het trottoir lopen? Dat is misschien nog wel bepalender dan het oversteekgedrag. Het oversteekgedrag zou met name een rol spelen op 50 kilometerwegen. Het probleem zit hem natuurlijk niet alleen in de 50km wegen, de meeste voetgangers zullen juist vinden in die verblijfs- en semi verblijfsstraten en grijze wegen (waarlangs je functies hebt) waar formeel nog steeds 50 km is. Daar heb je nog steeds veel voetgangers.

RM. Het is niet ondenkbaar dat de stad wordt overgenomen door de voetganger, ook omdat individualisering mensen zich veel sterker bewust zijn van hun eigen gelijk en hun eigen rechten. In de jaren 50 werd het leven gedomineerd door plichten, dat is langzaam maar zeker verschoven naar "ik heb recht op". Dat zie je overal terug, in het menselijk gedrag. Mensen gaan van hun eigen gelijk uit. Als ze geen gelijk hebben, dan zijn ze rijk genoeg om zich te isoleren. Dat was vroeger niet aan de orde. Je ziet dat dat in het verkeer ook gebeurd.

HH. Dan zou je richting dedicated lanes moeten met ZVs.

RM. Dan moet dan wel kunnen, daar zit een probleem. Dedicated lanes kan alleen maar als je de ruimte hebt, je hebt een toenemend ruimteprobleem. Het is oke om een groot stuk van je rit dedicated te werken, maar daar waar het grootste conflict ontstaan heb je een ruimteprobleem. Daar is concurrentie om de ruimte. Daar speelt dat veel meer een rol.

Appendix – Interview Dr. K. Kok

Kasper Kok is an assistant professor at Wageningen University in the department of Environmental Sciences (subdivision Soil Geography and Landscape). Kok has experience in Agricultural systems, Geographical Information Systems, Sociology, Land use dynamics, Spatial models, Scenario analysis and Simulation models. Kok is considered an expert in Fuzzy Cognitive Mapping with (a contribution to) 6 scientific publications. This explorative interview is set up to validate the strategies that are chosen for the construction of the FCM model and to discuss the results, strengths, weaknesses, opportunities and threats of the method.

You have chosen to execute interviews after the model is already developed. Usually model developers choose to do interviews in an early stage. It is interesting that you have chosen to execute interviews in the finals steps of the process. With time being a limiting factor in the workshop, you have the risk that not all determinants and relationships are used or assigned by the participants. By executing the interviews afterwards, missing determinants or relationships can be identified by the interviewee. The limited time for the workshop is not necessarily a negative aspect. If you provide participants with for example 10 determinants and two days for the construction of the model, it is expected that by the end of the workshop they have introduced 30 new determinants and an overly complex model. By limiting the time for model development, the process of unpacking determinants into new determinants is inhibited. Also, overly detailed relationships are less likely to be assigned. It is therefore possible to develop a FCM model in one hour, although it will have its own disadvantages.

Looking at the results of the workshop, group A introduced a new determinant and linked this to one other determinant. Both are not connected to any other determinants. Even though the participants found these determinants of importance, they are not part of the model. This has to be dealt with in post-processing. This group also introduced a short feedback-loop with a large positive value. If one of the determinants doubles, the other determinants doubles, which automatically lead to doubling of the initial determinant after several iterations. This can lead to an ever-increasing state value, which is not necessary logical. Kok suggests to ask the participants to choose one of these connections that they find most important. The squashing function in the FCMappers-software limit the value at 1, which make is impossible for the results to diverge.

In the process of combining multiple maps, it is possible that a relation indicated by one group (C1 to C2 +1) and another group (C2 to C1 +1) is combined. This results in a short feedback-loop that does not represent what both stakeholder-groups said. Therefore, Kok favours a workshop where the participants work on one model, because the discussion takes place at the same time. It is possible to create different models in multiple groups, but it is advised that the participants discuss the results afterwards and choose the correct relationship between determinants. Otherwise, the combined model might not represent the system in reality. The method makes it possible to mathematically combine three different maps into one. Kok favour working on one model with the entire group. That way the participants can discuss conflicting relationships directly, which result in less post-processing time for the modeller. It is also easier to capture the reasoning of the participants when they work in one group.

There are some typical roles that need to be fulfilled during a workshop. Observe and note-taking are important roles, but are hard to carry out when the workshop is given by one person. With a good note-taker, you gain insight if the participants came to a consensus or if they used to opinion of one individual. By creating groups of stakeholders that have a certain degree of conformity, consensus building is limited. In general, Kok believes that participants with opposite opinions should be grouped according to their opinion. When the modeller divide the participants into different groups of the same expertise, it is likely that by the end it is clearly noticeable which group developed a certain model. They are expected to introduce new determinants that are relevant for their perspective and expertise. FCM can therefore be useful to show where opposite opinions are, which is sometimes just a difference in a few arrows. In general, participants always agree which determinants are most important.

The contradicting relationships in the combined map are not changed into either a positive or negative relationship, but are indicated as a point of conflict. By doing this, you have to find out if the link is in an active part of the system or not. It is possible that two determinants describe the same variable or have a relationship, but this is not assigned by the participants because they are on the opposite side of the map. It is also possible that the relation is not identified by the participants because of this spatial separation. This is a threat in the construction of the map.

It is important that you convince people that you are not only looking at the model, but also at the system dynamics and its meaning. It is therefore important to realise what products you are presenting if the participants constructed a complex model. Your combined model is overly complex and might not be very useful to represent the system. Nevertheless, the outcome of the model is still very useful. Your choice not to simplify the model might be correct, since you risk nullifying the results of the workshop. You choose the most important determinants in the model to be investigated into further detail. It is important that you can explain the behaviour of these determinants.

You will not convince people of the results if your only reasoning is that this is the outcome of a black box. Try to at least make the black box a bit grey, so that you can show people what happens with the input data. If not, you can expect two typical reactions: (1) "The results are what I was expecting, thus I didn't need the model in the first place", or (2) "This is not what I was expecting, thus the model is no good". It is a challenge to convince people of your results if they don't understand the method. As soon as people trust the model, they are likely to accept the output. It is therefore essential that you convince people with reasoning, not only with a model. It is also important to mention that the system is not constructed by the modeller, but with the mental maps from stakeholders and professionals.

I use the FCM-method because of the feedback-loops and therefore the possibilities to show the dynamics of the system over time. In your role as adviser, you can look into adding or removing certain feedback loops to steer effects. It might possible that a large interference will only result in a minor change in the results. In that case, the feedback-loop was located in a part of the system that is insensitive for changes. The process of adding and removing feedback loops is time-consuming, and might therefore not be realistic for the remainder of your thesis.

Time is an ill-defined component in this method and can be a threat. Especially when feedback loops are present, it might be necessary to introduce dummy determinants or write the source code yourself to deal with delays. You have to check if there is a difference in time between the assigned links. You need to keep in mind that mathematicians say this method delivers a static output. If you want to reason on something over time, you require a differential equation instead of matrix calculations. The interpretation of the results is dynamic, but the calculations are static.

When Kok first started using this method, he believed 30% of the value was found in the map and 70% in the calculations. Today these percentages have switched places. 70% of the value of this method is found in the dynamic behaviour. The other 30%, the mathematics, is there to support the findings. Kok believes that this balance is also present in my methodology. At the end of the day the mental maps of stakeholders and professionals are captured and translated into a model. The method has its disadvantages and threats. If you face these negative aspects and deal with them, then you are on the right track. It can be useful to be very open and transparent on the model and its weaknesses, but keep in mind that your thesis will be criticized. In that case, it is important to have an answer ready for every weakness. Kok cannot come up with a different method that makes it possible to understand this level of system knowledge trough elicitation of mental maps from professionals.

Appendix – Transcript Interview Dr. K. Kok

Wageningen, 31-05-2017. Gaia building Wageningen University and Research. Ref: (Kok, 2017)

KK. De ruimte die de methode biedt om bijvoorbeeld menselijk gedrag en fysieke componenten als wegontwerp in één model te plaatsen is het grootste voordeel en het grootste nadeel. Voordeel is dat er geen enkele limiet is om het erin te stoppen. Nadeel is dat het kan zijn dat je appel en peren vergelijkt.

KK. *Over de tegenstrijdigheden in de verbanden, niet zelf oplossen maar tegenstrijdigheid houden* Het kan maar zo zijn dat het geen effect heeft als het in een stuk van het systeem zit wat niet veel invloed heeft op het andere deel van het systeem. Dat kan je het best eens zijn dat we het niet eens zijn.

KK. Interessant dat je de interviews achteraf gedaan hebt, de meeste mensen kiezen ervoor om deze op voorhand te doen.

HH. Ik wilde eerst het algemene model opbouwen, dan kan ik daarna de diepte in om het model te valideren.

KK. Het heeft te maken met hoeveel tijd je hebt. Als je maar een uur hebt voor de workshop dan loop je meer risico dat je wat mist, waardoor je de interviews beter achter kunt doen

KK. Toen ik begon met FCM dacht ik: Dit is goed, deze methode moet ik hebben (2009 eerste paper gepubliceerd Brazilië). Tijdens een onderzoek met veel verschillende nationaliteiten heb ik ervoor gekozen om geen workshop te doen, omdat je dan de hele tijd tussen die talen aan het heen en weer springen bent. Door de ontwikkeling van FCM heen ben ik een heel klein beetje sceptisch geworden, dat heeft vooral te maken dat mensen die dit zien die denken dat het in een uur kan. Daar moet je heel erg mee oppassen, je ziet duidelijk gebeuren dat als je begint met 10 concepten en je geeft mensen twee dagen om erover te praten, dan heb je aan het eind van de twee dagen 40 concepten. Er zijn natuurlijk niet 10 concepten die 1 rol spelen. Als je minder tijd hebt, dan gebeurd dit dus minder. Het mooie van gelimiteerde tijd is dat je het proces afremt om allemaal concepten uit te pakken naar een complex model. Het is daarom mogelijk om in een uur een model op te bouwen.

KK. Bij post-processing moet je rekening houden met een paar belangrijke zaken. In een lang proces heb je vaak de over gedetailleerde verbanden (zie post-processing, heb ik al aangepakt). In een uur loop je dit risico minder. Het andere risico is dat de pijlen heel vaak een processen, dus er zit nog een box op de pijl. Als je langer erover discussieert heb je kans dat ze dit proces uitpakken in nieuwe concepten.

KK. Een ander risico is dat twee concepten erg op elkaar lijken, maar ver van elkaar af staan op de kaart. De stakeholders zien de relatie tussen A en F niet meer omdat de stakeholders pas op het laatste erin hebben gezet en helemaal aan de andere kant staat. Er zijn dus weleens missende pijlen, gewoon omdat de concepten aan de andere kant staan (fysiek ver van elkaar). Hoe minder tijd voor de workshop, hoe minder deze fouten gemaakt worden.

KK. Missende pijlen (zoals bij groep A), duidelijk dat ze het erover gehad hebben en dus dat ze dit belangrijk vinden, maar op dit moment doen ze niks. Hier moet jij iets mee gaan doen. Omdat je dit combineert met de andere modellen zal de ene een driver worden, wat niet automatisch zo hoeft te zijn (check of dit ook zo is)

KK. Als je stakeholders indeelt in specifieke groepen (NGO's vs Overheden), dan zie je aan het einde heel goed welke groep het model heeft opgebouwd. Er zijn dan andere boxen uitgepakt.

KK. Voor mij is de methode zo handig vanwege de feedbacks, door het veranderende gedrag met verloop van tijd. Daar zitten twee gevaren aan; 1. Dat 1 knoop alleen maar ingangen heeft en er niet uit heeft (put) en 2. Wat het gedrag van de systeemdynamiek beïnvloed zijn de heen-en-weer pijlen. Zeker als ze allebei heel erg sterk zijn. Als de 1 verdubbelt, dan verdubbelt de ander, verdubbelt de een weer enz. De software van FCMappers gebruikt een squashing function die hier rekening mee houdt, en de maximale waarde op 1 afkapt (uitzoeken wat de impact daarvan is).

HH. Een nadeel van de software van FCMapper is dat je geen inzicht hebt in de wiskunde erachter, het is als het ware een black-box.

KK. Hele korte en sterke feedbacks, dan zeg ik altijd: Maak een keuze, welke je belangrijk vindt. B naar A of A naar B. Het systeem is er om iets te leren, dan moet je ook snappen hoe het systeem werkt. Dat werkt beter als je 1 van de 2 zwakker maakt.

KK. Stel groep 1 zegt dat A naar B +1 is, en een andere groep zegt dat B naar A +1 is, dan krijg je na combinatie dat beide zichzelf versterken, maar dat is niet wat ze hebben gezegd. Waar de causaliteit zit is best moeilijk, het zomaar combineren van de twee leidt tot systemen waarvan ik zou zeggen: Maar zo hebben ze het niet gezegd.

KK. Mensen combineren dit omdat het kan, maar ik ben er zelf heel huiverig voor. Daarom ben ik zelf een voorstander van een workshop aan 1 model, dan hoef je dit niet te combineren. 1x heb ik een workshop georganiseerd waar losse kaarten werden gemaakt, maar daarna moesten de groepen samenkomen om te kiezen welke verbanden belangrijk waren, of misschien toch allebei.

HH. Dit miste ik enorm in mijn workshop. Uitzoeken waar in het model dit voorkomt, en markeren

KK. Oppassen als je dit soort dingen in je model ziet, uiteindelijk zal dit niet het systeem beschrijven zoals het in werkelijkheid eruitziet.

KK. Verder heb ik heel veel discussies met wiskundige gehad. Bron: (2010) Alexi Boinhof en Fransouc Bouscait), dat gaat niet alleen over FCMaps, maar ook over andere group model models. Hij is het fundamenteel oneens met hoe KK FCM opbouwt. Het gaat dan vooral om de dynamische output.

KK. Ik werk met systemen die drivers moeten hebben, die invloed uitoefenen op een bal. De drivers zijn voeten die ertegenaan schoppen. Oorspronkelijk beschrijf ik het altijd als een systeem wat in evenwicht is, en de driver schoppen hem uit evenwicht. Wat je laat zien in de dynamische output is hoe de concepten veranderen. Hoe een post-doc het nu heeft opgeschreven (paper is afgewezen overigens), samen met Gray en Gray en Martin Wildenberg, wat je eigenlijk moet laten zien is de cumulatieve waarde ipv percentage verandering. De self-loops laat je hiermee weg (wat de software van FCMappers doet). De software kapt af op 1, daar ben ik het niet mee eens. Er is geen enkele reden om dat niet te doen. Uitzoeken waarom dit zo is.

KK. De interpretatie is voor mij praktisch hetzelfde, maar verschilt dus als je met practitioners of wiskundigen spreekt.

HH. Mijn focus ligt meer op de interpretatie, niet op de wiskunde.

KK. Je moet mensen overtuigen dat je niet alleen naar het model kijkt, maar naar de dynamiek erachter.

KK. Focus ligt in jouw model op centraliteit, dus daar doe je nog niet veel mee met fuzzy. Voor de scenariovorming gebruik ik de fuzzy wel. Visueel is dit niet meer bruikbaar voor het gecombineerde model, zelfs na een half jaar zullen stakeholders het model niet meer herkennen.

KK. Het model van Brazilië heb ik veel van geleerd, met name van de feedback-loops. Deze heb ik zelf opgesteld, waardoor het een representatie is van mijn werkelijkheid. Ik begon met 40 factoren, wat veel te gecompliceerd is. Ik heb vervolgens allemaal dingen bij elkaar genomen.

KK. Mensen die hele ingewikkelde systemen hebben gemaakt, hoe ga je dit laten zien? Ga je dan laten zien dat dit niet is wat je wil laten zien? Dan kom je weer bij de black-box uit, daar komen dan staafdiagrammetjes uit. Er zijn mensen die daarom hun systeem versimpelen.

HH. Ook over nagedacht, maar dan doe ik mijn workshop teniet. Dan ben ik liever kritisch achteraf.

KK. Wat je dan wel moet doen, als je een top 3 wil aangeven, dat je heel duidelijk aan de hand van de systemen kunt uitleggen waarom dit dan zo is. Enige reden mag dus niet zijn dat dit uit de software komt, dat overtuigt mensen niet. Als je zegt: Dit is uit de workshop gekomen, dit gaat van die naar die naar die en weer terug, dan kun je wat zeggen over hoe het systeem draait. Dit hoef je dus niet eens visueel te doen, maar dan kun je zeggen waarom dit soort elementen belangrijk zijn. Dan gebruik je ook de kennis die je zelf opdoet met het systeem, zonder te vertrouwen op de blackbox.

KK. Mensen hebben dan twee typische reactie, probeer het in ieder geval grijs te maken. Beetje doorzichtig, maar je snapt het nog net niet helemaal. Ene reactie als je de output laat zien: Is logisch, dat is wat ik al dacht ik had het model niet nodig. Dan luisteren ze niet meer. Of ze kijken naar de output en zien dat het niet is wat ze dachten, dan zeggen ze dat het model niet deugd en dat ze er dus niet naar hoeven te kijken. In beide gevallen is het heel moeilijk om mensen iets te laten zien wat ze niet snappen, en om dan te zeggen: Neem dit nou maar van mij aan.

KK. Op het moment dat er nog geen vertrouwen is in een tool of model, dan gaan ze op zoek naar redenen waarom het model niet deugt. Als ze het wel vertrouwen, dan nemen ze de output voor waar aan.

KK. Je hebt in ieder draagvlak gecreëerd doordat de experts het zelf hebben opgebouwd. Ik heb het niet zelf bedacht, maar gewoon opgeschreven wat de stakeholders hebben bedacht.

KK. Je moet zorgen dat je de mensen niet overtuigd met een model, maar met een redenering.

HH. Ik miste heel erg de redenatie van de experts, geen plaats voor gehad in de workshop. Gekke verbanden ga ik tijdens de interviews achterhalen. Bovendien snel tot consensus gekomen door beperkte tijd.

KK. In workshops wil je eigenlijk een aantal rollen die vervult kunnen worden. Observeren en note-taken zijn altijd belangrijke rollen, waar je geen tijd voor hebt als je de workshop in je eentje leidt. Dan weet je ook direct of er consensus is ontstaan of dat bijvoorbeeld 1 persoon het erdoorheen heeft gedramd.

KK. Consensus-building kun je voorkomen door mensen in een groep te zetten die het van nature al een beetje met elkaar eens zijn.

KK. In zijn algemeenheid zeg ik altijd; als je duidelijk groepen krijgt met tegengestelde meningen, dan is handig om te uit elkaar te trekken. FCM is heel goed om te laten zien waar deze tegengestelde mening dan zit. Soms zijn dit maar twee pijlen op een heel systeem. Er is eigenlijk nooit echt een verschil van mening welke concepten belangrijk zijn, maar wel over de relatie tussen die concepten.

HH. Mijn stakeholders zouden naar verwachting het niet fundamenteel met elkaar oneens zijn

KK. Doordat de groepen op elkaar lijken kun je makkelijker het model samenvoegen. Het is namelijk al direct gevalideerd.

KK. Ik ben nog steeds fan van de methode door de feedbacks, doordat je iets kunt zeggen over de dynamiek van het systeem na verloop van tijd. Je zou in de adviesrol kunnen sturen op het wegnemen of toevoegen van deze feedbackloops, zodat je effecten opvangt of voorkomt. (Handig, uitzoeken). Dan heb je misschien een langer proces nodig. Daar kunnen soms hele interessante dingen uitkomen, maar dan blijkt uit het model dat er niet zo veel veranderd. Dan blijkt dat je in een deel van het systeem zit wat heel ongevoelig is voor veranderingen. Het kan daarom zo zijn dat een bepaald deel van het systeem heel resiliant is.

KK. Het enige wat de wiskunde doet is doorredeneren wat ik anders zelf zou doorredeneren

KK. De tijdschaal met dummy variabelen is erg belangrijk in FCM, vooral door de feedback loops die een later effect hebben. Voorbeeld graan in uiterwaarden, waarvoor bomen werden gerooid die overstroming overleefden. Als je peak discharger hoger wordt, planten we de bomen weer, dus dan kunnen de dijken weer lager. Dan krijg je een systeem waarbij de dijkverhoging en boomplanting af en aan toe en afnemen, wat natuurlijk niet in de werkelijkheid gebeurd.

HH. Ik heb de tijd niet echt als factor meegenomen.

KK. Toch moet je wel opletten wat er gebeurd als de feedbackloop ergens eerder is. (Uitzoeken waar dit het geval is/ kan zijn).

KK. Zijn alle pijlen even snel? Als dat niet zo is, dan heeft dit invloed. Dit kan uitmaken voor het resultaat. (check of er tijdverschil in zit). Het is heel moeilijk om dit gedrag goed te vangen, dan zou je het echt zelf moeten programmeren, waarbij je vertragingen inbouwt (vanaf waarde 5 mag je pas door etc.)

HH. Welke software gebruikt u?

KK. Ik gebruik Excel, met een simpele matrix en vermenigvuldiging. Ik doe dit om het grijzer te maker. Wordt het niet, maar dan kan ik duidelijk laten zien wat er gebeurd. Het blijft een beetje bluffen, maar het werkt wel goed om anderen te overtuigen dat het een heel simpel modelletje is. (Die overtuiging moet ik meenemen in mijn verslag). Dit maakt het niet anders dan FCMappers, maar zal driekwart van de mensen overtuigen.

KK. Het zijn iteraties, geen tijdsstappen. Deze laatste stap is een gemis in de methode. Het moeilijkste waar het vastloopt met wiskundigen is dat zij zeggen dat een matrix statisch is. Als je over tijd wil bekijken, dan heb je een differentiaalvergelijking nodig. Je interpretatie is daarmee dynamisch, op een berekening die statisch is.

KK. Toen ik eraan begon dat ik: Ik heb hier een methode waar ik 30% van de waarde haal uit de kaart, en 70% uit de berekening, waar ik naar het dynamisch gedrag ga kijken. Dat is nu omgedraaid, dus ik denk dat 70% in de kaart zit en 30% in dynamisch gedrag. Deze balans ligt bij jou al wel goed. Ik gebruik die 30% vooral om beter te begrijpen wat ik hier eigenlijk zie. Als je het op die manier insteekt, als ondersteuning om de spagetthi-chart beter te kunnen begrijpen, dan is het een juist gebruik van de methode.

HH. Ik blijf benadrukken dat deze methode een tool is om handvatten te geven.

KK. Je moet wel oppassen dat je het niet al te voorzichtig verkoopt, want dit is uiteindelijk wel wat stakeholders ervan vinden. Je hebt de goeie mensen aan tafel gekregen, hun mening heb je gestructureerd, en het is hun mening van het systeem. Wat de stakeholders er tezamen van denken, dat komt naar voren in het model. Het blijft koffiedikkijken hoe het gaat veranderen, maar niet wat mensen er nu van vinden.

KK. De methode heeft gevaarlijke nadelen, maar als je die goed onder ogen ziet, dan ben je op de goede weg. Ook voor andere modellen geldt namelijk dat de gebruiker uitgaat van empirische data. Hier heeft ooit iemand ook bedacht, ik doe het maar zo. Je weet daarom niet precies het proces, maar je gaat er wel vanuit. Net als met zwaartekracht. Je weet wat het doet, maar het proces weet je niet precies. Hoe meer je open bent over wat je doet, hoe meer je afgeschoten kan worden.

HH. Ik wil wel heel open zijn in wat ik heb gedaan en waar verbeteringen te vinden zijn

KK. Dan moet je je wel heel doordrongen zijn van het feit dat er kritiek gaat komen, dan moet je dus goede antwoorden hebben waardoor je de kritiek weg kan nemen. Je moet ze niet laten zien dat je het niks vindt.

KK. Ik zou dus altijd, als ik kijk naar alle methodes die je kunt gebruiken met stakeholders in een gelimiteerde tijd, en hoe jij de strategie hebt gekozen, dan combineer je kennis van jezelf met die van stakeholders waarbij aanbevelingen volgen. Ik zou geen andere betere methode weten, met al zijn zwaktes tov andere mathematische modellen. Maar dat is niet het doel van deze methode, het gaat om inzicht in het systeem. systeemkennis moet het opleveren. Het gaat er niet om dat je precies weet wat een factor gaat doen, maar wel om of hij omhoog of naar beneden gaat.