Spatial impacts of vehicle automation and sharing on urban regions in the Netherlands: A fuzzy cognitive map modelling approach

Transport, Infrastructure and Logistics

Master thesis

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Connekt

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Spatial impacts of vehicle automation and sharing on urban regions in the Netherlands: A fuzzy cognitive map modelling approach

by

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Preface

This thesis report is submitted in partial fulfillment of the requirements of the degree of MSc. Transport, Infrastructure and Logistics at Delft University of Technology. The research project was carried out in cooperation with Connekt|ITS Netherlands. The research presents an exploration of spatial elements that are affected by vehicle automation and sharing. This research is aimed to enlighten city governments and research organizations.

I would like to thank my graduation committee for their guidance and support throughout my research. Prof. Bart van Arem had shown full support throughout the project and provided critical suggestions despite his full agendas. Dr. Dimitris Milakis and Dr. Jan Anne Annema helped me to maintain the research scope, provided unique perspectives and clarity during weekly meetings despite the fairly new FCM research method. Special thanks to Ms. Marije de Vreeze at Connekt who provided me with uncountable opportunities in and out of this research and supported me at every stage during my stay at Connekt. She also provided the chance to attend many mobility related congresses through which I was able to connect with important people in the field of mobility and gained lots of industrial exposure. Above all everyone in my committee showed lots of motivation in this research which helped me to be more ambitious.

This research is based on the input data obtained from anonymous experts. I would like to thank every expert for their time and friendly cooperation during the entire phase of the research. Special thanks to Dr. Kasper Kok for guiding me through FCM process and providing valuable tips for conducting the interviews. I would also like to appreciate Mr. Michael Bachhofer for explaining the working of FCMappers model that he created and Shaun Turney from McGill university for sharing the FCM modelling script for R despite their busy schedules.

Furthermore, I would like to thank all my friends from Delft, especially, Anne, Ani and Bon for providing joyful moments, creating amazing memories and sharing personal experiences that made me grow into a healthy intellectual being. Super thanks to all the colleagues at Connekt who made nearly every day with so much fun and liveliness. Lastly, I thank my parents for their infinite support without which I could not have studied at TU Delft.

Srikumaar Ramakrishnan Ganesan

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Executive summary

The current transport system is struggling to keep up with the rising mobility demands. This exerts pressure on present mobility infrastructure and traffic management. Vehicle automation and sharing are expected to solve the growing mobility issues.

Research shows that vehicle automation can make transport safer, efficient and enrich travel time based on the level of automation. Ideally, a fully automated vehicle (SAE level 5) can provide on-demand transport without requiring any driving intervention from the passenger in any environment. Sharing in mobility is expected to reduce the number of vehicles needed to service the mobility demands. Research shows that in a highly sharing economy, 10% - 30% of today's number of vehicles are sufficient to provide the current level of mobility in Lisbon, Portugal.

It is known that transport and land use are interrelated through Wegener's Land Use Transport Interaction (LUTI). This means changes to any one of these concepts influences each other. In this case, major transport advancements like vehicle automation and sharing can influence land use. Changes to land use is referred as spatial impacts. This is concerning especially for urban regions, where spatial changes are hard to accommodate.

The purpose of this research is to explore the potential spatial impacts of vehicle automation and sharing on urban regions. The focus of this research is on spatial impacts caused due to passenger and freight transport modes. The main research question is:

To what extent does vehicle automation and sharing influence urban regions in the Netherlands?

It is a necessity for the Dutch city governments to know the spatial impacts of cities to enable them to make informed investment and policy decisions. The spatial impacts are explored in a multi-disciplinary perspective for Amsterdam as a case-study in the Netherlands.

Vehicle automation and sharing on land use

Literature reveal that not only can vehicle automation be beneficial but can also change the way we live, the location where we live, shop and work. Such changes to origin and destination locations could subsequently cause changes to urban spatial elements. Further, vehicle automation could enhance sharing. Sharing could also influence land use. High levels of sharing and services like Mobility as a Service (MaaS) could discourage people from owning a car. This could induce spatial impacts on requirement of parking spaces. Sharing in freight helps avoid empty trips and utilize the maximum capacity of trucks. Though sharing in freight industry is in rudimentary stages, it is unsure if sharing in freight transport could have spatial impacts. Hence, sharing in freight is also considered in this explorative research.

This research focuses on exploring spatial impacts such as relocation possibilities, parking, and urban redesign of transport elements such as park and ride (P+R) facilities on dense urban regions due to effect of vehicle automation and sharing.

Research approach

In order to answer the research question, there does not exist enough data with scientific basis to explore the future spatial impacts. Hence, Fuzzy Cognitive Mapping (FCM) based modelling research technique is used. FCM modelling is carried out through the 5-step framework process (see Figure 1). Steps 1 & 2 are performed to capture input data through interviews. FCM modelling is carried out in step 3 while the individual fuzzy cognitive maps are combined in step 4. The modelled results are analyzed and tested in step 5.

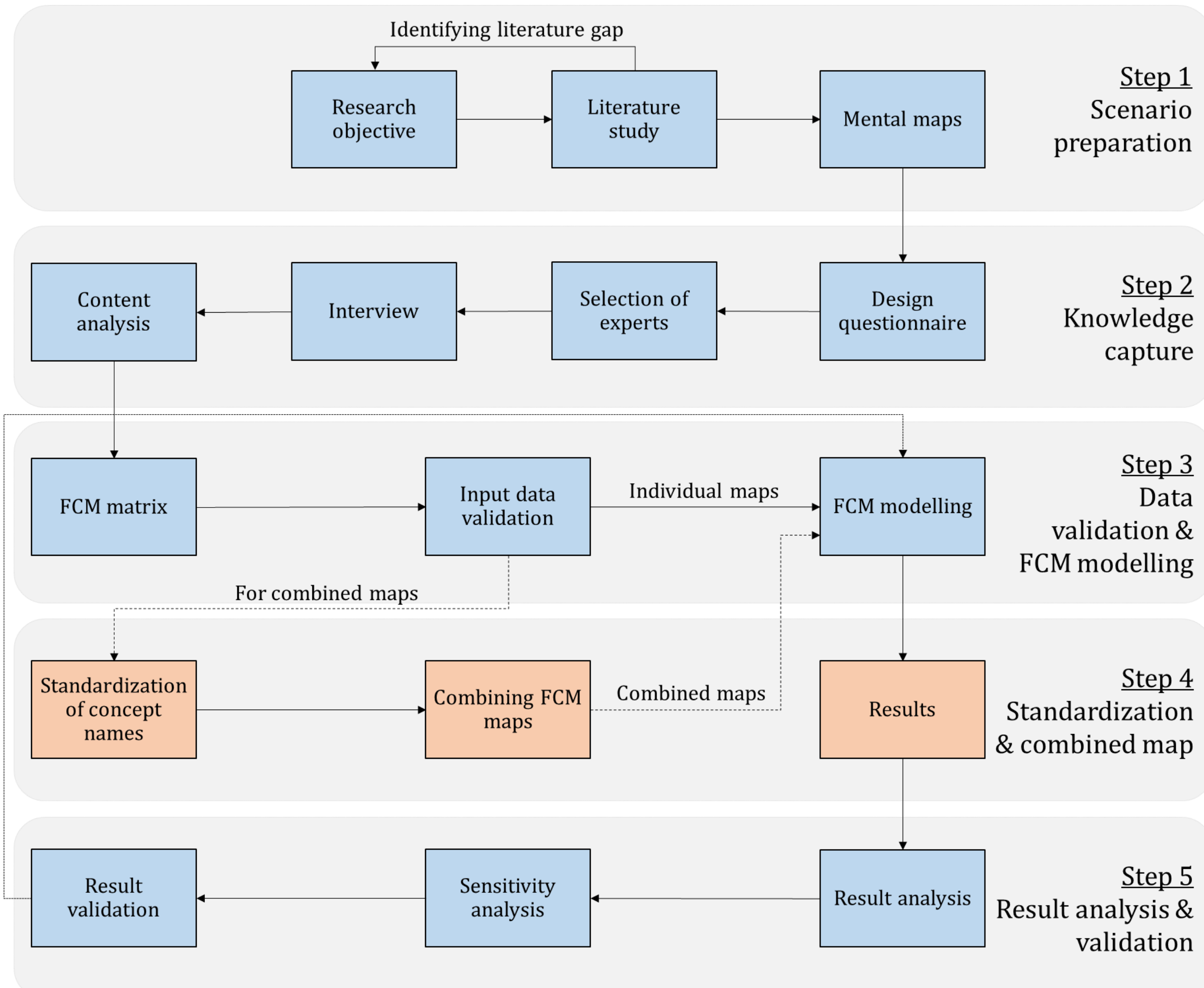


Figure 1 FCM framework adapted from (Jetter & Schweinfort, 2011), (Jetter & Kok, 2014)

FCM is a participatory scenario development process that allows to capture multi-disciplinary perspectives. FCM depends on expert interviews to create fuzzy cognitive maps, which serve as input for modelling scenarios.

Case study: Amsterdam

To further investigate the extent of impact of vehicle automation and sharing on land use, a case study is done for Amsterdam. Amsterdam is chosen because it is a dense urban region with ever-growing spatial and mobility demand limited by spatial constraints. Next to that the Government of Amsterdam wishes to know the spatial impacts to enable them to plan their investment and policies strategically.

First, literature study on impacts relevant to vehicle automation and sharing on and use were researched. This led to identification of impact factors that were discussed with experts during interviews. 8 experts were selected and interviewed from 4 different expertise areas. Individual face-to-face interviews were conducted. Upon explaining the research objective of the interview, the experts were asked to consider Amsterdam's spatial characteristics, and mobility challenges while creating fuzzy cognitive maps to reflect on the case study of Amsterdam.

The interviews resulted in each expert creating their own individual fuzzy cognitive map representing the causal (cause-effect) relationships that are rated within the range of -1 to 1. In total, 8 individual fuzzy cognitive maps were created from the interviews. Out of 8 maps, 7 maps represented passenger transport modes and 1 map represented freight transport mode. The interviews resulted in identification of spatial factors that could be influenced by vehicle automation and sharing.

The identified spatial factors for passenger transport are

- Accessibility
- Relocation of residents
- Relocation of companies and retail
- Change in land value
- AV friendly urban redesign
- Transfer nodes and P+R
- Spatial social interaction
- Parking facilities

And the identified spatial factors for freight transport are

- Relocation of factories
- Relocation of consolidation and distribution centers

FCM modelling

The individual fuzzy cognitive maps for passenger transport are combined to improve the reliability of the results. 4 individual passenger transport FCM maps are combined to form 1 combined FCM map for passenger transport using a new approach that is proposed in this research resulting in highest combinability. FCM modelling is performed for 1 freight transport FCM map and 1 combined passenger transport FCM map. FCMappers software is used to model FCM scenarios. The FCM maps are coded to matrices that is input into FCMappers one at a time and FCM modelling is done for the 4 scenarios, namely:

- High automation high sharing
- High automation low sharing

- Low automation high sharing
- Low automation low sharing

Sensitivity analysis on certain factors is performed. Changing the influence ratings for 'level of automation' towards 'peoples adaptivity to automated vehicles' had no impact on the results.

Results, conclusions and recommendations

This research lead to preliminary results and the main results. The preliminary results are the FCM map for freight transport and combined FCM map for passenger transport. Both FCM maps led to identification of spatial elements and their causal relationships. It is found that, relocation characteristics depend mainly on costs in freight case. The map also reveals that sharing does not directly affect relocation characteristics of factories and distribution centers.

In passenger transport case, it is found that relocation to father and cheaper locations mainly depend on parking facilities and disutility of car travel in passenger transport case. Parking facilities support relocation and disutility of car travel constrains relocation. The map further reveals accessibility and implement-ability of higher automation levels depend on AV friendly urban redesign. If AV friendly redesign is insufficient, it leads to rise in disutility of car travel.

The model results for freight case seem to have questionable results. However, the results on passenger case seems reasonable. The main results concerning spatial factors from FCM modelling conclude the following:

- Relocation of factories and distribution centers to centralized locations occur only if the costs increase. High automation scenario is expected to reduce the costs in freight industry, thus causing no relocation. No relocation is expected in low automation scenarios. Sharing has no effect on relocation characteristics.
- Weak relocation of residents, companies and retail can occur only in high automation and high sharing scenario as land value towards city center regions in Amsterdam is expected to increase in this scenario.
- Medium impact in parking spaces can be expected as parking requirement tend to decrease in high sharing scenarios. This could liberate parking space in Amsterdam that could be used for other purposes like buildings or parks.
- Medium impact in AV friendly urban redesign is expected to facilitate vehicle automation in high automation scenarios. This in turn improves accessibility in these scenarios. Additional research should be done to explore geographical locations and demand estimates for planning spatial elements concerning AV friendly urban redesign such as transfer nodes and P+R facilities and pick up drop off points.

It is recommended that the city government should focus as much on sharing as on vehicle automation to aim for high automation high sharing scenario. Results on mobility impacts reveal that high automation low sharing scenario causes medium-weak negative impacts on mobility and traffic which would largely reduce transport efficiency and aggregate transport problems.

AV car ownership rate is identified to be an uncertain factor to estimate. Trip length of car is expected to fluctuate on the due course of reaching a saturation. Further research is recommended before designing policy measures.

FCM was found to be an effective tool to explore the causal relationships and provide preliminary insights on impact areas. Detailed research is recommended on the identified impact areas. Also, this research does not consider spatial economic though they are largely related to spatial impacts. Further research on spatial economic perspective is recommended on the same subject.

Contents

List of figures

List of tables

Nomenclature

Acronyms

AV	Automated vehicle
CACC	Cooperative adaptive cruise control
C-ITS	Cooperative intelligent transport system
FCM	Fuzzy cognitive mapping
HORECA	Hotel, Restaurant, and Cafes
ICT	Information and communication technologies
ITS	Intelligent transport systems
MAAS	Mobility as a Service
OD	Origin destination
OEM	Original equipment manufacturer
SAE	Society of automotive engineers
V2I	Vehicle to infrastructure communication
V2V	Vehicle to vehicle communication
VoTT	Value of travel time
USDOT	United States Department of Transportation

Terminology

Autonomous vehicles	Vehicles with driving automation capabilities that monitors environment, decides, and executes driving tasks without V2I or V2V.
Cooperative vehicles	Vehicles with driving automation capabilities that executes driving tasks with communication with other vehicles or infrastructure.
Automated vehicles (AVs)	Vehicles that use combination of autonomous ITS and cooperative ITS to execute automated driving tasks.
Driving automation	Vehicle automation
Travel time enrichment	It denotes realization of productivity of travel time through secondary activities.
High automation	Advanced level 4 and level 5 automation as per SAE standards of driving automation.
Low automation	Level 2 and level 3 automation as per SAE standards of driving automation.
Spatial elements	Built urban elements such as retail, companies, housing, land, parking spots, roads, shared spaces, distribution and consolidation centers, warehouses, factories.
Spatial impacts	Impacts on land use and spatial distribution of spatial elements.

Suburbanization	Also perceived as urban sprawl in this research, vice versa.
Spatial structure	Also called as urban form of a city, town.
Transferia	A *conceptual* land in urban region that facilitates as pick up drop off point, park and ride and a multimodal transfer point for passengers.
Urban freight	City logistics that deal with day to day delivery of freight shipment. Example B2B and B2C services such as post, online shopping.
System (in FCM)	The set of concepts defined by experts in their FCM to associate with spatial elements, level of automation and sharing.
System (in description of FCM)	The fuzzy cognitive map created by experts which serves as input for FCM modelling.
Concepts, factors (in description of FCM)	Terms used to denote components defined by experts in this research.
FCMappers	Software used to model scenario based fuzzy cognitive mapping technique.

1 Introduction

It is evident from new regulations by USDOT (U.S.Department of Transportation, 2016) and involvement of the Netherlands by Declaration of Amsterdam (European Commission, 2016), that driving automation is in fast paced development with cities, wanting and hoping to solve urban mobility woes with the benefits of automated driving (Litman, 2014). Automated driving enables personal benefits such as travel time enrichment, more comfort in driving and transport benefits such as reduced parking area, traffic efficiency, safety, lower emissions and fuel savings (Litman, 2014), (U.S. Department of Transportation, 2015) (Somers, 2015). In fact, driving automation enhances the prospect to share vehicles. Sharing economy is looked up to as it is believed to have potential for efficient use of vehicles (Sołtys & Smolnicki, 2016) and effective use of infrastructure (Le Vine, Zolfaghari, & Polak, 2014), (International Transport Forum, 2015). The benefits may vary based on the extent of sharing similar to level of automation - with higher levels of automation and sharing yielding highest benefits (Correia, Milakis, van Arem, & Hoogendoorn, 2016). See Table 1(R).

Driving task Level of automation		Execution of steering and acceleration / deceleration	Monitoring of driving environment	Fallback of performance of dynamic driving task	System capability (driving modes)
0	No Automation	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	System	Human driver	Human driver	Some driving modes
3	Conditional Automation	System	System	Human driver	Some driving modes
4	High Automation	System	System	System	Some driving modes
5	Full Automation	System	System	System	All driving modes

Personal benefits	Transport benefits
Travel time savings due to travel time enrichment Comfort in driving Safety	Prospect for sharing Reduced parking area Traffic efficiency Safety Fuel savings Reduction in vehicle emission

Table 1 SAE levels of driving automation SAE standards J3016 (L)(SAE International, 2016), personal and transport benefits of automated driving (R)

Spatial impacts are changes caused on spatial elements by external developments. *Spatial* is a term that relates to space. *Spatial elements* exist in our surroundings as built environment. Example buildings, roads, people, parks. The distribution of such spatial elements, called *spatial distribution*, refers to how the space is occupied by various spatial elements. In this research, spatial distribution refers to land use characteristics such as density of spatial elements.

Literature from (Shaheen & Cohen, 2013) reveal that not only can vehicle automation be beneficial but can also change the way we live, the location where we live, shop and work. Such changes to origin and destination locations could subsequently cause changes to urban spatial elements. For instance, new parking facilities maybe required to be planned at specific nodes to accommodate fully automated vehicles serving passengers around the block in the city. This could mean that one can anticipate spatial changes due to automated vehicles (Correia et al., 2016).

Sharing in mobility is expected to reduce the number of vehicles needed to service the mobility demands. Research shows that in a highly sharing economy, 10% - 30% of today's number of vehicles are sufficient to provide the current level of mobility in Lisbon, Portugal (International Transport Forum, 2015). Further, vehicle automation could enhance sharing. Sharing could also influence land use. High levels of sharing and services like Mobility as a Service (MaaS) could discourage people from owning a car. This could induce spatial impacts on requirement of parking spaces.

This research focuses on exploring spatial impacts – changes in land use such as relocation possibilities, parking, and urban redesign of transport elements such as park and ride (P+R) facilities on dense urban regions due to effect of vehicle automation and sharing.

1.1 Problem statement

There exists a strong relation between land use and transport on each other (see Figure 2(L)). This doctrine has held the basis for spatial planning in many research works (Wegener & Fürst, 1999). Automated driving is considered to be the next biggest technological advancement in the field of transport since the last century (Milakis, Van Arem, & Van Wee, 2017). Hence changes in transport is expected to influence land use. The effect of change in land use in urban regions is concerning as urban regions are usually complex, dense thus making it difficult to estimate the impacts. Furthermore, urban regions are constrained by availability of space to enable changes to existing spatial elements defining urban form.

One of the common transport problem faced in cities is parking. The average parking search time varies from 3.5 to 14 minutes and the average share of traffic cruising for a parking spot is recorded to be 30% in the US (Shoup, 2006). Similarly, cities face congestion, safety problems that automated driving technology may solve. The expected benefits of automated driving are huge to ignore (Alkim, 2016). Hence, it is important to be aware of the spatial impacts that automated driving can bring to cities. A holistic system-wide impacts expected from automated driving is visualized by (Milakis et al., 2015) as the ripple effect of automated driving (Figure 2(R)).

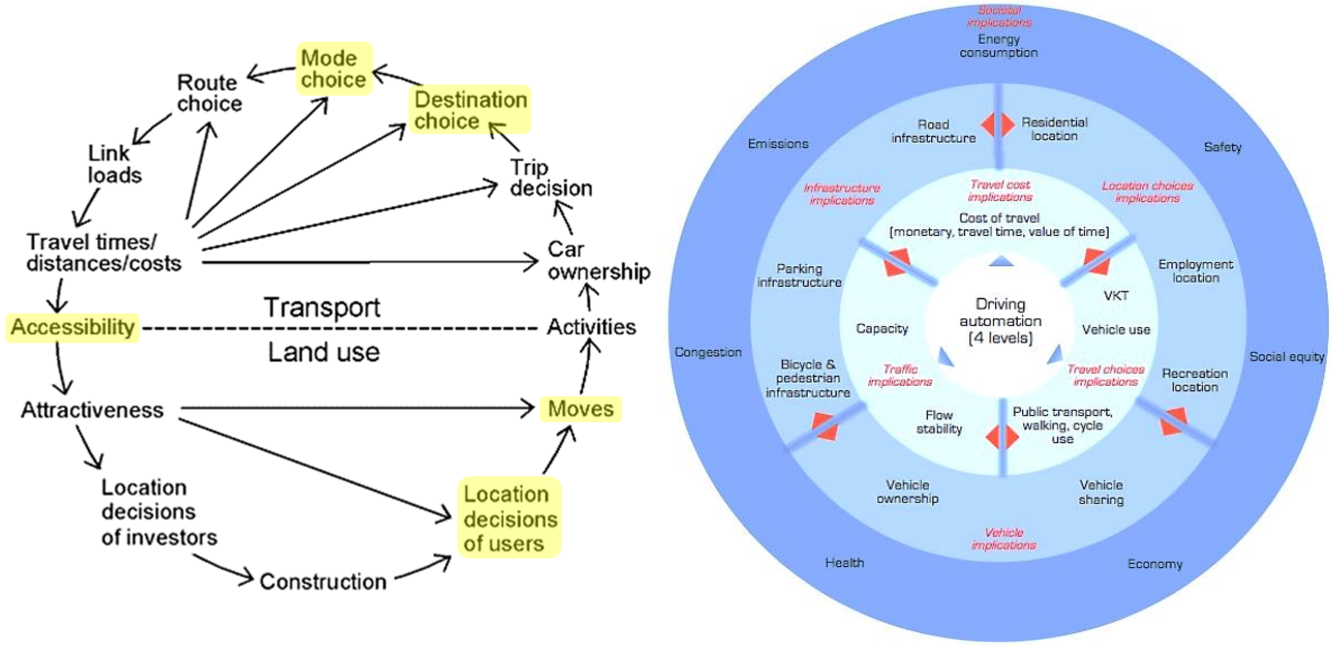


Figure 2 The land use transport feedback cycle (L), (Wegener & Fürst, 1999), The ripple effect of automated driving (R) (Milakis, Van Arem, & Van Wee, 2017)

1.2 Research question

The objective of this research is to identify the spatial impacts of automated vehicles and to explore to what extent do automated vehicles spatially impact urban regions. To achieve this goal, firstly, factors influencing the spatial distribution will be identified followed by analyzing the extent of influence of factors. By subjecting the factors to scenarios, the factors impacting spatial form and spatial elements will be explored. The research question is

To what extent does vehicle automation and sharing influence urban regions in the Netherlands?

This research question may be answered through the following sub-research questions

1. *Through which causal paths do vehicle automation and sharing influence spatial elements?*
2. *Which are the most important factors in the identified causal paths?*
3. *Which factors are uncertain and sensitive in these causal paths?*
4. *To what extent do the changes in vehicle automation and sharing influence spatial elements?*

Research motivation

1. Literature gap

There is very limited literature on exploring spatial impacts of vehicle automation and sharing, jointly, in urban regions. In 2015, OECD study on mobility impacts of AV for Lisboa, Portugal, revealed that AV car sharing can reduce the number of cars required to just 10% of current use (International Transport Forum, 2015). Similar calculation results were found in research papers of (Bischoff & Maciejewski, 2016) for Berlin. However, these studies reflect mainly on mobility impacts. Despite numerous researches on exploring the plausible impacts of AV, some research concludes that research on impacts of AV on urban traffic environment is missing (Correia, Milakis, van Arem, & Hoogendoorn, 2016). A recently published report by Boston Consulting Group on the impacts of self-driving vehicles for Amsterdam city, reveals that designing still needs scientific basis (The Boston Consulting Group, 2016). Hence, there is a need for research with solid basis on not only exploring spatial impacts but also finding the extent of impact of AV on urban regions. Furthermore, this research also sheds light on impacts of automated freight vehicles on urban regions.

2. Research approach

This research aims to explore the spatial impacts of vehicle automation and sharing for future cases through a multi-disciplinary multi-perspective approach. It is not a straight forward approach to estimate the future accurately, however by representing future cases through scenarios, a better sense of accuracy can be achieved. Moreover, better understanding of spatial impacts and quality of research can be attained by exploring the scenarios through multi-disciplinary multi-perspective approach. This research uses fuzzy cognitive map (FCM) based scenario planning approach to address the research topic. This research is also one of the first to use FCM based scenario planning approach in the field of transport planning (Vogt, Wang, & Bettinardi, 2015). Relevance of using FCM as research methodology in this explorative research is explained in chapter 2 - Research methodology.

3. Timely question

The Dutch government is the first in Europe to sign the declaration of Amsterdam on cooperation in the field of automated and connected driving on April 14, 2016; which enables to devise rules and regulations to allow automated vehicles to be used on roads in Europe. The city government of Amsterdam wishes to explore the opportunities, impacts and vision for automated vehicles to (1) strategize infrastructure planning, land use and transport policies, (2) and because of its relevance for society.

Thus, to summarize,

1. There is a need for research to explore the spatial impacts.
2. This research attempts to explore the spatial impacts in a multi-disciplinary multi-perspective approach through fuzzy cognitive map modelling technique for passenger and freight modes.
3. Timely research to explore the spatial impacts of vehicle automation on urban regions.

1.3 Research scope

The scope of this research can be best visualized as in Figure 3. The research project is bound by the following:

1. System boundary:
   This research implements multidisciplinary multi-perspective approach in gaining knowledge on spatial impacts of AV thus capturing the cause and effect relationship in a holistic view. This is through interview of experts from different backgrounds of expertise. On this attempt, internal factors that exert a direct and transparent influence on the system of spatial impact is considered. External influencing factors such as economic growth, employment rate is not considered in the system scope.

2. Time scale:
   This research aims to develop scenarios for medium-long term perspective.

3. Transport type:
   This research considers passenger and freight transport in the system. Passenger modes cover personal transport mode – cars, bicycle, walking and public transport – buses and trams, trains. Freight transport vehicles considered are – trucks, small electric AV trucks.

4. Spatial impacts:
   Spatial impacts are changes caused on spatial elements by external developments. In this research, relocation of residents, companies, retail, parking facilities, changes in land value, transfer nodes and park and ride facilities, spatial social interaction spots, and accessibility are the spatial elements that will be researched and explored.

5. Scenarios:
   In this research, level of automation is classified into two categories: high automation and low automation. High automation encompasses SAE automation levels 4 and 5 while low automation comprises SAE automation levels 2 and 3. This research is aimed to test scenarios for exploring the impacts based on level of automation and degree of sharing. Namely: High automation high sharing, high automation low sharing, low automation high sharing, and low automation low sharing.

6. Geographical scope:
   An urban region in the Netherlands that has complex traffic characteristics will be used as a user case to model the impacts of vehicle automation and sharing.

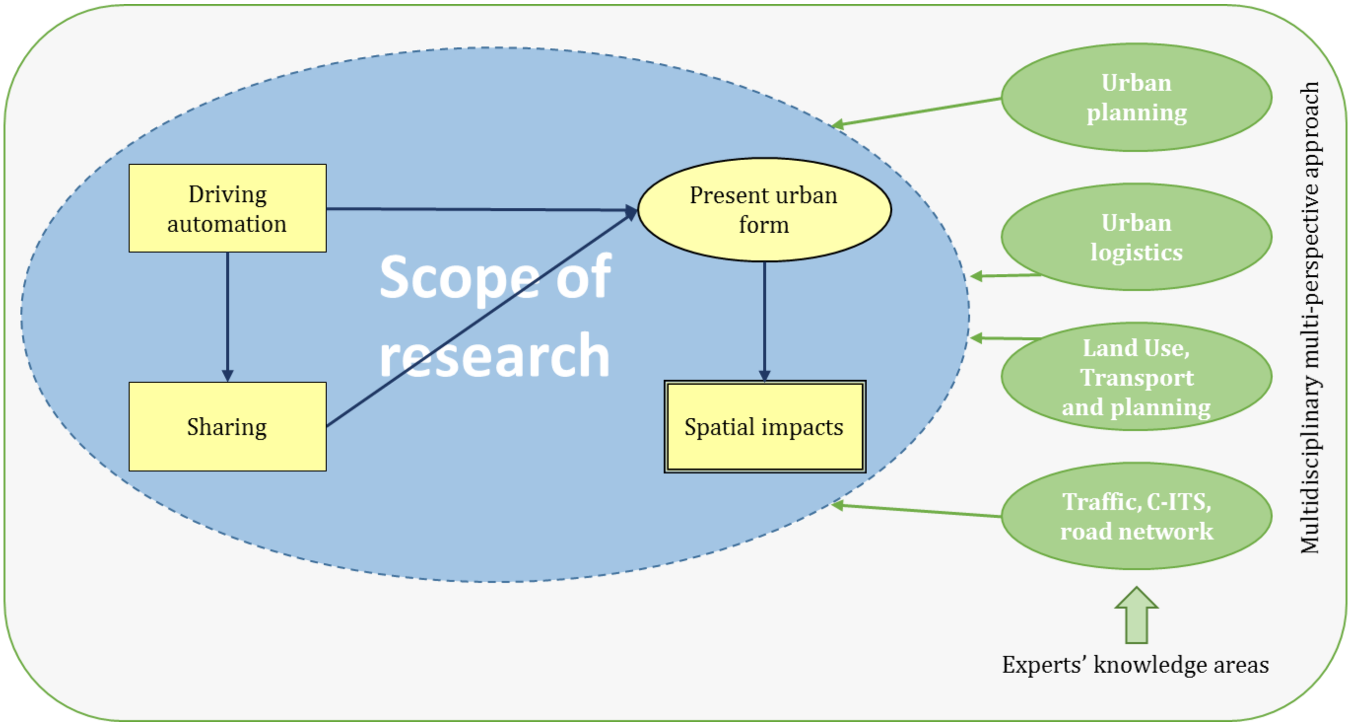


Figure 3 Scope of research with approach (Source: own)

2 Research methodology

Research methodology is the process followed to achieve the research objectives defined in this explorative study. This chapter provides an introduction to scenario planning approach and details why FCM is applied as the research method in this study in section 2.1. This is followed by explication of the 5-step FCM framework in section 2.2. Each step of the framework is detailed in the subsequent subsections. This chapter aims to provide the reader enough knowledge about the FCM methodology used in this research.

2.1 Introduction to scenario planning and FCM

Usually planning beforehand helps to overcome uncertainties while executing an event. *Scenario planning* simplifies the number of what–if scenarios while it considers most of the variable elements that influence the environment of an event. Moreover, it also conveys how various elements could interact with other elements under certain conditions (Schoemaker P. J., 1995). In contrast to traditional planning, scenario planning enables to explore complex environment with many uncertain variables (Schoemaker P. J., 1991) while ensuring the system is internally consistent thus providing rich picture and enabling informed decisions.

Scenarios are a result of scenario planning techniques. Scenarios are built in order to be educated about possible outcomes of the uncertain nature of future (Porter M. , 1985). A scenario is an internally consistent view of possible future situation. It is not a prediction, rather, it is a range of plausible situations that are likely to occur. Scenarios help to innovate the future by breaking down the scope and providing insights on near term, medium term and long term planning. Hence, there is a potential to innovate for solutions depending on temporal requirement (Hiltunen, 2009).

Scenario planning can be exercised by many techniques. Sometimes, combination of scenario planning techniques can be used in a methodological process to perform desired analysis. Selecting a scenario planning technique depends on variety of factors – the requirement of extent of normative-ness of scenarios, timescale – short term planning or long term planning, spatial scales of view, method of data collection and availability (Van Notten, Rotmans, Van Asselt, & Rothman, 2003). There are many scenario planning techniques available. A tool box of popular scenario planning techniques is shown in Table 2. In this research, Fuzzy Cognitive Mapping (FCM) tool is used. A detailed description of these techniques can be read at Annex 1: Scenario planning methods.

There already exist various studies on scenario planning of automated vehicles that uses qualitative approach such as intuitive logics (Milakis, Snelder, van Arem, van Wee, & Correia, 2017). However, numerical data does not exist to create future scenarios based on quantitative approach. Qualitative approach can be combined with quantitative approach to overcome the shortcomings of quantitative approach (Kosow & Gassner, 2008).

	Intuitive logics	INTERAX (Interactive Cross Impact Simulation)	MORPHOL	Trend Impact analysis (TIA)	Interactive Future Simulations (IFS)	Fuzzy Cognitive Mapping (FCM)	Cross Impact Analysis (CIA)
Purpose	Ranging from one time research to developing strategy	One time activity - explorative estimation and policy evaluation	Usually one time activity - developing effective policy and strategic decisions	One time activity - explorative estimation and policy evaluation	One time activity - explorative estimation and policy evaluation	One time activity – explorative estimation, scenario building and strategic decisions	One time activity - explorative estimation and policy evaluation
	Long term planning, follows disciplined intuition from narratives to produce equally plausible scenario alternatives	Long term planning, Simulation model using Monte Carlo simulation, incorporates CIA	Long term planning, morphological analysis	Historic data extrapolation with probabilities	Simulation model, incorporates CIA	Medium and long term planning, iterative model, incorporates CIA	Captures interrelationship between influencing factors, incorporates conditional probability
Scope	Descriptive or normative	Descriptive	Descriptive	Descriptive	Descriptive	Descriptive	Descriptive
Type	Qualitative	Quantitative and qualitative	Quantitative	Quantitative	Quantitative	Qualitative and quantitative	Quantitative
Advantages	Can develop flexible and internally consistent scenarios, not restrained by lack of quantitative data	Provides opportunity to see simulation result and change data to develop scenario in addition to advantages of CIA	Can be used for complex problems that cannot be solved with mathematical methods	Combines statistical forecasting with probability, considers qualitative factors	Encourages contingency planning	Captures indirect effects, results in more robust scenarios, provides multi-perspective holistic view	Can be incorporated in other scenario development methods, stimulates new ideas

Table 2 Comparison of popular scenario planning methods assimilated from (Amer, Daim, & Jetter, 2013), (Bradfield, Wright, Burta, Cairns, & Van Der Heijden, 2005), (Ritchey, 2003), (Enzer, 1981)

The FCM method provides the freedom to build scenarios with qualitative storylines and quantitative fuzzy logic data (van Vliet, Kok, & Veldkamp, 2010). Such a research technique is scenario based fuzzy cognitive mapping (FCM) - a semi-quantitative conceptual model (see Figure 4) (Van Vliet, 2011). Qualitative approach is best advised for projects with large scope and long term planning whereas quantitative approach is better suited for short term and medium term planning (Kosow & Gassner, 2008).

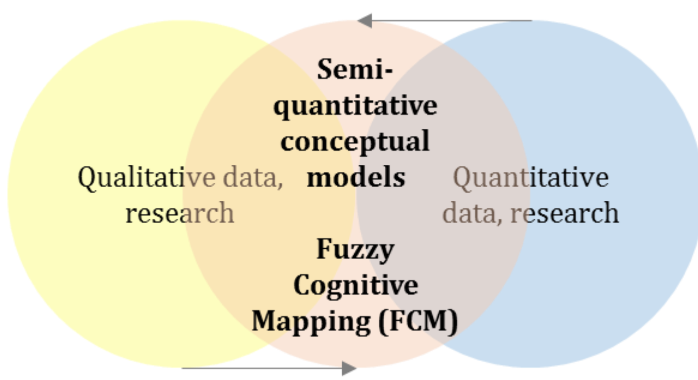


Figure 4 FCM - a semi-quantitative conceptual model (Source: own)

FCM is an extension of cognitive map invented by Kosko (Kosko, Fuzzy cognitive maps, 1986). Cognitive map represents the expert-created system comprising nodes and arrows. The nodes denote concepts and arrows denote the relationship between the concepts. It helps understanding interrelationships and likelihood between various concepts. Since these models are created by experts, there could exist diverse number of models depending on the expertise of the expert and topic of focus. The FCM method adds fuzzy values, discrete values in the range of -1 to 1, to the cognitive maps thus quantifying the concepts and their relationships through weights (Kosko, Fuzzy Engineering, 1997). An example of fuzzy cognitive map is shown in Figure 5. As FCM fosters system thinking, construction of such maps provides a holistic view of the entire system, helps identifying key issues and explore alternative futures (Jetter & Schweinfort, 2011).

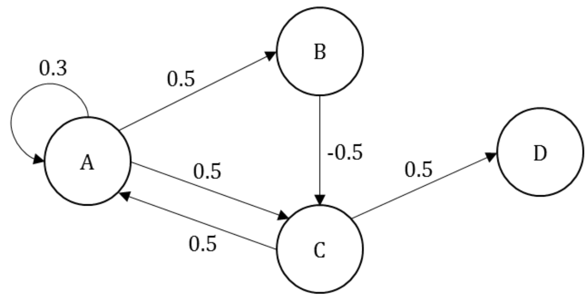


Figure 5 An example of a fuzzy cognitive map (Source: own)

<u>Relevance of FCM to this research</u>

In this research, FCM based scenario planning approach is used to explore the spatial impacts of vehicle automation and sharing on urban regions in the Netherlands. FCM is ideal for this research especially because of its methodology type that allows to identify issues and explore alternative futures. In this society of constant change and innovation, the defined research objectives can be explored by identifying key concepts. The advantages, 1. the ability to integrate fuzzy logic with qualitative storylines yielding to better quality of result (van Vliet, Kok, & Veldkamp, 2010), 2. ability to research possible futures where no straight forward data is available, makes it attractive to be used in this research. FCM allows testing conditional scenarios. This makes it ideal to test scenarios for varying levels of automation and degrees of sharing. The system considered for scenario development is often complex and consists concepts that are indirectly interrelated. This is captured in FCM as it incorporates cross impact analysis.

Though FCM is a new approach in scenario development (Amer et al., 2013), it is being applied in variety of fields like energy sector, environment, water and soil (Kok, 2009) (Jetter & Schweinfort, 2011) (Mouratiadou & Moran, 2007). This is one of the first research to use FCM in the field of transport planning for exploring spatial impacts of future transport and mobility.

2.2 FCM framework

FCM adopts a "participatory scenario development framework" (van Vliet, Kok, & Veldkamp, 2010). This research follows a mix of frameworks suggested in literature (Jetter & Kok, 2014), (Jetter & Schweinfort, 2011) and taking into consideration the practical constraints. The amendment made to the FCM framework is mostly resequencing of the sub-steps, which is not restricted (Jetter & Kok, 2014). Figure 6 shows the 5-step framework followed in this research.

In brief, the framework of fuzzy cognitive mapping (FCM) approach includes 5-steps namely 1. scenario preparation, 2. knowledge capture, 3. data validation and FCM modelling, 4. standardization and combined map, and 5. Result analysis and validation. The sub-sections below provide detailed explanation about the steps, sub-steps along the flow of arrows exposing the feedback loops in this framework.

2.2.1 Step 1: Scenario preparation

This step is a preparatory step to acquire input data for scenario analysis. Scenario preparation contains three sub-steps that aims to have clarity on research objective, conduct literature study on the relevant topics and create mental map to help understand the researcher and the interviewees about the research focus.

2.2.1.1 Research objective

The first sub-step *Research objective* aims to gather clarity on research topic. Clear and well defined research questions after consulting state of the art developments in the field can help to reduce ambiguity and help obtain quality input data for scenario analysis. Defining *research objective* for experts is critical as it highly influences the knowledge input from expert. The research objectives should be stated in such a way that the expert's perception of key issues does not differ from desired topic (Jetter & Kok, 2014). The objective of this research is to *explore the spatial impacts of vehicle automation and sharing on urban regions in the Netherlands*.

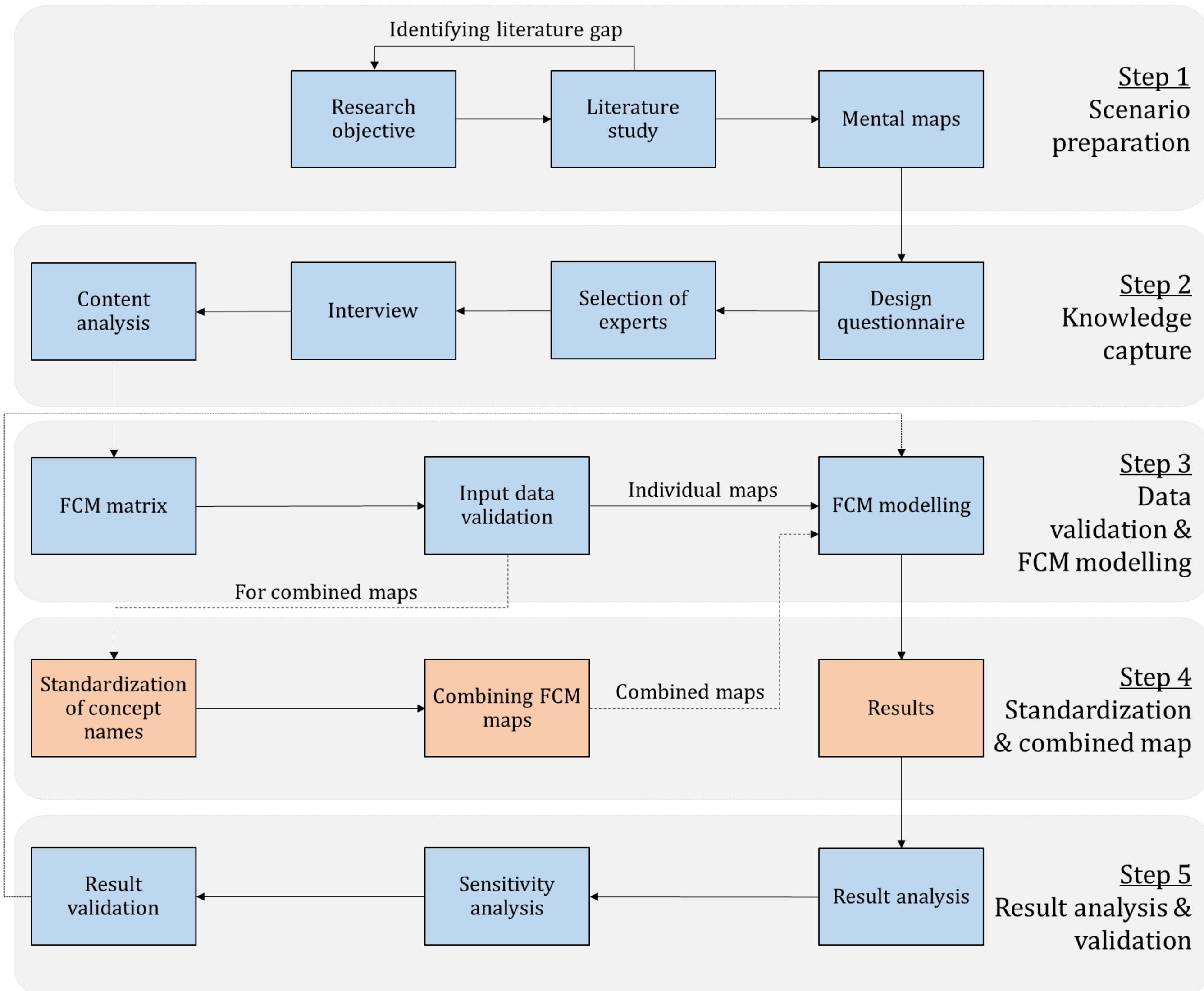


Figure 6 FCM framework adapted from (Jetter & Schweinfort, 2011), (Jetter & Kok, 2014)

This can be achieved through fuzzy cognitive maps devised by experts. To create a quality and robust map, it is necessary to educate the experts about land use transport interaction, the driving capability of automated vehicles on mobility and explaining the concept of car sharing apart from FCM technique itself. Further, the spatial impacts can range over various areas and spatial levels. Hence a literature study of the above-mentioned themes is carried out and represented in a rough mental map.

2.2.1.2 Literature study

The second sub-step *literature study* encourages the researcher to acquire deep scientific knowledge and developments in the study area. *Literature study* helps support the process of framing a well-defined research objective and provide scientific basis for preparing mental maps. The sub-steps literature study and research objective are dependent on each other. Literature study depends on the objectives that are to be researched. Supporting scientific knowledge from literature study may reveal identification of literature gap or sometimes cases where the topic has already been researched through a specific method. These kinds of constraints lead to adjustment of research objective, hence the feedback loop.

Literature study on spatial impacts of vehicle automation on transport modes (automated car, public transport, freight vehicles) helps create mental map and pool of factors that are relevant to identify spatial impacts. Firstly, Table 3 shows automated vehicles and its characteristics on environment (ERTRAC, 2015). This helps the experts to understand the type of modes and their driving capabilities. Passenger and freight transport are taken into consideration in this research. SAE level of automation is used as reference. SAE level 3 is considered to be low automation, SAE level 4 is considered to be high automation whereas SAE level 5 is considered to be full automation.

Automation level/ Type	**SAE level 3 (low automation)**	**SAE level 4 (high automation)**	**SAE level 5 (full automation)**
Technology	Highway chauffeur, traffic jam chauffeur	Parking garage pilot, truck platoons	Robot taxi, truck platoons
Passenger mode characteristics	Highway chauffeur: car	Automated shuttles (last mile), buses, limited parking automation	Fully automation without driver intervention
Freight mode characteristics	Highway chauffeur: truck	Truck platooning, last mile-urban freight delivery vehicles	Fully automation without driver intervention
Environment	Limited sections: highways	C-ITS, controlled environment: highway/urban	Anywhere

Table 3 Implications of vehicle automation on passenger and freight transport modes adapted from (ERTRAC, 2015)

Secondly, Table 4 shows the relevant areas of impacts identified through literature research and interviews with experts (Van Nes, 2016), (Van Wee, 2016). The impacts are identified on various areas because these factors could have indirect relation to spatial impact. The purpose of presenting these impacts to the experts is to provide them an idea of the kind of impacts being researched and encourage creative thinking of factors that are not listed, thus developing a robust fuzzy cognitive map. Most of the identified factors is based on Wegener's land use-transport feedback cycle, which forms the backbone of literature study.

Literature	**Area**	**Relevant factors**
(Wegener & Fürst, 1999)Land-Use Transport Interaction: State of the Art	Land use transport interaction (LUTI)	Transport modes, travel time, travel cost, travel effort, accessibility, relocation factors, origin destination relocation
(SAE International, 2016)Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems, (ERTRAC, 2015)Automated driving roadmap	Driving automation	Level of automation
(KiM Netherlands Institute of Transport Policy Analysis, 2015)Driver at the wheel?	Car sharing, Driving automation	Degree of sharing, level of automation

(Cervero & Tsai, 2004)City Car Share in San Francisco, California: Second-Year Travel Demand and Car Ownership Impacts	Car ownership	Travel cost
(Barth & Shaheen, 2002)Shared-use vehicle systems: Framework for classifying car sharing, station cars, and combined approaches		Car ownership, demographics Parking space
(International Transport Forum, 2015)Urban Mobility System Upgrade: How shared self-driving cars could change city traffic	Car sharing	Vehicle kilometers travelled Multi-nodal shared-use vehicle systems, last mile connectivity Reduction in number of cars, car travel, reduced parking requirement
(Cepolina & Farina, 2014) A methodology for planning a new urban car sharing system with fully automated personal vehicles	Mobility	Level of Service, punctuality, comfort, reliability
(Graduate school of Stanford Business, 2016) White paper on technological disruption and innovation in last-mile delivery	Mobility, Last-mile	Last mile connectivity, freight
(Kamargianni, Li, Matyas, & Schäfer, A Critical Review of New Mobility Services for Urban Transport , 2016)A Critical Review of New Mobility Services for Urban Transport	Mobility as a Service (MaaS)	Mobility as a Service (MaaS), Information and communication technologies (ICT)
(Sivak & Schoettle, 2015) Influence of current non-drivers on the amount of travel and trip patterns with self-driving vehicles	Travel pattern	Trip length, possible increase in travel demand, increase in number of car trips
(Litman, 2014)Autonomous Vehicle Implication Predictors: Implications for Transport Planning	Traffic, Road infrastructure	Congestion, safety, driving comfort, increased road capacity, efficient parking, reduced pollution, ITS,
(Meijers & Burger, 2010) Spatial structure and productivity in US metropolitan areas	Spatial characteristics	Suburbanization (urban sprawl), spatial structure (urban form),
	Spatial level - Zones	City center, municipality, metropolitan area, regional level
(Petersen, 2004) Land Use Planning and Urban Transport	Spatial – transport infrastructure	Ring roads, motorways, transition zones - on/off ramps
	Spatial elements	Green spots - parks, social spaces – restaurants and square, retail space, office space, residential area
(Geurs & Van Eck, 2001) Accessibility measures: review and applications	Transport and land use Accessibility	Residential (origin), office and retail (destination) relocation. Relocation of urban freight

		consolidation and distribution centers, factories. Land value.
(Townsend, 2014) Re-programming mobility	Infrastructure constraints, accessibility	Urban redesign, pick up/drop off points,
(Levin & Boyles, 2015) Effects of Autonomous Vehicle Ownership on Trip, Mode, and Route Choice	Transport policies	Empty trips, parking fee, car-free city center, electric vehicles
	Trends Innovative disruptions	Lifestyle trends, flexible working hours, work from home, online shopping

Table 4 Literature study on relevant factors for spatial impacts

It is to be noted that factors for relocation of origin destination relies on various factors such as rent, land value, availability of land, quality of surrounding environment, accessibility, and agglomeration factors (Koster, 2013). This research does not focus in detail on land use economics that are largely related to spatial relocation. However, a factor denoting change in land value is indicated as an overall measure.

2.2.1.3 Mental maps

Mental map is the third sub-step in scenario preparation process. Mental map is form of visual representation of concepts and scenarios related to research area. The idea is that visual representation of research related concepts, objectives, ideas can help the researcher and the interviewees to understand the system scope, system boundary and concepts to focus on. The *mental map* created from literature study can be found in Annex 2: Mental map.

2.2.2 Step 2: Knowledge capture

Knowledge capture is the second step of FCM framework. In this research, this step contributes to acquiring input data for scenario analysis. While Step 1 focusses on the question, "What input data is required?", the four sub-steps in Step 2 answer the questions "how to collect the input data?" and "from whom to collect the input data?".

The main objective of this step is to capture knowledge from experts in the form of interviews and fuzzy cognitive maps. Generally, knowledge elicitation from experts can be done by different ways: from questionnaires, content analysis, through interviews (Aura Din & Moise, 2012). In this research, questionnaires are used to assist interview process. This step, knowledge capture, comprises 4 sub-steps. Firstly, to design a questionnaire simultaneously selecting experts. Once the experts are selected, interview is carried out resulting in development of fuzzy cognitive maps followed by content analysis as shown in Figure 7. Each sub-step is explained in detail below.

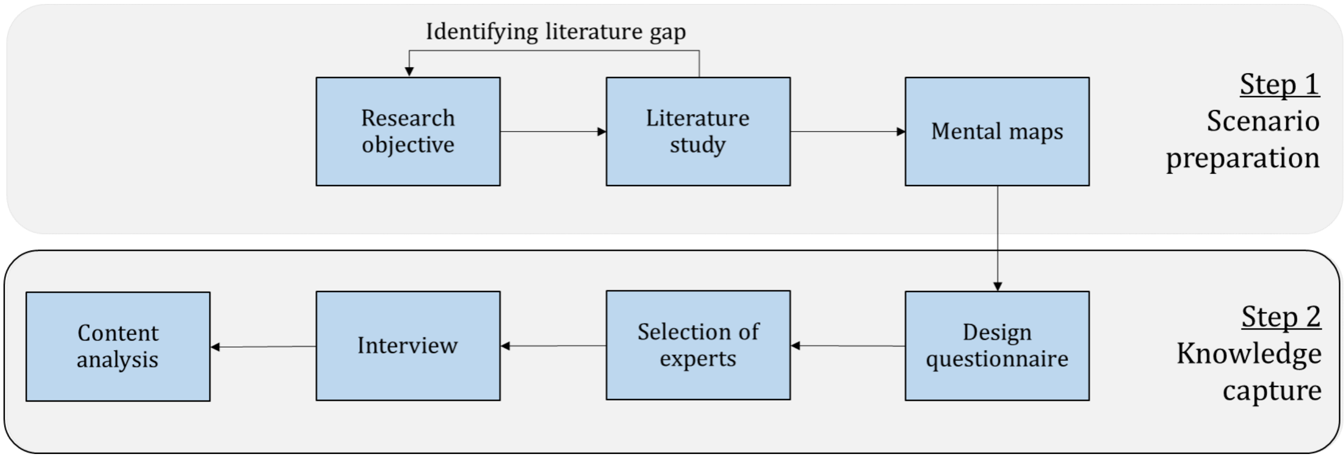


Figure 7 Step 2 - Knowledge capture of FCM framework and its sub-steps

2.2.2.1 Design questionnaire

The first sub-step *Design questionnaire* follows the process of creating mental maps. Questionnaires can be helpful to guide interviews in a structured approach. FCM literature encourages questionnaires to be designed such that it supports and facilitates expert thinking, sprouts creativity, explores uncertainties, and finally obtain expert-drawn fuzzy cognitive maps (Jetter & Kok, 2014).

Questionnaires are means of participatory approach, to obtain data in a short period. The questionnaire comprises four parts. First, an introduction of research objectives and process of how to achieve the goal is stated. Secondly, a short introduction on FCM technique and an example of fuzzy cognitive map is described. This helps the experts to be familiar with the FCM process. The third part comprises information on automated vehicles – level of automation, benefits of AV, scenario assumption and implication of driving automation on transport modes. The fourth part comprises the factor pool and urges experts to choose key concepts by narrating relationship between factors. This also captures the weights of concepts that signifies the importance of the concept. The procedure intended while interviewing experts with questionnaire is to first discuss the factors in the pool and then choose factors that can be used to build the fuzzy cognitive map (Özesmi & Özesmi, 2004). Factor pool created from mental map and literature enables faster development of cognitive maps. The questionnaire can be found in Annex 3: Questionnaire**.**

2.2.2.2 Selection of experts

The second sub-step *selection of experts* involves the process of choosing the right experts to be interviewed to acquire the required input data. In this research, the aim is to address the research objectives from a multi-disciplinary multi-perspective approach. Selection of experts is an important process in this research as the raw data for modelling and generating scenarios is obtained from the experts. Hence, the experts chosen should have sound knowledge and rich experience. The statistics of chosen experts and their expertise can be found in chapter 3 section 3.2.1 Selection of experts**.**

2.2.2.3 Interview

Interview is an important sub-step of FCM framework, that enables to obtain input data in the form of fuzzy cognitive map for scenario modelling. The third sub-step is a face to face interview with expert that facilitates collecting and bridging qualitative and quantitative data. Questionnaire and mental map support interviews encouraging experts to think in a plausible and out-of-the-box approach in anticipating future scenarios. Moreover, interviews facilitate collecting, and bridging qualitative and quantitative data.

The interview process can be classified into 5-step process as shown in Figure 8. The interview process is obtained by taking the best techniques from (Özesmi & Özesmi, 2004) and (Aura Din & Moise, 2012), kept in mind the practical constraints.

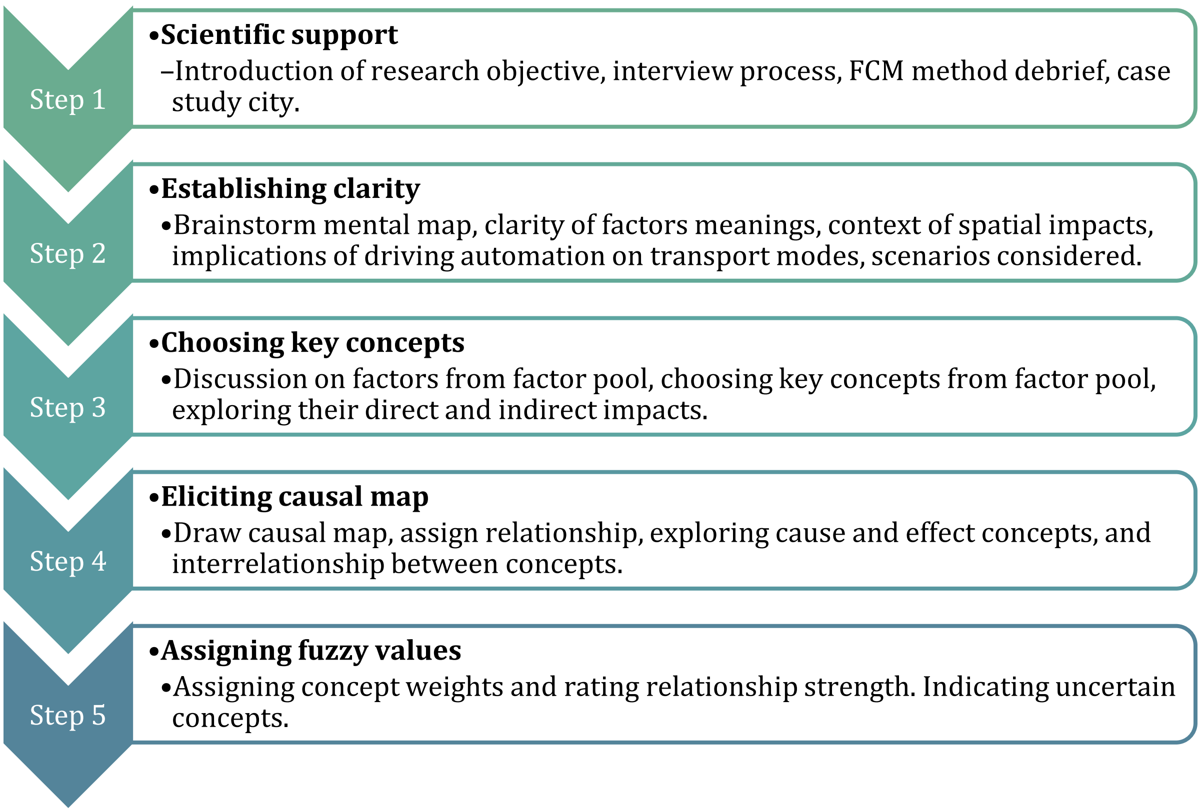


Figure 8 Interview process assimilated from (Özesmi & Özesmi, 2004) and (Aura Din & Moise, 2012)

The *first step* of interview process is to provide scientific support to the experts. The experts need to be introduced to the research objective and clarify the scope of the research. The experts also need to be briefed about the interview process itself. Further, it is important to make sure the experts understand the FCM research method and its process used in this research and how their input can be valuable. In this step, the experts should be briefed about the case study and scope that is considered in this research.

The *second step* of interview process focusses on establishing clarity for the experts. The mental map created from literature review should be discussed with the experts to give them a sense of reference to what the research scope entails. At this point, it is also important to clarify the context of terms used such as spatial impacts itself. This applies especially to the factors listed in the factor pool. Discussion on scenarios considered in this research can help experts understand the scope and aim of the research. Through this step, it is important to ensure that the expert and the interviewer (in this case, the researcher – the author of this research) are on the same page.

In the *third step*, the goal is to discuss the factors and their cause and effect relation leading to experts choosing key concepts that influence the system. This can be accomplished by asking open-ended questions to the experts. The open-ended questions are directed towards factors identified in mental map and factor pool to reason the cause and effect relationship between the factors (Özesmi & Özesmi, 2004). The experts should be encouraged to be creative in their thought process and identify concepts of their own if they feel it is an important concept. The term *concept* is used to denote the key factors chosen by the experts. This step leads to qualitative narration of expert's knowledge.

The *fourth step* involves experts to draw causal maps with the chosen concepts. It is recommended to use large sheet of paper to facilitate experts to draw causal map. To draw a causal map, the concepts are first written on paper followed by connecting them with arrows. A detailed map is created by questioning the cause-and-effect of each chosen concept and their interrelationship. *Causal maps* are visual maps that represent the relationship between nodes (in this case - concepts). Next, the experts are asked to assign the relationship (arrows) between concepts. For instance, consider concepts C_1 and C_2, with arrow from C_1 to C_2 as shown in Figure 9. If "+" is assigned on the arrow, it implies that an increase (or decrease) in C_1 causes an increase (or decrease) in C_2. In case of "–" being assigned, it implies that if C_1 increases then C_2 decreases or vice versa.

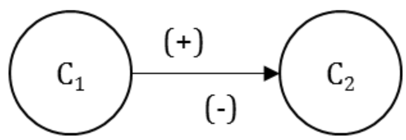


Figure 9 An example of relationship between concepts (Source: own)

The fifth step involves experts to rate the arrows (relationship between concepts) and assigning fuzzy weights to concepts and arrows. *Fuzzy weights* in FCM are discrete numerical values with a specific range. The concepts can be assigned weights within the range of 0 to 1, where 1 represents highest degree of expert confidence, importance on concept while 0 represents lowest degree of expert confidence, importance on a concept.

The arrows can be rated within the range of -1 to 1. For simplicity, the rating scale is represented as --, -, 0, +, ++, see Table 5. The purpose of the rating scale is to help experts to rate easier and faster. To rate arrows by rating scale is optional. Experts are encouraged to use values between -1 to 1 if they wish to provide distinguished rating, example 0.3, -0.7. Sometimes experts were unsure about the rating, which describes strength of relationship between two concepts. Under such cases, sensitivity analysis is conducted by varying rating to the extremes during FCM modelling. These results are again sent to experts as a part of model validation process.

The end of the interview process is when the experts have nothing more to add to the cognitive map (Özesmi & Özesmi, 2004). The outputs of this sub-step are interview transcripts and fuzzy cognitive maps, which is the input for scenario analysis. The interview transcripts may be found in Annex 4: Interview transcript

Rating scale	Denotation	Numerical equivalent
--	Double minus represents strong negative influence.	-1
-	Minus denotes medium negative influence.	-0.5
0	Zero implies no relationship between concepts.	0
+	Plus denotes medium positive influence.	+0.5
++	Double plus represents strong positive influence.	+1

Table 5 Explanation of rating scale and numerical equivalent

The advantage of face to face interview is that it allows to capture complete knowledge of expert, without having any disagreements or interference. Thus, has allowed to capture controversial opinions (Jetter & Kok, 2014). While the disadvantage is the amount of time required to coordinate and conduct interviews with each expert, travel time, time to draft interview transcripts and the time on awaiting reply from experts through email. An example of fuzzy cognitive map resulting from this sub-step is shown in Figure 10

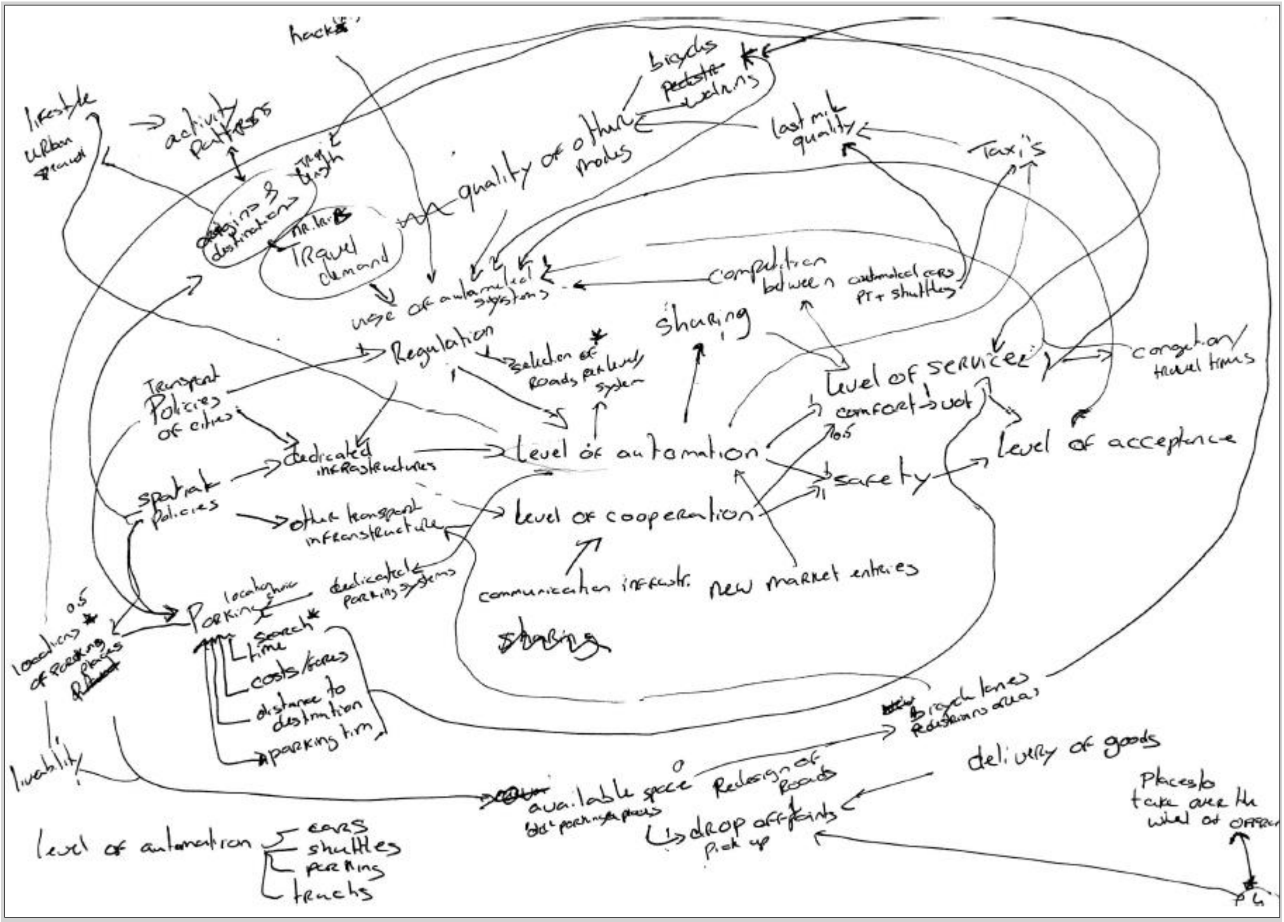


Figure 10 An example of interview output - fuzzy cognitive map

2.2.2.4 Content analysis

Content analysis is a process of analyzing written text to draw cognitive maps. It can also be used to capture concept meanings as defined by experts and develop incomplete fuzzy cognitive maps. *Content analysis* is the fourth sub-step in step 2 of FCM framework. Content analysis is a process of analyzing written text to draw cognitive maps. This sub-step helps to complete a fuzzy cognitive map, check logic of connections (internal consistency) through interview transcripts of the respective experts. It helps in clarifying concept meanings defined by experts. This sub-step may lead to identification of new concepts that the experts wishes to add to the fuzzy cognitive map. The expert can agree or disagree to add the suggestions to the map.

It should be ensured that the concept stated by experts convey the right meaning and is understood by the researcher in the right context. If not, the concept terminology should be made explicit to avoid confusion in understanding the context. The fuzzy cognitive maps can be digitalized which may help to perceive the concepts and their relations with minimal clutter leading to better understanding of the system. Content analysis involves checking the maps for internal consistency. The internal consistency of fuzzy cognitive map can be checked by analyzing the connections between concepts. The fuzzy cognitive map is built by 'concept causing an effect' practice, it should also be checked if an effect can influence the cause and if contrasting relationships are present in the system. Here, *system* refers to expert created fuzzy cognitive map.

Usually one of the 3 steps of knowledge capture are followed in research (Özesmi & Özesmi, 2004), (Aura Din & Moise, 2012). In this research, 3-way knowledge elicitation is used (questionnaire, interview, content analysis) to create FCM. This is done to ensure capturing as much knowledge leading to robust fuzzy cognitive maps.

To summarize the first two steps, literature study helps create mental map and questionnaire, which in turn yields fuzzy cognitive map by interviewing selected experts. A visual summary is represented in Figure 11. It is important to note that individual interviews with each expert contributes to their own fuzzy cognitive map resulting in multiple fuzzy cognitive maps.

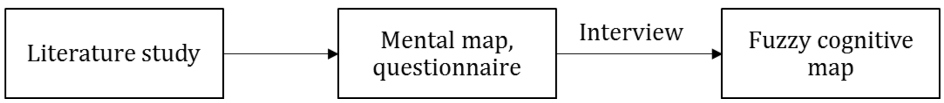


Figure 11 Main events of steps 1 & 2 of the FCM framework (Source: own)

2.2.3 Step 3: Data validation and FCM modelling

The third step focusses on data validation and FCM modelling of gathered input data. This step guides on attaining the required validated input for FCM modelling and explains the FCM modelling process itself. The complete fuzzy cognitive map resulting from content analysis in step 2 of FCM framework can be coded into FCM matrix. FCM matrix is the first sub-step in Step 3 of FCM framework. This is followed by validation of FCM matrix and fuzzy cognitive map through experts. The last sub-step leads to FCM modelling where the input data is iterated to produce results through FCM modelling. Working of FCM model, its components, formulation, and output of FCM model are discussed in this section. Figure 12 shows step 3 of FCM framework and its sub-steps. Each sub-step is explained in detail below.

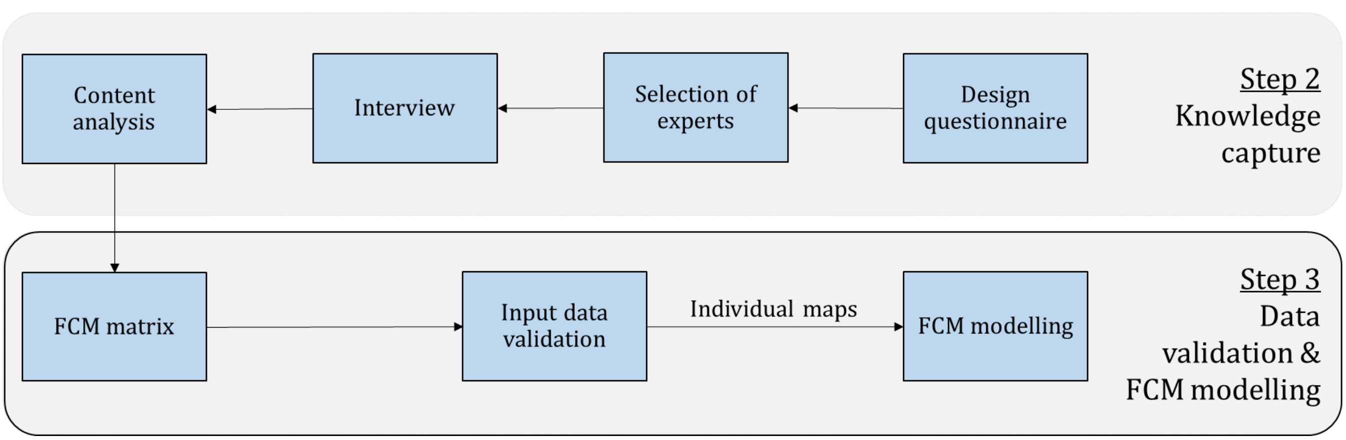
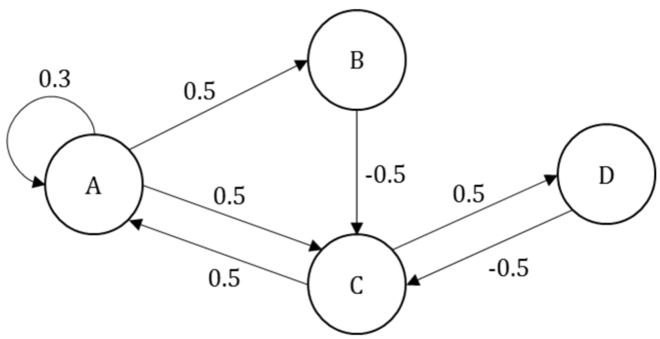


Figure 12 Step 3 - Data validation and FCM modelling and its sub-steps

2.2.3.1 FCM matrix

In literature, FCM matrix is denoted by the term "adjacency matrix". The fuzzy cognitive maps can be represented in the form of matrix that shows fuzzy ratings depicting the degree of influence of one concept over other concepts (van Vliet et al., 2010).

An example of coding a simple FCM matrix is explained based on Figure 13. First, a matrix should be created with all concepts in row and column in the same order. The number of concepts in fuzzy cognitive maps form the number of rows, columns of the FCM matrix resulting in a square matrix. The matrix should be read 'from row to column' manner. This allows coding the assigned ratings to the matrix. The coding is a manual process that can be done by following the direction of arrows and the rating value assigned over those arrows in fuzzy cognitive map and noting them in the matrix. For instance, in Figure 13, an arrow from concept A to concept B has a rating of 0.5. The corresponding cell in the matrix is filled with 0.5 which represents concept A has an influence of 0.5 on concept B. Concept B has no influence on concept A in this case. So, this is filled with 0 in the corresponding cell in the matrix.



	A	B	C	D
A	0.3	0.5	0.5	0
B	0	0	-0.5	0
C	0.5	0	0	0.5
D	0	0	-0.5	0

Figure 13 FCM matrix illustration (Source: own)

Concepts can also be assigned to have self-loops on itself. In Figure 13, concept A has a self-loop on itself with a rating of 0.3. This means concept A will exert an influence on itself at strength of 0.3. In such cases, the diagonal of the matrix carries a rating between -1 to 1 rather than zero. FCM matrix helps experts to review the rating quickly. FCM matrix forms the input for FCM modelling.

During the interview process, it is possible that the experts do not fully complete the maps. This could occur due to instances like lack of time. In such case, the incomplete relationships are marked with question mark, so that experts can fill the values during the sub-step - data validation process as explained below.

2.2.3.2 Input data validation

The second sub-step is *input data validation*. The reliability of FCM based scenario modelling relies on the quality of input data. The input data of every fuzzy cognitive map should be validated before being used for scenario modelling.

The digitalized fuzzy cognitive map and FCM matrix should be shared with the respective experts along the new concepts obtained from content analysis. This process allows the experts to fill incomplete parts (question marks), review, validate and make final changes to the input data if any. The experts should be asked to review the fuzzy cognitive map, consider the new concepts, and complete the map to their satisfaction. During this process, it is important to inform the experts that they can change the ratings and concepts that they had already assigned earlier in case they change their mind.

2.2.3.3 FCM modelling

The final sub-step of step 3 is *FCM modelling*. The validated FCM matrices, which serves as input, are modelled through FCM software “FCMappers”. The input, FCM model (blackbox) and output of the FCM model is shown in Figure 14. In brief, FCM matrix and state vector forms the input of FCM model. Running the model produces 3 outputs, structure of the FCM (influencing, dependent, important concepts), degree of impact and dynamicity of concepts. Each box is explained in detail in the subsequent paragraphs in the same sequence. FCM Output is discussed in detail in section 2.2.5 Step 5: Result analysis and validation.

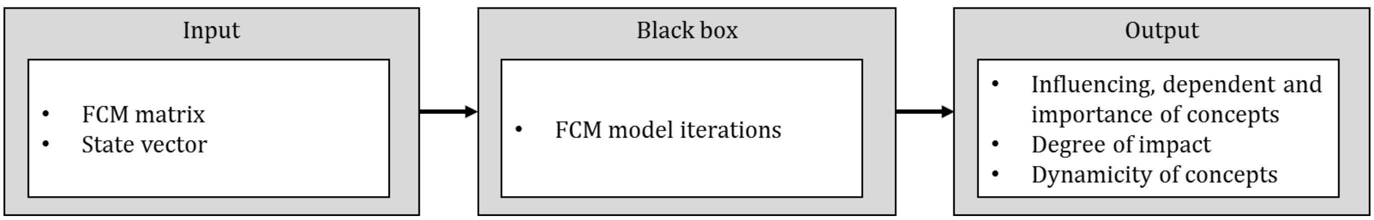


Figure 14 Input, output elements and FCM model (Source: own)

a) <u>FCM model and input</u>

The FCM model is an iterative model that allows testing scenarios producing steady-state equilibrium values for the considered fuzzy cognitive map system. While FCM matrix serves as the input to FCM model, state vector forms the scenario input that is tested through FCM model run. As FCM is an iterative model, the output is achieved when it reaches steady-state equilibrium. An overall system-view of FCM model is shown in Figure 15.

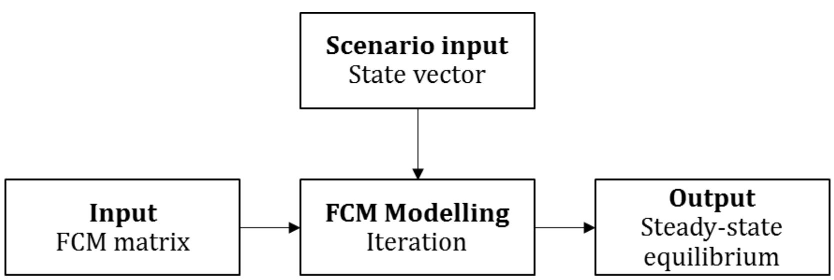


Figure 15 Overall system-view of FCM model (Source: own)

State vector is a vector matrix that takes values in the range [0,1]. Assigning values to specific concepts in state vector allows to explore the effect of that specific concept on other concepts, thus the entire system. The concept representing the scenario to be tested is assigned a value in the range [0,1] with values corresponding to remaining concepts assigned 0. FCM allows testing multiple scenarios to be impacted on the system. Thus, impact of two or more concepts can be tested on the system. Further, state vector allows to test sensitivity of any concept(s) letting observe how it reacts with the system and how system reacts to it.

This research focuses on exploring the spatial impacts of varying levels of automation and sharing (high automation high sharing, low automation low sharing, high automation low sharing and low automation high sharing). Hence, the values corresponding to concepts "level of automation" and "sharing" in the state vector are assigned non-zero values leaving the remaining concepts with zero. This allows testing the impact of those concepts on other concepts, thus the entire system. Value of 1 is assigned to measure high influence and 0.1 for low influence of the concept(s) representing scenario conditions to be tested in FCM model. An example of state vector for a hypothetical FCM matrix with 6 concepts is shown in Figure 16 for *high automation high sharing scenario*.

1	Driving automation
0	A
1	Sharing
0	B
0	C
0	D

Figure 16 Example of state vectors for high automation high sharing scenario

b) FCM model process

The process occurring during the FCM model run can be described in 5 steps.

Step 1*: Read concept rating*
Step 2*: Multiply FCM matrix with state vector*
Step 3*: State vector subjected to squashing function*
Step 4*: New state vector formed, equilibrium values calculated*
Step 5*: If state vector is different than previous iteration, go to step 2. Else stop.*

The FCM model has two inputs (i) the FCM matrix and (ii) the state vector. In the first step, the interrelationship between concepts and their strength of relationship is read from the FCM matrix. The state vector, representing the scenario, is multiplied with the FCM matrix in the second step. This leads to a new vector matrix. In step 3, a logistic squashing function is used to keep the values of vector matrix within bounds of 0 and 1. Thus, this is a new state vector, which also represents equilibrium values if there is no difference in state vector between two subsequent iterations. This summarizes step 4. Steps 1 to 4 represent the process occurring in one iteration in a FCM model. In step 5, the model checks for difference between the state vector values of the previous and current iteration. If there is no difference, the model stops and records as the result of FCM iteration. If the values do not match, then the process leads to step 2 of multiplying the new state vector with FCM matrix and the whole process repeats iteratively until an equilibrium is reached. The iterative formula and squashing function used is shown below.

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

Where, A_i and A_j are concept values with relationship between concepts from A_j to A_i. W_{ji} denotes the weight of relationship from concept *j* to concept *i.* K represents iteration. *N* is the number of concepts in the system (fuzzy cognitive map). The function *f* denotes logistic squashing function as stated below.

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

FCM modelling software - FCM Mappers

The FCM model used in this research is *FCMappers* – an excel based software developed by Michael Bachhofer (Bachhofer, 2016). This is a free FCM software available capable of handling complex cognitive diagrams and is acknowledged in scientific journal articles (Jetter & Kok, 2014), (Aura Din & Moise, 2012). Since the software is excel based, it is user-friendly, straight forward and quick to learn. The user interface of the model is shown in Figure 17.

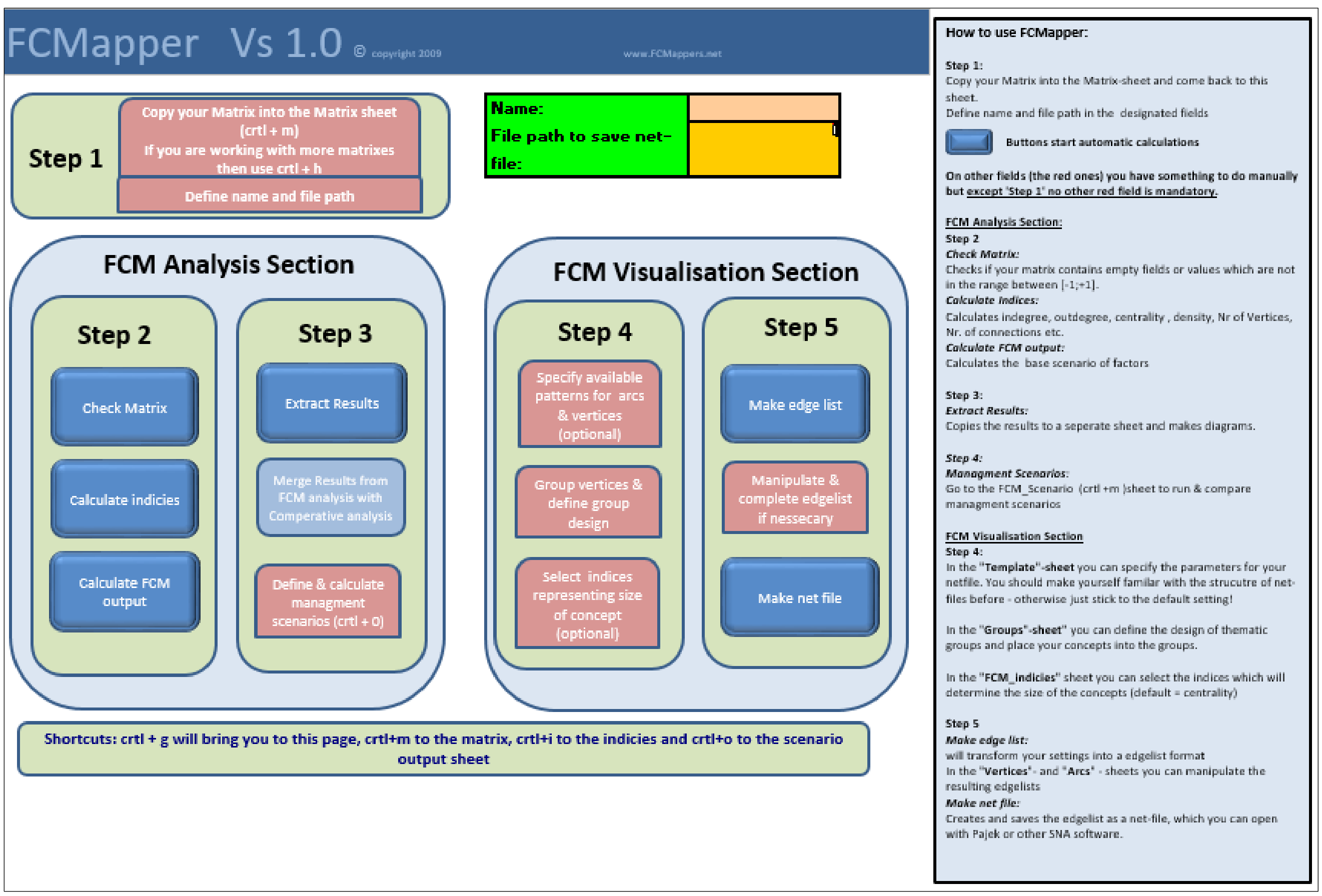


Figure 17 FCMappers user interface

Model Run

When FCMappers model is run, firstly, the model checks if values of FCM matrix are within the range of -1 to 1. If not, model indicates an error allowing the user to correct the data. Secondly, the model checks for presence of self-loops. Self-loops are direct feedback loops to the concept representing positive or negative influence on the concept itself. The diagonal of the FCM matrix reveals presence of self-loops, if any. Thirdly, the model calculates FCM indices which is the first level of result obtained from the fuzzy cognitive map.

The next step in model run is the model iteration. The iterative process can be visualized by Figure 18. The working of FCM model can be explained in analogy to neural network method (Özesmi & Özesmi, 2004). When the first iteration begins, all the concepts are activated in the direction of the arrows assigned and begin changing states as the state vector and the arrow weights (FCM matrix) is multiplied. The presence of direct and indirect feedback loops in the system allows concepts to activate pre-activated concepts thus capturing influence of all concepts present in the system map on each other. Thus, in complex maps, it is hard to point out what causes the change on a factor as it is the result of all concepts present in the system. Hence, the FCM model can also be considered as a black box as shown in Figure 14.

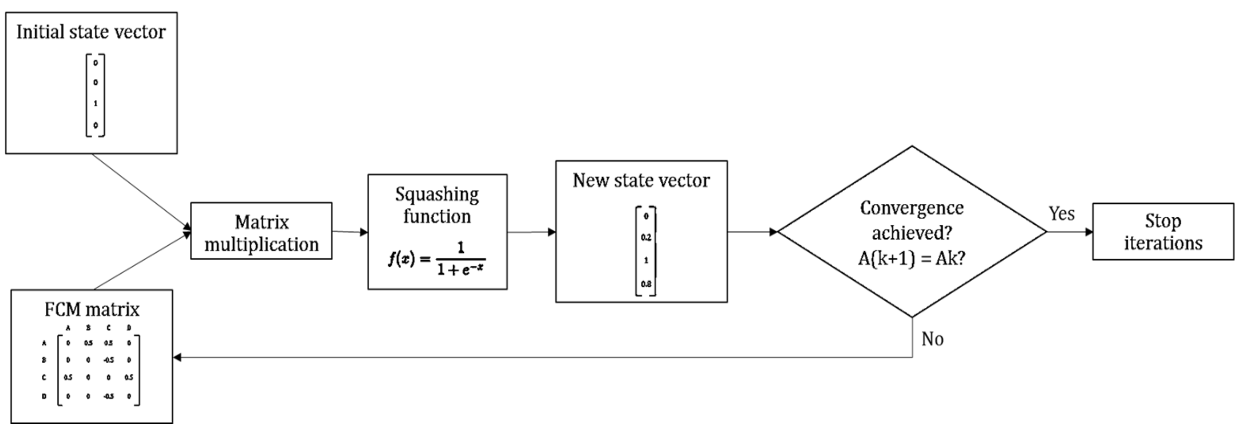


Figure 18 FCM model iterative process (Source: own)

Fourthly, in addition to FCM matrix, the state vector is input to test scenario and sensitivity analysis. The value of the state vector forms the activation value for the respective concepts during the iterative process. During every iteration, the value of the respective concepts is reset to the assigned values specified in the state vector. Table 6 shows the state vector values keyed in for the concepts – level of automation and level of sharing.

Scenarios\concept weight	**Level of automation**	**Level of sharing**
High automation high sharing	1	1
High automation low sharing	1	0.1
Low automation high sharing	0.1	1
Low automation low sharing	0.1	0.1

Table 6 Testing values for scenario conditions

2.2.4 Step 4: Standardization and combined map

The fourth step of FCM framework is *standardization and combined maps*. This step comprises 3 sub-steps as shown in Figure 19. Standardization of concept *names* is explained in section 2.2.4.1. Standardizing concept names allows combining process to create combined maps. *Combined map* and the process of combining is explained in section 2.2.4.2. In this research, a novel method of combining maps is formulated and explained in section 2.2.4.3. The *results* are discussed in section 2.2.5 Step 5: Result analysis and validation.

2.2.4.1 Standardization of concept names

The first sub-step is *standardization of concept names*. While combining multiple individual fuzzy cognitive maps from different experts, it is necessary to make sure that the concepts conveying same meaning have the same name. This process is framed as standardization of concept names among all the fuzzy cognitive maps collected. This brings uniformity and consistency in concept meaning. It avoids situation where confusions may arise while checking the internal consistency of the *combined fuzzy cognitive map*.

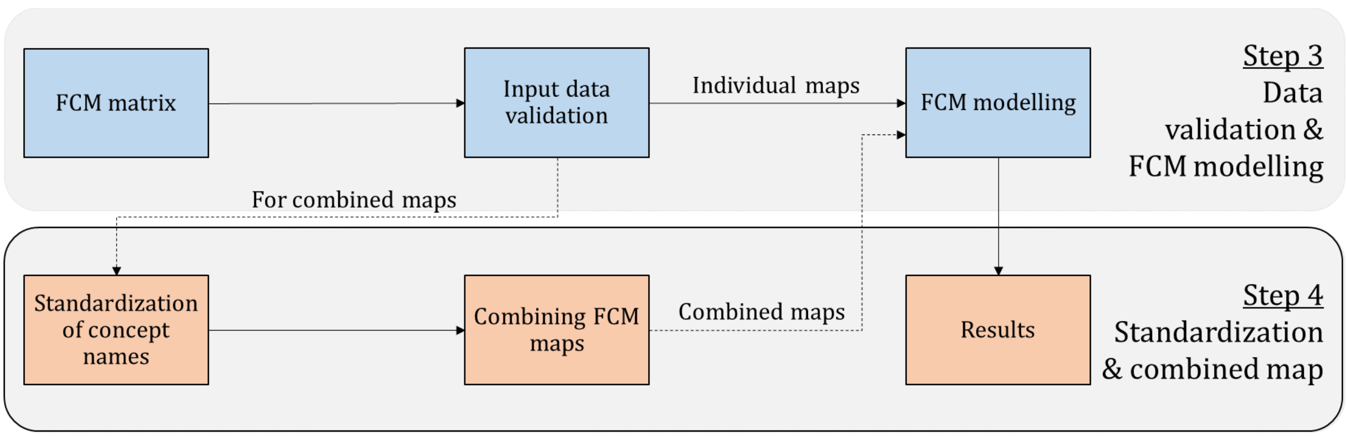


Figure 19 Step 4 - Standardization and combined map of FCM framework and its sub-steps

2.2.4.2 Combined map

FCM method allows to aggregate individual cognitive maps to form combined cognitive map (Amer et al., 2013). Combined cognitive map provides opportunity to capture multi-perspective multi-disciplinary knowledge of experts into one system, thus possible to explore impacts of joint system. This provides a holistic overview of the subject topic. Figure 20 shows the overall schematic diagram of FCM process involving combined cognitive map.

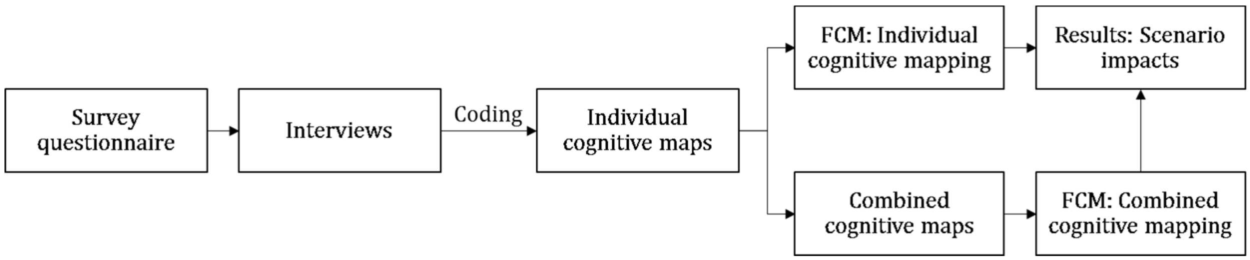


Figure 20 Overall schematic diagram of FCM process

The process of combining individual cognitive maps is stated below based on literature (Jetter & Kok, 2014), (Özesmi & Özesmi, 2004)

Step 1*: Identify and standardize concept names with same meanings.*
Step 2*: Merge all concepts names to one map with no repetition of concept name or meaning.*
Step 3*: Check for common connections with contrasting weights. Both weights of the connections are preserved for conducting sensitivity analysis.*
Step 4*: Keep the weight same for non-similar connections and average the weight of connection for common connections.*
Step 5*: Check internal consistency of combined map.*
Step 6*: Create FCM matrix from the combined fuzzy cognitive map.*
Step 7*: Perform FCM modelling and sensitivity analysis.*

2.2.4.3 New methodology for combining cognitive maps

The abovementioned process of combining individual cognitive maps works well when all individual maps have majority of common concepts. Common concepts are those concepts which are defined by experts in all cognitive maps. It is important to note that "creativity" and "commonness" of concepts are a tradeoff in any FCM research. To combine individual cognitive maps, there needs to exist majority of common concepts among each map to facilitate aggregation. (Eden & Ackermann, 2004) uses expertise of people who did not take part in the interview, called "remote experts", to combine maps into single set of interrelated arguments. But the downside to this approach could be that the experts are subjected to choose certain common concepts which the expert may not be specialized in. When experts are forced to relate such common concepts that are outside their specialization, it could lead to ambiguous and incomplete relationships in cognitive maps. This also hinders the motive to capture multi-disciplinary multi-perspective approach on the research topic. Moreover, the creativity and expert's knowledge on the respective expertise is not completely captured in the model.

Combining individual maps with common concepts can improve the credibility and reliability of the cognitive map thus the results. In other words, the result derived from "n" experts is more reliable than result from "1" expert. Creativity in the model can improve quality of scenarios and capture plausible uncertainties. Encouraging experts to be creative in building cognitive maps leads to cognitive maps having less common concepts. Combining individual cognitive maps with least common concepts can lead to internally inconsistent combined cognitive map hence inconsistent results. Literature fails to address the issues of combining individual cognitive maps with least common factors. To partly solve this issue, cognitive maps can be strategically chosen from a group of individual cognitive maps for aggregation. The strategy in choosing the individual cognitive maps for aggregation is that, the maps with highest number of non-common concepts should be avoided resulting in combining maps with least non-common factors. The process of choosing individual cognitive maps is stated below

***Step 1**: Analyze concepts*

First the concepts of each individual cognitive map is qualitatively analyzed for its meaning. The meaning of the concepts can be analyzed by cross-verifying the cognitive map with interview transcript.

***Step 2**: Qualitative grouping*

Concepts with similar meaning from every individual map is grouped. For instance, concepts like "transport land use urban form" and "spatial structure" can be grouped to same category as they are defined the same meaning by the experts. This reveals commonness of concepts among the individual cognitive maps.

***Step 3**: Choosing strategy*

The maps having least number of non-common concepts can be potentially combined. These can be any number of maps in any combination. Figure 21 shows an example where individual cognitive maps 1 and 2 are aggregated to form combined cognitive map 1, and individual cognitive maps 3, 4 and 5 are aggregated to form combined cognitive map 2. The level of commonness of concepts between the two groups of individual cognitive maps (1,2) and (3,4,5) can be different but it should be ensured that the number of non-common concepts within maps, say 1 & 2, should be lowest.

***Step 4**: Aggregation*

The combined cognitive maps can be further combined if the number of non-common factors is low (Combined cognitive map 4 - level 2 in Figure 21). This process can be repeated until the maps can no longer be combined either because all maps being combined or because the number of non-common factors are considerable hindering meaningful aggregation.

This results in various possibilities of combined cognitive maps as shown in Figure 21, which can be inferred to explore their results and implications. This process does not entirely solve the issues of combining individual cognitive maps with high uniqueness of concepts but it takes a step closer to aggregate the models leading to meaningful, credible, multi-perspective results.

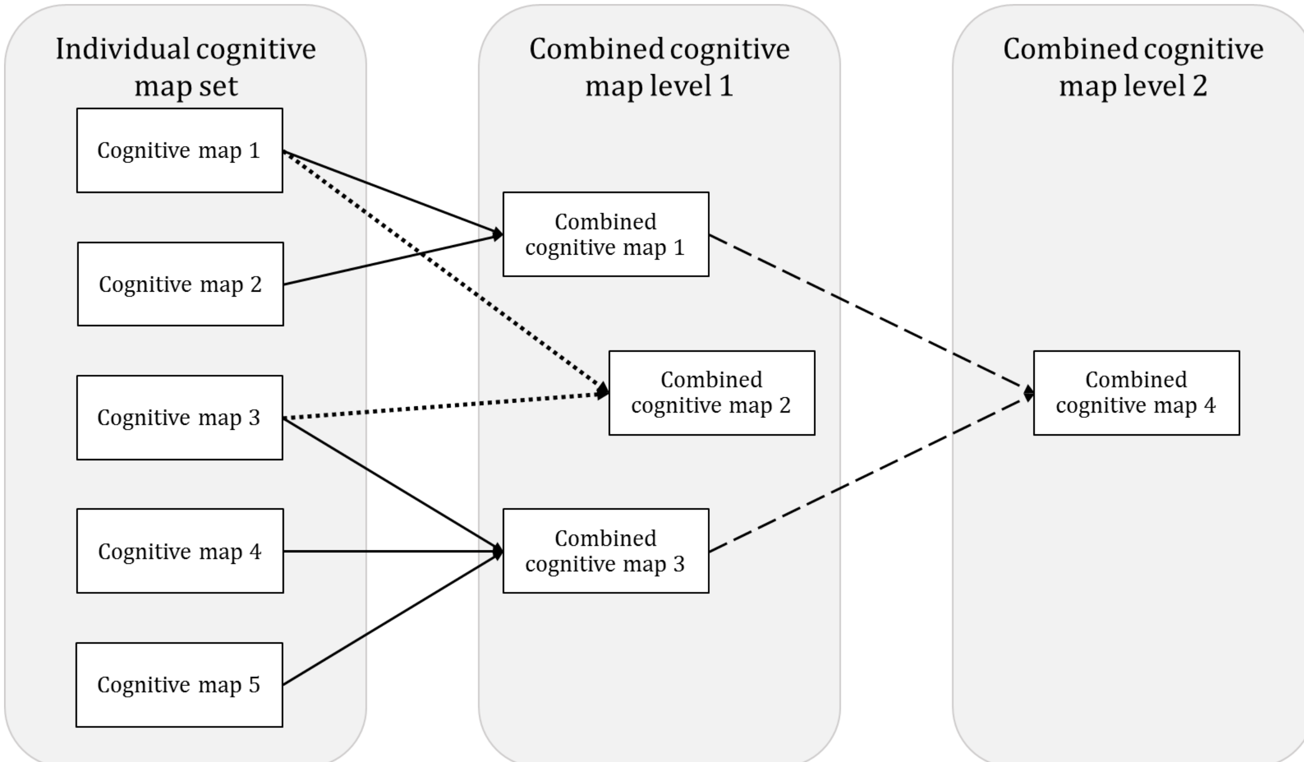


Figure 21 Illustration of new methodology of combining cognitive maps (source: own)

Maps of different experts could have different rating benchmarks. This can be identified by analyzing highest weight awarded in a map. The highest possible rating "1" that can be awarded to rate relationship strength between concepts is the common benchmark. When the highest rating in a map is not 1, the ratings in that map is converted such that its highest rating is 1. The factor multiplied to equate the highest rating is multiplied with all concepts in that map.

Method of aggregation

In this research, aggregation of maps is done manually by analyzing strength and relationship between concepts in cognitive maps. Combining cognitive maps manually helps to identify the logic of cause-effect and inter-relationships between concepts. By this process, contrasting and similar logics in cognitive maps can be noted and preserved. Similar and contrasting views indicate strong and weak links in a cognitive map respectively, and understand the contrasting logic of experts. The rating of similar relationships between common concepts are averaged to form combined cognitive map. The rating of contrasting relationships between common concepts are preserved for sensitivity analysis before being added. Sensitivity analysis is run in the FCM model to test the model behavior for contrasting relationships. Non-common relationships in cognitive maps are let as is.

Process for manual aggregation

Step 1*: Identify common and non-common concepts. Analyze similar, contrasting and non-common relationships between individual cognitive maps.*
Step 2*: Check if both FCM matrices are on same benchmark rating. If not, factor the FCM matrix such that the*

highest rating is 1.
***Step 3**: Create a new FCM matrix containing standardized name for concepts with similar meaning, and all non-common concepts from both FCM matrices. Check for non-repetitiveness of same concept meaning in the FCM matrix.*
***Step 4**: The ratings of common concepts with same cause-effect relationships are averaged. The ratings of non-common relationships are kept as is. This way the FCM matrix is filled with ratings that represent interrelationship between concepts. Concepts with no relationships are marked with 0.*
***Step 5**: Transform the combined FCM matrix to cognitive map to check for internal consistency. This is done by analyzing cognitive maps for logic of cause-effect relationships between concepts. Check for duplicate connections that accounts for double connection effect.*
***Step 6**: Run the FCM model for simulating scenarios of combined FCM matrix.*

Combined FCM maps are modelled the same way as individual FCM maps.

2.2.4.4 FCM modelling output

Subjecting the model to scenario input conditions, 3 output results can be obtained from the FCM model. They are

1. Structure of FCM (FCM indices)
2. Direction and degree of impact.
3. Dynamicity of concepts for the subjected scenarios.

The model output, which forms the result of FCM model, is explained in detail in section 2.2.5 Step 5: Result analysis and validation.

2.2.5 Step 5: Result analysis and validation

The final step of FCM framework encompasses 3 sub-steps as shown in Figure 22. Section 2.2.5.1 explains the 3-output result of FCM modelling and their analysis. This is followed by sensitivity analysis that is explained in section 2.2.5.2. The last sub-step details result validation in section 2.2.5.3.

The modelled results produced in step 4 is analyzed and validated in step 5. This step comprises 3 sub-steps. *Result analysis* is the first sub-step where the 3-output results obtained in step 4 is analyzed

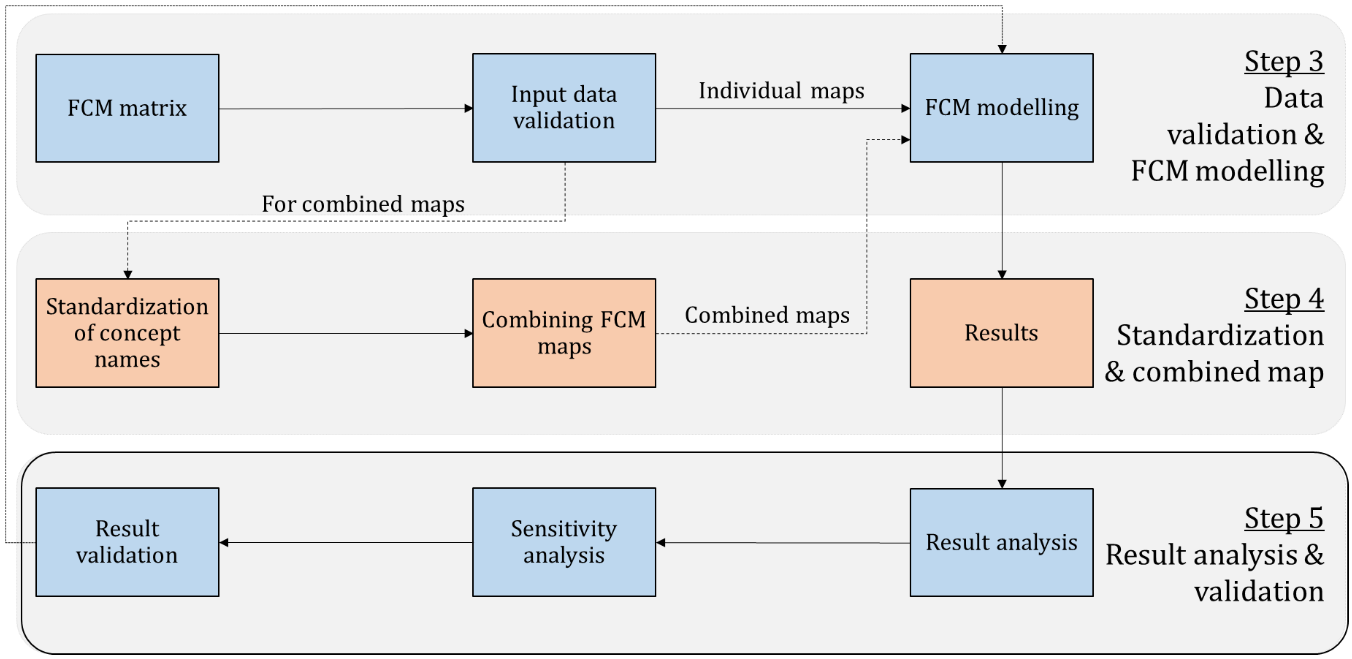


Figure 22 Step 5 - Result analysis and validation of the FCM framework

2.2.5.1 Result analysis

Result analysis helps in determining the behavior of concepts and distinguishing uncertain concepts. It improves understanding of the concepts to be able to make implications of the estimated results. Each of the 3-output results has its own analysis leading to model implications of output elements. FCM modelling process yields 3 output results, which are

1. Structure of FCM (FCM indices)
2. Direction and degree of impact.
3. Dynamicity of concepts for the subjected scenarios.

The *structure of fuzzy cognitive map*, also known as FCM indices, reveals the characteristics of fuzzy cognitive map in terms of *density, indegree, outdegree and centrality*. Based on indegree and outdegree, the concepts can be classified into *transmitter, receiver, or ordinary concepts*. Indegree represents the number of arrows that a concept receives from other concepts. In a FCM matrix, the column sum represents the indegree of a concept, denoting the strength of connections from other concepts. The outdegree represents the number of arrows leaving from a concept to other concepts in the system. In a FCM matrix, the row sum represents the outdegree of a concept. Transmitter refers to those concepts that only have arrows leaving the concept but not entering from other concepts (zero indegree). Receivers are those concepts that only have incoming arrows and no outgoing arrows from the concept (zero outdegree). Ordinary concepts are those that have both incoming and outgoing arrows. Centrality is the sum of indegree and outdegree of a concept, and denotes the strength of ordinary concepts. Ordinary concepts can be tended towards transmitter or receiver based on their ratio of indegree and outdegree. Centrality denotes the *importance* of a concept in the system, outdegree denotes the *influential* character of concept or driver in the system, while indegree denotes the character of a concept to be influenced (*dependency* of a concept). In Figure 23, concept A is the transmitter with three outgoing arrows and concept D is the receiver concept with one incoming arrow. Concepts B and C are ordinary concepts with one incoming and one outgoing arrow each.

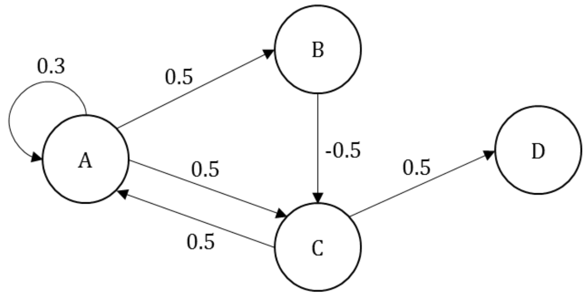


Figure 23 An example of fuzzy cognitive map (Source: own)

The FCM model also calculates the *direction and degree of impact* by comparing the equilibrium values of modelled scenario with base scenario. The equilibrium values reveal concept rankings relative to each other in steady state scenario for the defined system. In the base scenario, all the values in the state vector is assigned 1. By comparing the equilibrium value of the modelled scenario with base scenario, the degree of impact of each concept is calculated. When concepts are assigned values in state vector for testing scenarios, the model enforces the assigned value to be multiplied with FCM matrix for each iteration. This allows testing for specific concept based scenarios in FCM modelling.

The impact on concept is due to the influence of every other concept defined in the fuzzy cognitive map. And the degree of impact is *relative* to the impact of every other concept defined in the fuzzy cognitive map. *Degree of change* is classified based on 4 categories based on the extent of difference. *Direction of change* is identified based on the sign of difference, which could be negative or positive. Negative difference denotes negative change and positive difference denotes positive change. Table 7 summarizes the classification of degree and direction of change associated with colors.

Difference	Degree of change	
(+/-)0.01	Strong positive change	Strong negative change
(+/-)0.001	Medium positive change	Medium negative change
(+/-)0.0001	Weak positive change	Weak negative change
(+/-)0.00001	Very weak positive change	Very weak negative change

Table 7 Classification of degree and direction of change

Dynamicity of concepts can be analyzed from iteration values of each concept. *Iteration values* can be explained as the series of values reached by a concept at the end of each iteration. *Iteration value graphs* show the dynamicity of concepts. The iteration values of concepts are plotted on a line graph to analyze the changes in iteration values depicting the dynamic behavior of each concept. The graph shows the dynamic behavior of all concepts per iteration. This helps to understand the strength of feedback loops, the amount of dynamics that sensitive parameters have on other concepts.

A stable line in iteration value graph implies no dynamicity in the behavior of the concept. Dynamicity in concepts allows to understand the uncertainty associated with a concept in a defined system (fuzzy cognitive map). This can alert the researchers to keep check on such concepts while exploring scenario based impacts.

2.2.5.2 Sensitivity analysis

The second sub-step is *sensitivity analysis*. Sensitivity analysis is carried out to test the variability of results when the state vector or relations between any concept is varied. Sensitivity analysis allows testing of results for assumptions of experts, and for concept ratings that experts are unsure. In such cases, the sensitivity analysis can be carried out to test the positive and negative relation between unsure concepts. This step could give additional insights on behavior of concepts that could form a part of result implications. Sensitivity analysis also allows to find the main cause of certain behavior of concepts thus understanding the dynamics of the model. Sensitivity analysis can be performed by modifying the value in the FCM matrix which serves as input for FCM modelling for positive and negative relationship. The impact of scenario can also be checked by varying the strength of value in state vector within 0 and 1 for respective concepts and observe the behavior of model to such changes. These changes should be observed for any peculiar changes and should be discussed with experts during result validation.

2.2.5.3 Result validation

The third sub-step is *result validation*. Validating results is an important process to verify the result's credibility. This can be done by digitally sharing the results including results of sensitivity analysis with respective experts. *Transparency* of FCM process, *plausibility*, and *consistency* of results are considered to be validation criteria in FCM (Amer, Daim, & Jetter, 2013). The experts should be asked to reflect on the result and its implications. In case experts have a different reflection on the results, the new input of experts should be considered redirecting to FCM modelling. This forms a feedback loop in the FCM framework representing arrow connecting the process from result analysis to FCM modelling.

Further, results can also be validated by comparing with the results of other scientific researches in this field. This can reveal if the results of this research are aligned with the results of researches through other approaches. Perhaps, it could also help identify dissimilarities in results between researches which is also vital to learn.

2.3 Conclusion

To explore the possible future spatial impacts of automated vehicles, FCM based scenario building technique is used. In brief, the 5-step framework of Fuzzy Cognitive Mapping (FCM) approach includes literature study, input data acquisition through expert interviews, combining fuzzy cognitive maps, FCM modelling and results validation. In this research, the FCM modelling is aimed for 4 scenarios of varying levels of automation and sharing namely: high automation high sharing, high automation low sharing, low automation low sharing, low automation high sharing. The overall process of the entire FCM framework is visually summarized in Figure 24.

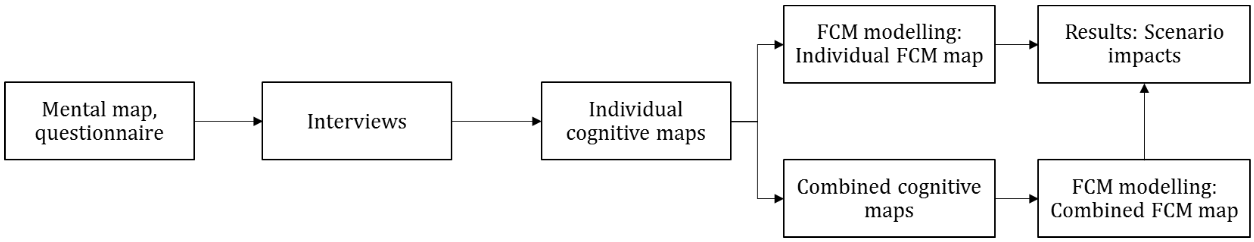


Figure 24 Overall summary of FCM framework (Source: own)

To summarize, this chapter explains the importance of scenario planning and motivation for choosing FCM as the method of research. This chapter further explains in detail the research methodology through 5-step FCM framework. Furthermore, in this research a new method of FCM map aggregation is proposed for methodological advancement in combining FCM. Each sub-step is explained and the process flow is clarified with explanation on feedback loops in the FCM framework.

3 FCM modelling: Case study Amsterdam

This chapter begins with explaining the case study - Amsterdam's characteristics and challenges in section 3.1. Section 3.2 discusses the gathering of FCM input data from the experts. This is followed by FCM modelling of the gathered input data in section 3.3. This chapter ends with a brief conclusion in section 3.4. Important sub-steps in these processes is visualized in Figure 25.

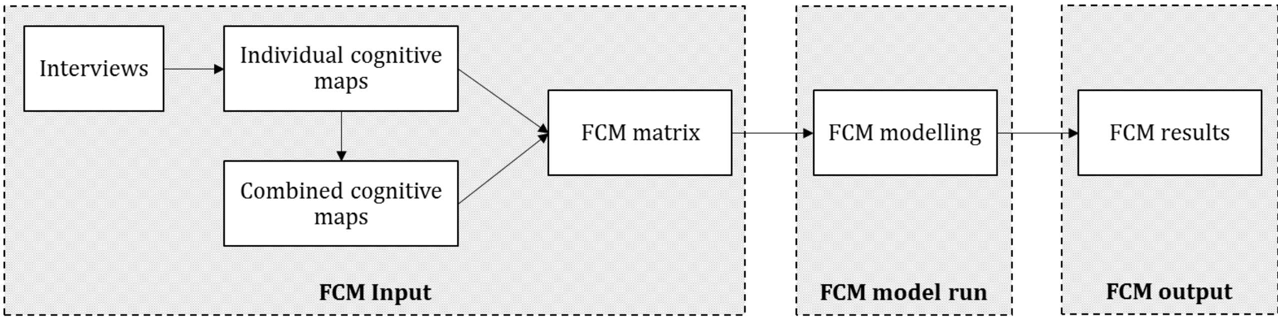


Figure 25 Important processes of FCM framework (Source: own)

3.1 Introduction to case study

Amsterdam is a dense urban region with ever-growing spatial and mobility demand limited by spatial constraints. Known for historical significance, architecture, spatial structure, and liveliness of the city, this attracts considerable amount of people to live in Amsterdam. Amsterdam, spread over a land area of 165km^2, houses 834,713 residents with population density 5069/km^2 (Centraal Bureau voor de Statistiek, 2016). As a financial and business capital, Amsterdam provides high number of jobs that also attracts people living outside Amsterdam. About 5 million jobs (employment) has been recorded in Amsterdam in 2016. Figure 26 (L) shows gradually increasing trend in employment and office establishments since 2012.

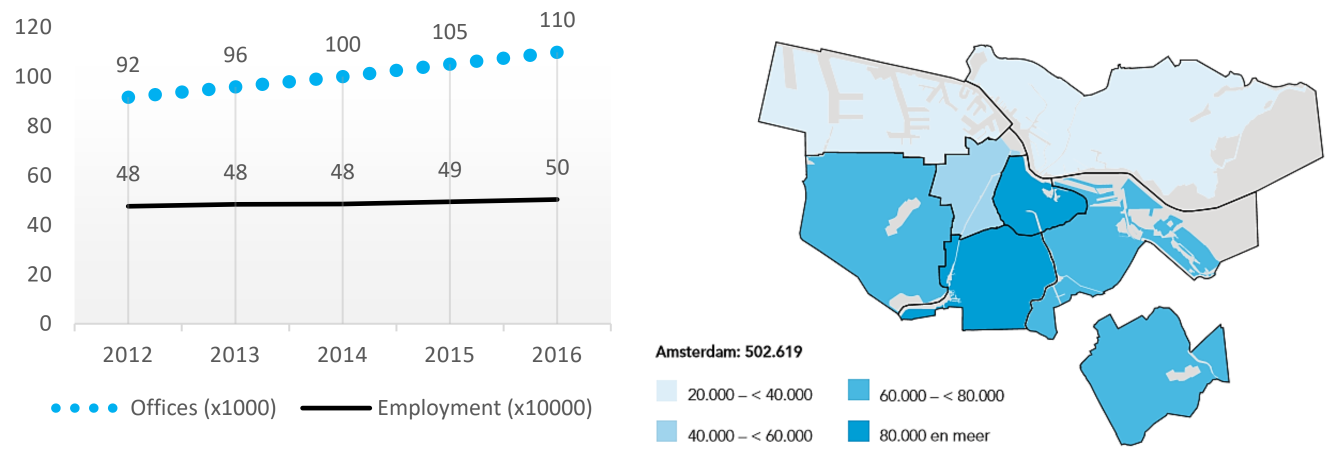


Figure 26 Office and employment statistics in Amsterdam (L), Employment spatial distribution in Amsterdam (R) (Onderzoek, Informatie en Statistiek, 2016)

Spatial distribution of jobs in Amsterdam is four times more concentrated to the South relative to North Amsterdam. In particular, the city center of Amsterdam and Amsterdam Zuid districts form major job attraction points in Amsterdam. The employment spatial distribution map is shown in Figure 26 (R).

This research uses the case of Amsterdam to explore the spatial impacts of automated vehicles. Characteristics of Amsterdam is similar to any other complex urban region except for narrow streets, numerous canals, extensive bicycle use, parking and space constraints as shown in Figure 27.

Figure 27 Narrow streets in Amsterdam (L), Biking in Amsterdam (R) (Sources: Euro-t-guide.com, Bicycle Dutch)

Housing characteristics

Amsterdam's housing statistics reveal a continuously increasing number of houses. With land area being a constant, the residential density has grown correspondingly. Every year Amsterdam tends to get denser than previous years. Statistics show that number of houses increased by 53% and the housing density increased by nearly 50% in Amsterdam in the year 2015-2016 compared to 2014-2015 (see Figure 28).

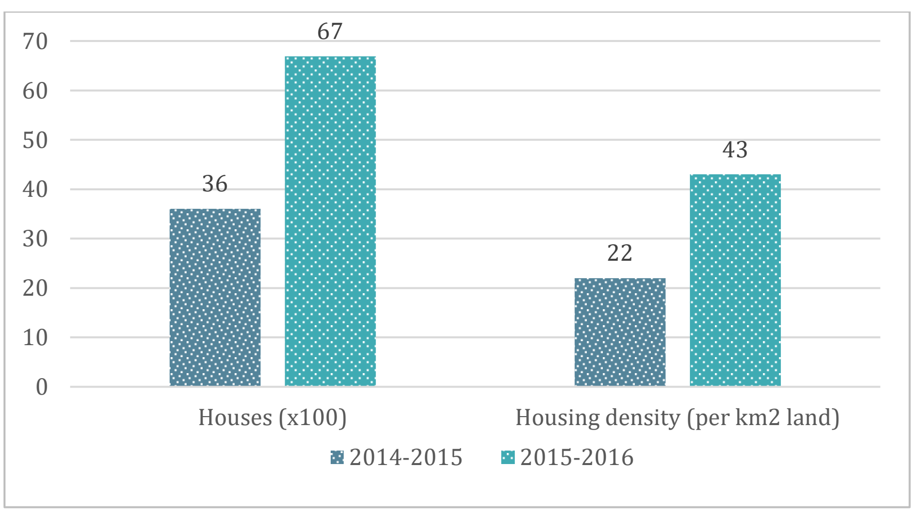


Figure 28 Number of houses and housing density statistics for Amsterdam city (Onderzoek, Informatie en Statistiek, 2016)

The challenge

Land use is constrained by availability of space. While the demand of people is constantly increasing, the supply of infrastructure is constrained by lack of space. High demand of housing in dense urban city like Amsterdam exerts pressure on land economics leading to high land prices. Urban transport infrastructure such as roads are limited to expansion due to the built environment and canals. These characteristics are likely to impact the mobility infrastructure especially on highways A2, A4 and A5 that connects Amsterdam to the southern Randstad.

Another challenge is to answer the research questions qualitatively whilst there is insufficient data for spatial impact cases due to automated vehicles. Furthermore, research on spatial impacts of automated vehicles on urban environment is missing (Correia et. al., 2016). This research takes the first step to base qualitative findings on quantitative data through FCM.

3.2 FCM model input

This section explains the steps taken by the researcher to gain FCM model input through the FCM framework. The main objective is to gather individual cognitive maps from selected experts through interview process as shown in Figure 29. Further, these individual cognitive maps are combined to form combined maps. FCM matrix forms the input for FCM modelling.

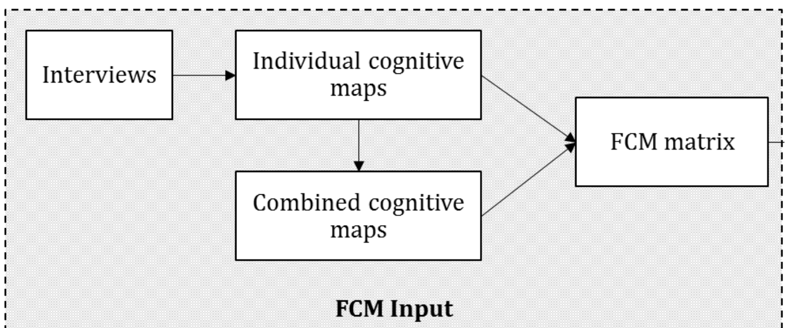


Figure 29 Important processes for FCM input gathering

With the questionnaires being designed in section 2.2.2.1 of chapter 2, the input gathering process begins with selecting relevant experts for interviews.

3.2.1 Selection of experts

In this research, expertise areas covering passenger and freight transport, land use transport interaction, urban planning, transport network, with common background in automated driving are targeted. An expert pool is created from three sources. First, by identifying experts from academic institutions. Second, from database of Connekt organization and third, by contacting Dutch authors, who published journal articles that forms part of literature in this research. Networking through authors led to finding relevant experts for the research. Table 8 shows the statistics of number of experts chosen and interviewed, classified as per their expertise. The experts chosen are from academic institutions, research organizations and government agencies. Availability of experts could possibly limit or expand new areas of expertise to be interviewed.

A total of 10 experts were interviewed among which 8 experts participated in construction of fuzzy cognitive mapping following their interview. While 2 experts did not participate in FCM process due to their limited time to participate in this process. A problem faced with selecting experts was not the task of identifying experts but being constrained by their unavailability. The experts who took part in this research are considered anonymous.

S.No	Expertise	Experts Interviewed	Experts participating in FCM
1	Land use transport interaction, transport and planning, transport modeling, scenario planning	3	3
2	Automated driving, cooperative intelligent transport system (C-ITS), network analysis, traffic management	2	2
3	Transport and urban planning, urbanization and mobility	2	2
4	City logistics, E-mobility, supply chain management	1	1
5	Strategic area smart mobility expert, automated vehicles, C-ITS	2	0
	Total number of experts	10	8

Table 8 Number of experts and their expertise

3.2.2 Interview

Interviews facilitate collecting, and bridging qualitative and quantitative data. Each expert in this research was interviewed separately.

Firstly, the experts were introduced about the research objective which is to explore spatial impacts of vehicle automation and sharing in dense urban regions by identifying uncertain factors that influences spatial setting. A brief explanation about the interview process itself was provided. A simplistic overview of FCM methodology was explained. The possibility to combine qualitative storylines and quantitative data for scenario modelling was highlighted. Experts were debriefed about components of a fuzzy cognitive map with an example of completely different themed fuzzy cognitive map (Özesmi & Özesmi, 2004). Feedback loops improve model quality and hence its importance were explicitly mentioned. Experts were informed about the goal of the interview, which was to obtain a fuzzy cognitive map. The case of urban region considered in this research is Amsterdam. Hence the experts were asked to consider the typical spatial characteristics of Amsterdam while exploring spatial impacts.

Secondly, clarity was provided over factors that are dealt with in this project. Classification and benefits of levels of automation was explained along with implications of driving automation on transport modes. Clarity on spatial levels and context of the term spatial was clarified. The experts were enlightened about the scenario that this research aims to model: high automation high sharing, low automation low sharing, high automation low sharing and low automation high sharing scenarios. Further, experts were shown the pre-created mental map leading to brain storming ideas and factors. Clarity was provided over factors, whose meaning and or context were unclear for the expert.

Once, the experts were familiar with the factors in factor pool and mental map, the experts were asked open-ended questions (Özesmi & Özesmi, 2004) like

- "*Which level of automation is most likely to be implemented first?*"
- "*What kind of changes can be expected at central business districts due to AV?*"
- "*Is it that the actual impact of travel time savings only happens in higher levels of automation? What is your perspective?*"

Such open-ended questions were directed towards factors identified in mental map and factor pool. This led to experts choosing important factors which they think can be key concepts in FCM. It was informed that the factor pool is not complete representation of factors but gives an idea of the kind of factors expected. As this research is an explorative study, experts were encouraged to be creative and were given freedom to reason their own concepts. The possible direct and indirect impacts of chosen concepts were explored.

Then, the experts were asked to draw causal maps based on their narratives of cause-effect relationships of chosen concepts. This was drawn on a large A3 size paper. The concepts were first written followed by connecting them with arrows. By questioning the cause-and-effect of each chosen concept and interrelationship between concepts, a detailed causal map was created. Experts were deliberately asked to consider the concepts of *level of automation* and *sharing* to be able to develop the required scenarios with the FCM model. Experts were asked to assign the relationship (arrows) between concepts.

Finally, upon completion of drawing causal map, the experts were asked to rate the arrows determining the relationship between the concepts. The experts were provided the rating scale (refer Table 5) and were encouraged to use values between -1 to 1. Sometimes experts were unsure about the rating, between two concepts. These connections were noted to carry sensitivity analysis.

(Özesmi & Özesmi, 2004) states that "The interview is finished when experts feel that they have completed their maps and have nothing more to add." But in most cases, due to limited time availability, step 4 and step 5 of interview process were not complete at the end of the interview. Hence, the map was enriched with a list of key concepts that researcher felt could be added after the process of content analysis, where interview transcripts were scanned to explore missing connections or concepts. These suggestions were communicated to experts through email allowing them to add those concepts if they agree. The statistics on stage of completion of the maps is shown in Table 9.

Stage of completion	Fully Complete	Rating incomplete (Step 5)	Map incomplete (Step 4)	Total
Number of maps	2	2	4	8

Table 9 Stage of completion of fuzzy cognitive maps after interview

The output of the interview was a hand drawn fuzzy cognitive map. The duration of interview ranged from 45 minutes to 120 minutes with an average of about 90 minutes. The interviews were recorded and later transcribed which can be found in Annex 4: Interview transcript.

3.2.3 Content analysis

In this research, the interview transcript of respective experts serve as the source to analyze content. The interview transcripts were analyzed for concept relationships, concepts itself, that could be added to experts-drawn fuzzy cognitive map. The incomplete maps were enriched with missing concepts and links by the researcher. The experts were asked to agree or disagree to add the suggestions to the map. In some cases, the process of completing the map led to identifying new concepts that could be a part of expert's FCM. So, the experts were asked if the additional concepts play a role in the system and if the expert wishes to incorporate them into the FCM. It was also ensured that the concept stated by experts conveyed the right meaning. For instance, "parking" is a concept stated by couple of experts. It is checked from interview transcript if parking means "parking demand" or "required parking space" and the concepts were made explicit in their meaning. Then, the fuzzy cognitive maps were digitalized and checked for internal consistency.

The concepts explored through content analysis were suggested to experts through email. The number of new concepts suggested depended on the extent to which experts had completed their fuzzy cognitive map during the interview. The experts were also requested to complete rating the relationship between the concepts where the maps were incomplete.

During the interview process the experts were asked to create fuzzy cognitive map based on Amsterdam's challenges and spatial characteristics to capture spatial impacts of automated vehicles for Amsterdam city. Among 8 FCMs created, one FCM that is specialized in *spatial impacts of automated freight vehicles* is used to elaborate on FCM modelling and result analysis. The digitalized fuzzy cognitive map of this case is shown in Figure 30. The spatial related impacts identified in this map are colored in blue. The fuzzy cognitive maps derived from the experts are the preliminary results obtained from interviewing experts about future scenarios on the subject topic.

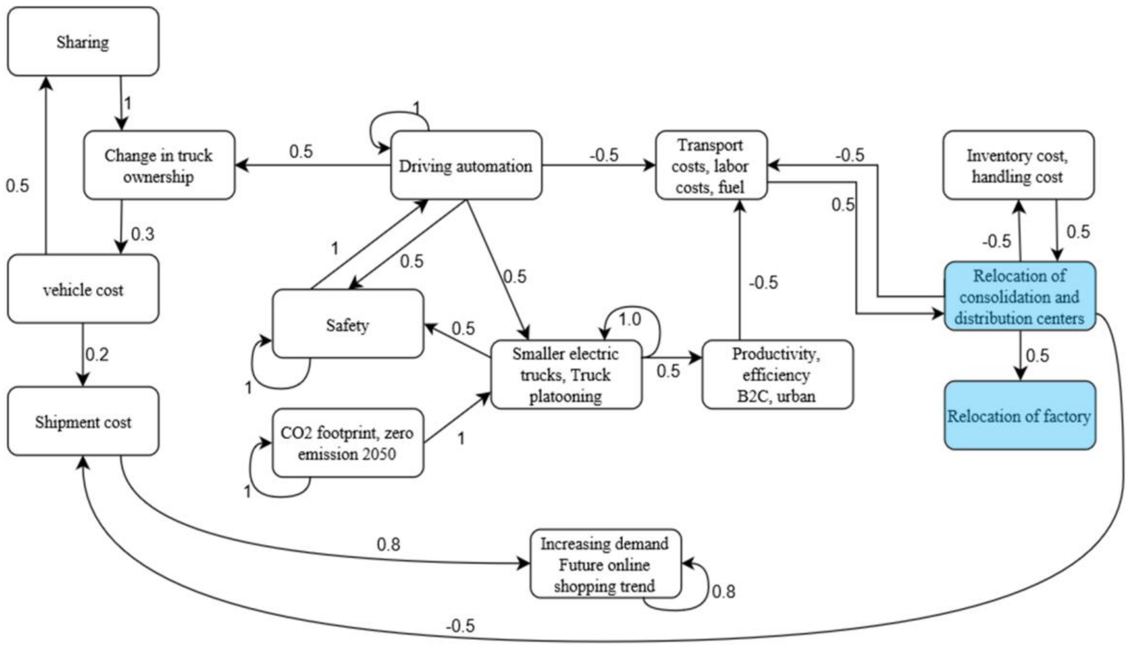


Figure 30 Digitalized fuzzy cognitive map of spatial impacts of automated freight vehicles

3.2.4 FCM matrix and input data validation

The digitalized FCM maps were then coded to FCM matrix, The FCM matrix of corresponding fuzzy cognitive map (Figure 30) is shown in Table 10**.**

	Driving automation	change in ownership to truck manufacturers	Sharing	Vehicle cost	Shipment cost	Future shipment demand	Small electric AV trucks	Safety	CO_2 emission footprint	Productivity, efficiency	Labor, fuel costs	Relocation of factory - more centralised	Relocation of distribution & consolidation centers closer to customers	Inventory cost, handling costs
Driving automation	1	0.5	0	0	0	0	0.5	0.5	0	0	-0.5	0	0	0
change in ownership to truck manufacturers	0	0	0	0.3	0	0	0	0	0	0	0	0	0	0
Sharing	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Vehicle cost	0	0	0	0	0.2	0	0	0	0	0	0	0	0	0
Shipment cost	0	0	0	0	0	0.8	0	0	0	0	0	0	0	0
Future shipment demand	0	0	0	0	0	0.8	0	0	0	0	0	0	0	0
Small electric AV trucks	0	0	0	0	0	0	1	0.5	0	0.5	0	0	0	0
Safety	1	0	0	0	0	0	0	1	0	0	0	0	0	0
CO_2 emission footprint	0	0	0	0	0	0	1	0	1	0	0	0	0	0
Productivity, efficiency	0	0	0	0	0	0	0	0	0	0	-0.5	0	0	0
Labor, fuel costs	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0
Relocation of factory - more centralised	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Relocation of distribution & consolidation centers closer to customers	0	0	0	0	-0.5	0	0	0	0	0	-0.5	0.5	0	-0.5
Inventory cost, handling costs	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0

Table 10 FCM matrix of spatial impacts of automated freight vehicles

The digitalized fuzzy cognitive map and FCM matrix were emailed to the respective experts along the new concepts obtained from content analysis. The experts were asked to review the fuzzy cognitive map, consider the new concepts, and complete the map to their satisfaction. The experts were also presented the FCM matrix to review the ratings they had awarded and were asked to fill the missing ratings (the question marks). During this process, the experts were informed that they can change the ratings and concepts that they had already assigned earlier in case they change their mind.

There were 97 concepts in total after data validation from the 8 experts. The range of concepts per map varied from 16 to 9. Average number of concepts per map was 12, which is typical number of concepts for analysis of FCM (Özesmi & Özesmi, 2004). The number of spatial factors identified was 27 out of which 16 factors were unique. The most common concepts present in all 8 maps were “level of sharing” and “level of automation”.

3.2.5 Combined map

In this research, 8 fuzzy cognitive maps were collected from experts. 4 cognitive maps were combined based on new approach to form a combined cognitive map. The selection of maps for combining was only based on commonness of concepts and not expertise of the maps. Manual analysis on commonness of concepts revealed that combining corresponding cognitive maps from expert 1, expert 2, expert 5 and expert 7 resulted in highest combinability. The combinability of specific maps was found by analyzing the standardized concept groups among all 8 maps. The combination strategy is shown in Figure 31.

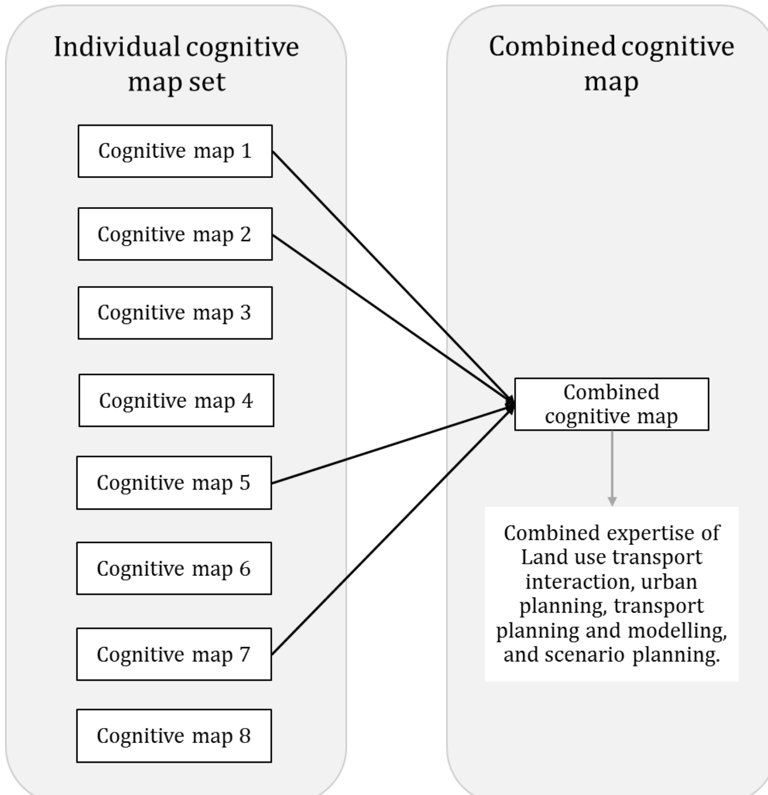


Figure 31 Map combination for combined cognitive map

The combined cognitive map entails expert's expertise of land use transport interaction, urban planning, transport planning and modelling and scenario planning. Color coded grouping of standardized concepts is shown in Table 11. The concepts defined in the maps were grouped by their commonness among other maps and colored based on their standardized concept meaning. The standardized concepts are: level of automation and level of sharing, accessibility, transport modes, disutility of car travel, car trips and trip frequency, car ownership, relocation and lifestyle.

This table shows 44 concepts. After combining, the number of concepts were down to 29. This shows 36% of total were common concepts, achieved using the new methodology for combining. This is the highest of all combinations of combining maps. This also means that the FCM matrix comprises 64% creative uncommon concepts. Though 4 maps were combined in this research, it should be noted that the process of manually combining fuzzy cognitive maps is heavily time consuming.

Expert 1	Expert 2	Expert 5	Expert 7
Level of automation	Car ownership	Level of automation and sharing	Lifestyle & business model
Origin destination relocation	Level of automation	Safety	Level of automation and sharing
Accessibility	Level of sharing	Disutility of car travel	Transport Land Use Urban Form
AV friendly urban redesign	Vehicle cost	Lifestyle preferences	Spatial social interaction
Resident decision on closeness of OD vs. quality of life	Adaptivity of people to AV	Resident relocation	Transport modes
Multimodality	Car trips, trip frequency	Relocation companies	
Transfer nodes and P+R	Accessibility	Transport Land Use Urban Form	
Disutility of car travel	Pick up / drop off points	Transport modes	
Level of sharing	Origin destination relocation	Car trip length	
Parking density	Relocation Retail	Car trips, trip frequency	
Car trips, trip frequency	Relocation Companies	Last mile, Mobility as a Service	
Car ownership	Residents relocation	Travel time budget	
	Change in Land value		
	Parking facilities		
	Disutility of car travel		

Table 11 Grouping of concepts to create combined cognitive map

Manual aggregation process detailed in section 2.2.4.3 resulted in combined fuzzy cognitive map. The combined cognitive map represents the case for automated passenger vehicles. The resultant combined cognitive map is shown in Figure 32. And the combined FCM matrix is shown in Table 12.

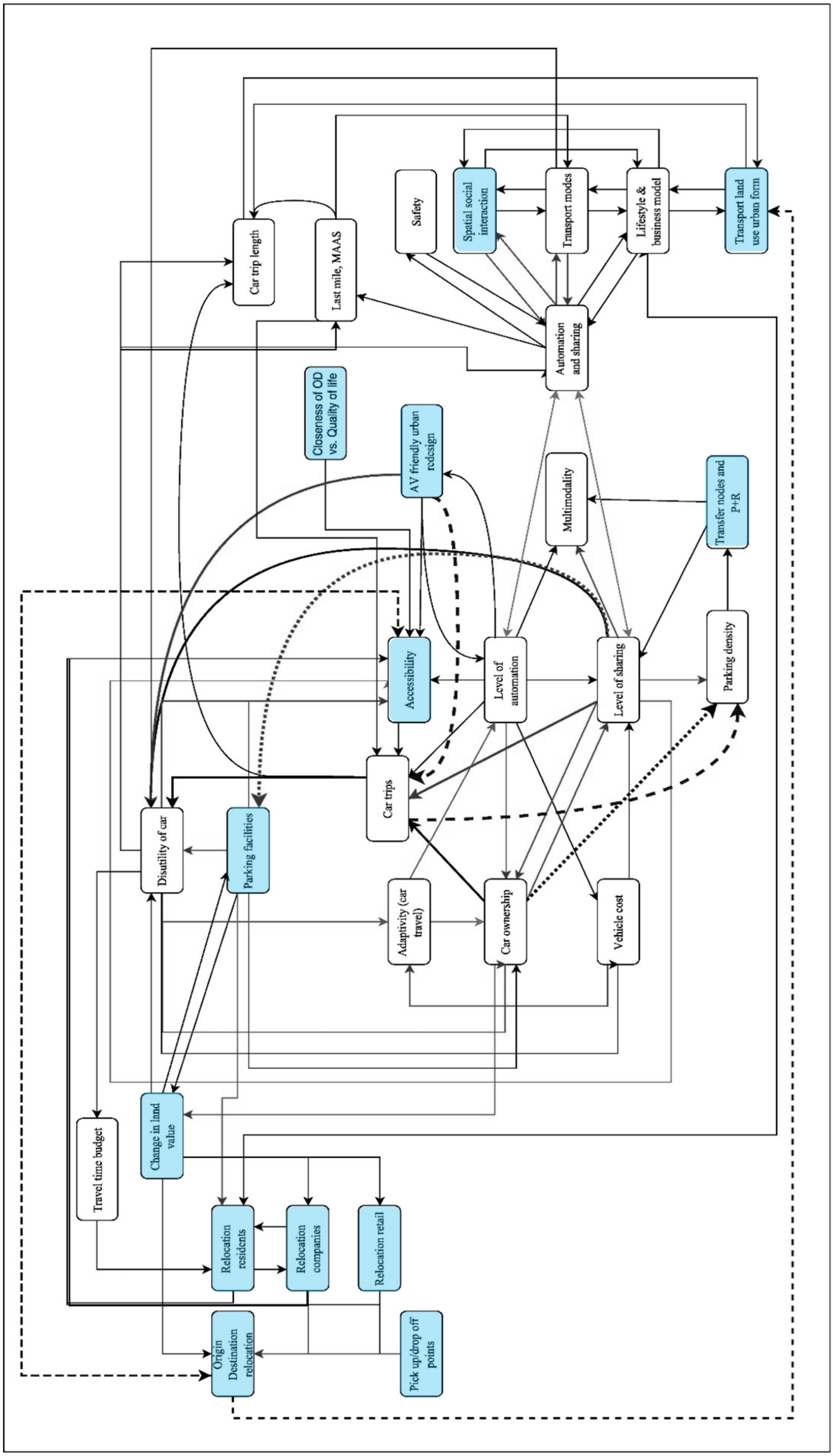


Figure 32 Combined fuzzy cognitive map for automated passenger vehicles

	Level of automation	Accessibility	Level of sharing	Disutility car travel	Car ownership	Origin Destintion relocation	Car trips, car usage	Vehicle cost	Adaptivity	Parking facilities	Pick up / drop off points	Relocation Retail	Relocation Companies	Residents relocation	Change in Land value (Inc)	AV friendly urban redesign	Closeness of OD vs. quality of lif	Multimodality	Transfer nodes and P+R	Parking density	Lifestyle & business model	Level of automation and sharing	Transport Land Use Urban Form	Spatial social interaction	Transport modes	Safety	Car trip length	Lastmile, MAAS	Travel time budget factors
Level of automation	0	0.5	0.3	-0.5	-0.2	0	0.1	0.2	0	0	0	0	0	0	0	0.5	0	-0.5	0	0.5	0	1.0	0	0	0	0	0	0	0
Accessibility	0	0	0	0	0	0.3	0.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Level of sharing	0	0	0	0.3	-0.3	0	-0.3	0	0	-0.5	0	0	0	0	0	0	0	-0.5	0	-0.5	0	1.0	0	0	0	0	0	0	0
Disutility car travel	0	-0.7	0	0	-0.4	0	0	0.1	-0.2	0	0	0	0	0.1	0	0	0	0	0	0	0.2	0	0	0	0	0	-1.0	1.0	-0.5
Car ownership	0	0	-0.5	0	0	0	0.5	0	0	0	0	0	0	0	-0.4	0	0	0	0	0.3	0	0	0	0	0	0	0	0	0
Origin Destintion relocation	0	0.3	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
Car trips, car usage	0	0	0	0.1	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
Vehicle cost	0	0	0.7	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
Adaptivity	0.4	0	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
Parking facilities	0	0.3	0	-0.7	0.5	0	0	0	0	0	0	0	0	-0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pick up / drop off points	0	0	0	0	0	-0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0
Relocation Retail	0	0.2	0	0	0	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Relocation Companies	0	0.2	0	0	0	0.2	0	0	0	0	0	0	0	0.4	0	0	0.2	0	0	0	0	0	0.3	0	0	0	0	0	0
Residents relocation	0	0.6	0	0	0	0	0	0	0	0	0	0	0.4	0	0	0	0	0	0	0	0.1	0	0.3	0	0	0	0	0	0
Change in Land value (Inc)	0	0	0	0.3	0	0.5	0	0	0	0.6	0	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AV friendly urban redesign	0.5	0	0	-0.2	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
Closeness of OD vs. quality of li	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Multimodality	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
Transfer nodes and P+R	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	0	0	0.5	0
Parking density	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
Lifestyle & business model	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0	0	0	0	0	0	0	0.3	0.4	0.4	0.3	0	0	0	0
Level of automation and shari	1.0	0	1.0	-1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0	0	-0.2	-0.8	0.3	0	1.0	0
Transport Land Use Urban For	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	0.3	0	0
Spatial social interaction	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	-0.6	0	0	0.5	0	0	0	0
Transport modes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.4	0.2	0.5	0	0	0	0	0
Safety	0	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
Car trip length	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0	0	0	0	0	0	0
Lastmile, MAAS	0	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0
Travel time budget factors	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

Table 12 Combined FCM matrix for spatial impacts of automated passenger vehicles

The combined matrix represents the scenarios for spatial impacts of automated passenger vehicles. The meaning of concepts is explained in 3 categories: Spatial concepts, mobility concepts and dummy concepts. This can be found in Annex 5: Concept meanings.

3.3 FCM modelling

FCM modelling was done using FCMappers software for all the 8 individual maps and 1 combined map**.** To model, firstly the FCM matrix was input and run for the base scenario. Secondly, the state vectors were input and run for each scenario. The state vectors for each scenario is shown in Table 13 keyed in for the concepts – level of automation and level of sharing.

Scenarios\concept weight	Level of automation	Level of sharing
High automation high sharing	1	1
High automation low sharing	1	0.1
Low automation high sharing	0.1	1
Low automation low sharing	0.1	0.1

Table 13 State vector values for scenario conditions

Once the input was keyed into the model, the model was run for every scenario. The model ran iterations to achieve equilibrium state. The iterative process can be visualized by Figure 33.

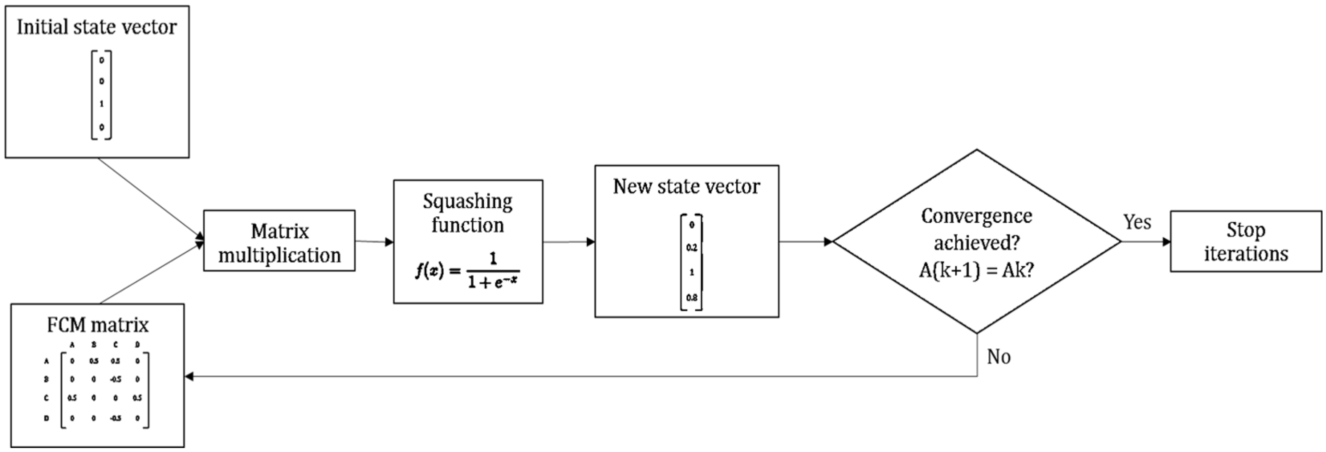


Figure 33 FCM model iterative process

By running the model, the 3 output results were created. The results are explained in detail in chapter 4 FCM model results .

3.4 Conclusion

This chapter first presented the case study – Amsterdam's challenges and characteristics. It discussed some spatial characteristics showing how dense, urban and complex the Amsterdam city is. These challenges and characteristics were discussed with the selected experts during the interview process. The interview process was conducted among 10 experts with the assistance of questionnaire designed (refer Annex 3: Questionnaire). 8 out of 10 experts participated in FCM process and created 8 individual fuzzy cognitive maps. All these maps were checked for internal consistency, digitalized, enriched through content analysis process and were validated by the experts.

1 combined map was created by combining 4 individual maps that were strategically chosen through the newly proposed methodology for combining maps. The formation of combined map marks the preliminary results of this research. The fuzzy cognitive map and FCM matrix of automated *freight* vehicles and automated *passenger* vehicles were presented. All the maps were modelled through FCMappers software for 4 scenarios – high automation high sharing, high automation low sharing, low automation low sharing and low automation high sharing.

Overall, the results were obtained for both individual FCM Map and combined FCM map that leads to identifying the spatial impacts of vehicle automation and sharing for future scenarios. This is discussed in chapter 4 model results and implications.

4 FCM model results

This chapter explains the model results of FCM modelling. The chapter follows the process of step 5 in FCM framework. The 3 level results obtained from FCM modelling are analyzed and their meanings are explained through result interpretation in section 4.1. Then, results of sensitivity analysis are discussed in section 4.2. The findings of contrasting relationships and logic between experts are discussed in this section. Section 4.3 discusses result validation. This chapter concludes with conclusion in section 4.4.

Model results

There are three results obtained from FCM modelling. 1. FCM indices, 2. Dynamicity of results, 3. Degree and direction of impact. The FCM indices depends on structure of FCM such as number of concepts, number of connections, type of connections. Dynamicity of results depends on the iteration values and equilibrium values of FCM model run. Degree of impact is obtained from difference of equilibrium values between base scenario and input scenario. Table 14 shows the result output, analysis elements of the result and its implications.

	Output elements	**Analysis**	**Implication of output elements**
1	Indegree, outdegree, centrality, transmitters, receivers	Higher values of output elements	Importance of a concept, concepts that drives a system.
2	Iteration values	Trend of Iteration values	Dynamicity of concepts
3	Equilibrium values	Comparison of equilibrium values with base scenario	Degree of impact of a concept

Table 14 Result output, analysis, and implication

4.1 Result analysis

To simplify the readability of this report, modelling results of 1 individual FCM map - reflecting automated *freight* vehicles and 1 combined cognitive map - reflecting automated *passenger* vehicles are presented.

4.1.1 Result analysis: automated freight vehicles

Result 1: Structural analysis

Structural analysis helps determine the impact of important concepts in the FCM and classify them to various behavioral categories: transmitter, receiver, and ordinary (Eden et. al., 2007).

The fuzzy cognitive map of *freight* consisted 14 concepts leading to 24 connections between concepts that included 5 self-loops. The density of fuzzy cognitive map was 0.12. *Density* of the map reveals how densely inter-connected are the concepts in the fuzzy cognitive map. Density was calculated by dividing the number of connections by maximum number of concepts. This fuzzy cognitive map had 1 transmitter and 1 receiver concept. The remaining 12 concepts were ordinary.

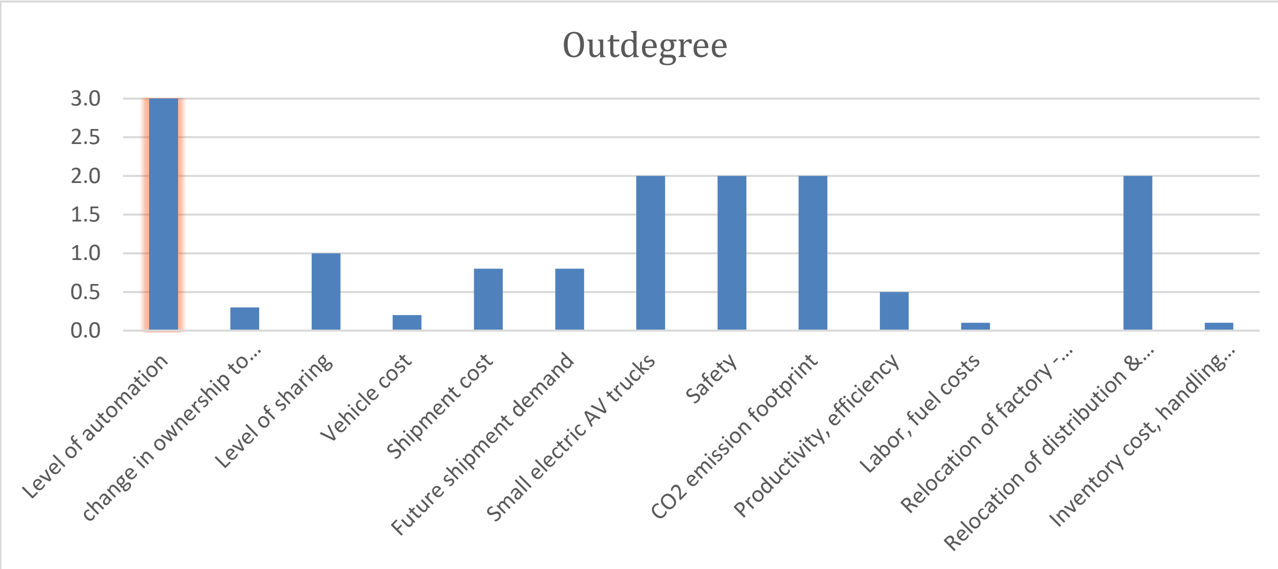
The concept *level of sharing* behaved as transmitter and the concept *relocation of factories to centralized locations* behaved as receiver. Concepts that contained self-loops were *level of automation, future shipment demand, use of small electric trucks, safety,* and *reduction of CO_2 emission footprint.* These concepts had a positive connection to themselves. Hence, if the concept were in an increasing trend, it increased strongly and if it were in a decreasing trend, it decreased strongly. Table 15 shows the characteristics of FCM indices.

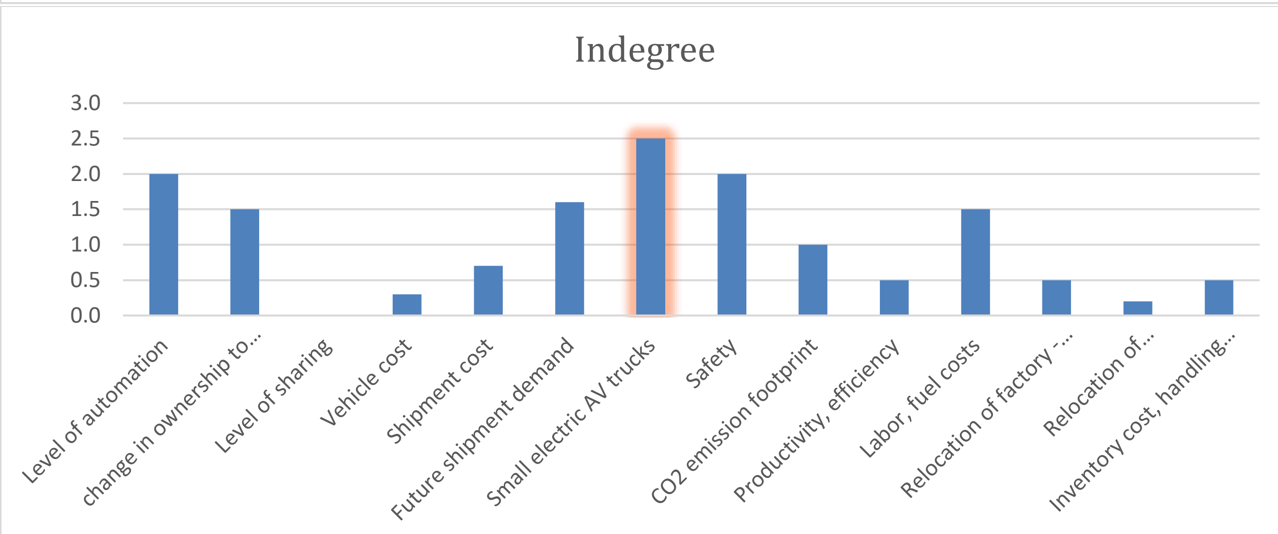
FCM indices	**Value**
Number of concepts	14
Number of connections	24
Number of receiver concepts	1
Number of transmitter concepts	1
Number of ordinary concepts	12
Map density	0.122
Number of self-loops	5

Table 15 Characteristics of FCM indices - freight

The outdegree, indegree and centrality of all concepts defined in the fuzzy cognitive map are shown in Figure 34. *Level of automation* showed highest outdegree meaning it behaves as the driver of the system. Other major drivers of the system were *small electric AV trucks*, *safety, relocation of distribution and consolidation centers* and *reduction of CO2 emission footprint.* This is because the expert believes that level of automation, safety and commitment to reduce CO2 emission are the motivators in the freight system.

Small electric AV trucks showed highest indegree of the system meaning it is highly dependent on other concepts and heavily influenced by them. *Safety, level of automation, ownership structure, future shipment demand, labor and fuel costs* were also concepts that were influenced and dependent on other concepts. It is to note that *level of sharing* is least influenced by other concepts.


Outdegree
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Level of automation
change in ownership to...
Level of sharing
Vehicle cost
Shipment cost
Future shipment demand
Small electric AV trucks
Safety
CO2 emission footprint
Productivity, efficiency
Labor, fuel costs
Relocation of factory -...
Relocation of distribution &...
Inventory cost, handling...


Indegree
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Level of automation
change in ownership to...
Level of sharing
Vehicle cost
Shipment cost
Future shipment demand
Small electric AV trucks
Safety
CO2 emission footprint
Productivity, efficiency
Labor, fuel costs
Relocation of factory -...
Relocation of...
Inventory cost, handling...

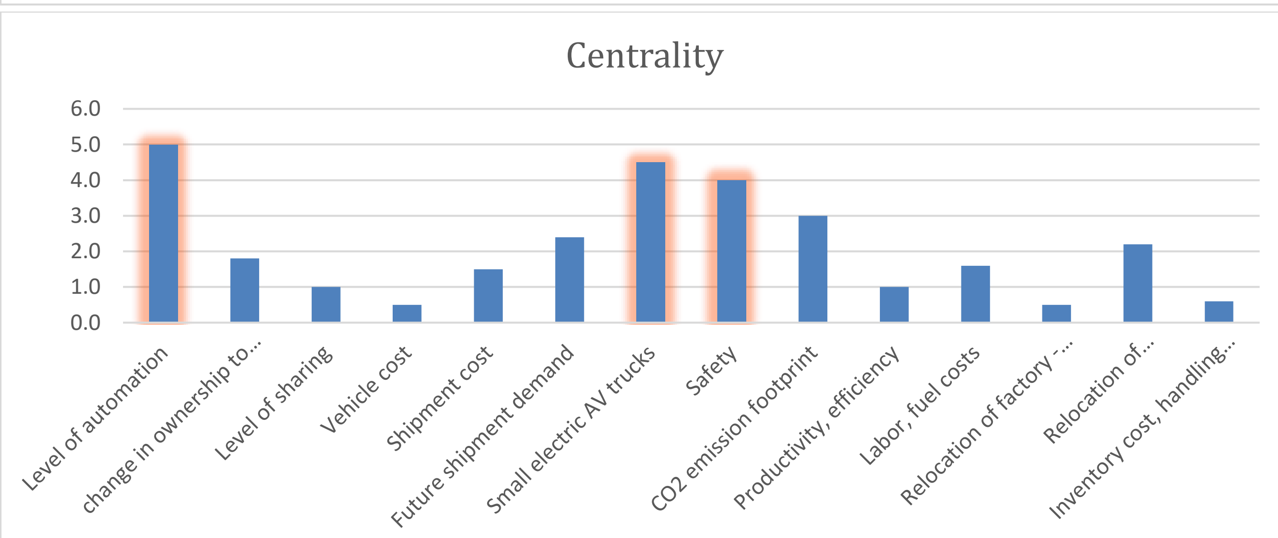

Centrality
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Level of automation
change in ownership to...
Level of sharing
Vehicle cost
Shipment cost
Future shipment demand
Small electric AV trucks
Safety
CO2 emission footprint
Productivity, efficiency
Labor, fuel costs
Relocation of factory -...
Relocation of...
Inventory cost, handling...

Figure 34 Outdegree, indegree and centrality of FCM

Relocation of distribution and consolidation centers tended to behave as transmitter as it had a high difference between outdegree and indegree. L*abor, fuel costs and change in ownership* tended to behave as receiver concepts as their indegree were higher than outdegree. *Level of automation, safety*, and *small electric trucks* were important concepts in the system. Table 16 shows the behavioral tendencies of concepts.

Concepts	**Transmitter / receiver / driver**
Level of automation	Driver
change in ownership to truck manufacturers	Receiver
Level of sharing	*Transmitter
Future shipment demand	Receiver
Small electric AV trucks	Driver
Safety	Driver
CO2 emission footprint	Transmitter
Labor, fuel costs	Receiver
Relocation of factory - more centralized	*Receiver
Relocation of distribution & consolidation centers closer to customers	Transmitter
*means the concept is a pure transmitter or pure receiver	

Table 16 Structural analysis of FCM for freight

Shipment cost, vehicle cost, productivity & efficiency and inventory, handling costs were concepts that did not have high indegree or outdegree. Thus, they were relatively less important in the system. Nevertheless, they had indirect connections that influenced the degree of spatial impacts.

Result 2: Dynamicity of concepts

Equilibrium values were plotted against iteration values in the line graph shown in Figure 35. The timeline considered in this FCM was short – medium time period of 10 years and is fixed by the expert. It is to note that the iteration values do not correspond to specific year.

Figure 35 shows that near equilibrium conditions were reached within first 5 iterations. The entire system reached equilibrium in 27 iterations. All concepts started from equilibrium value 1 as set in the base scenario. Base scenario reveals the behavior of a concept and when it is enforced to start iteration with highest value of 1.

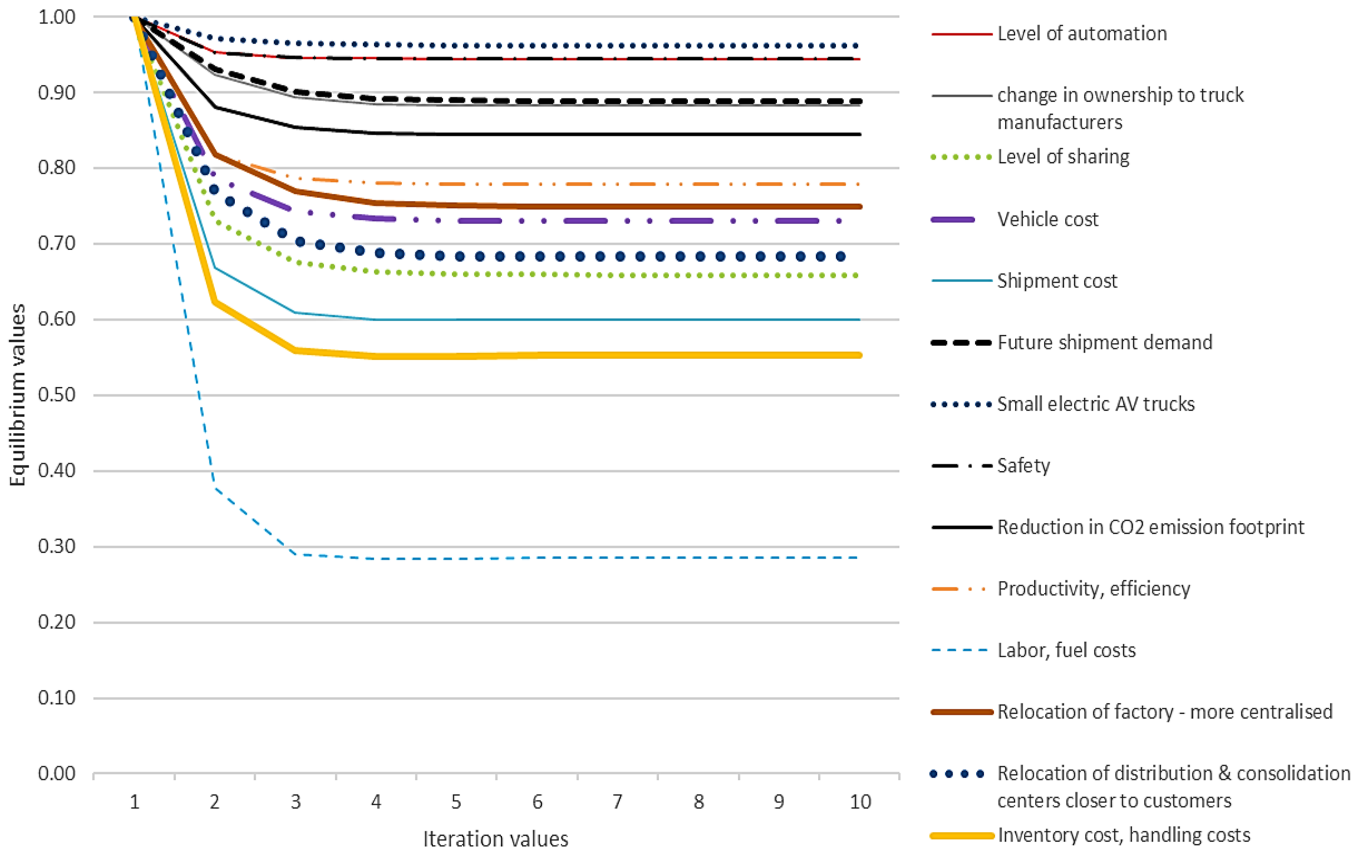


Figure 35 Modeled iteration value graph of automated freight vehicles

All concepts followed similar path in achieving respective equilibrium values. It was also observed that none of the concepts changed direction to contrasting sides which would reveal dynamic behavior. This shows that controlling positive feedback loops results in very stable system.

- *Small electric AV trucks* stabilized with the highest equilibrium value. This implies that *small electric AV trucks* creates relatively a higher influence on the system that is depicted in fuzzy cognitive map.
- *Labor, fuel cost* and *inventory, handling costs* stabilized with lower equilibrium values relative to other concepts in the system. Reduction of these costs relatively impact the overall system to a minimum level.
- *Relocation of factory to centralized location* was ranked higher than *relocation of distribution and consolidation centers*. So, relocation of factories has higher influence and impact on the system relative to *relocation of distribution and consolidation centers*.
- It can be observed from equilibrium values that *change in ownership to truck manufacturers* was more likely due to *level of automation* than *vehicle cost.*
- *Level of sharing* had relatively less effect on spatial relocation concepts - *relocation of factory to centralized location* and *relocation of distribution and consolidation centers.*

Result 3: Degree and direction of impact

The degree and direction of impacts determined from FCM model is presented below. The spatial impacts on the system is summarized in the form of quadrants that represent the 4 input scenarios. The results have four quadrants that mention the 4 input scenarios. The color of the concepts denotes the degree of impact and direction of impact. Shades of orange denote negative change and shades of green represent positive change as shown in Table 7. The impacts in each scenario is relative to each other. It cannot be compared with reality. The impacts perceived are grouped specific to themes for easier understanding of impacts of automation and sharing on spatial planning. Table 7 summarizes the classification of degree and direction of change associated with colors for reference.

Difference	Degree of change	
(+/-)0.01	Strong positive change	Strong negative change
(+/-)0.001	Medium positive change	Medium negative change
(+/-)0.0001	Weak positive change	Weak negative change
(+/-)0.00001	Very weak positive change	Very weak negative change

Table 17 Classification of degree and direction of change

Spatial impacts

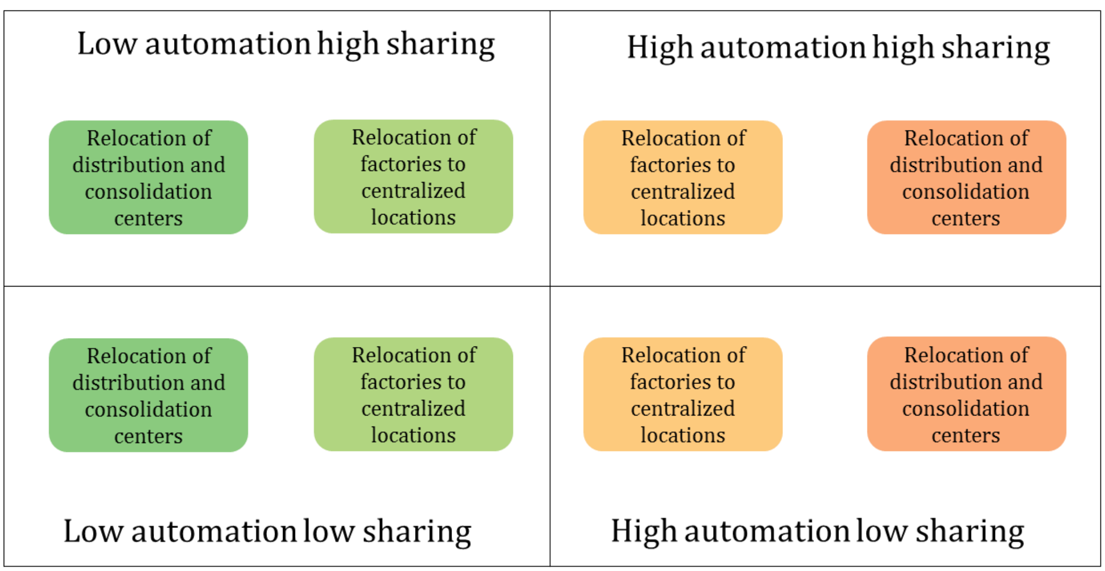


Figure 36 Spatial impacts of automated freight vehicles

Result interpretation

- Medium and weak *negative* changes in relocation concepts showed that spatial relocation impacts were unlikely to occur in high automation scenarios.

- Medium to weak *positive* changes in relocation concepts show that spatial relocation impacts might occur in low automation scenarios.
- The concept *relocation of consolidation and distribution centers* showed relatively stronger change than *relocation of factories to centralized locations*.
- *Level of automation* had strong influence on *relocation* more than *level of sharing* in freight.
- *Level of sharing* in freight had negligible influence on *relocation* relative to *level of automation*. Sharing is considered in freight because it could help to avoid empty trips and utilize the maximum capacity of trucks.

Cost impacts

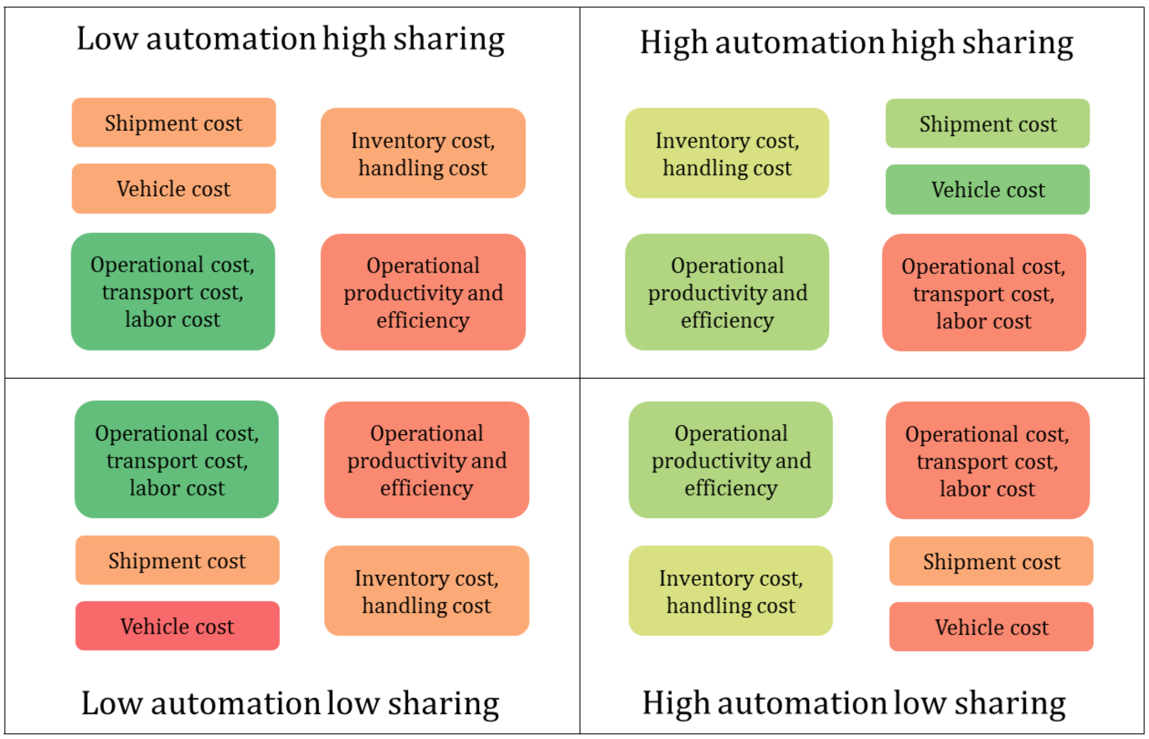


Figure 37 Cost impacts of automated freight vehicles

Result interpretation

- The model predicted *operational, transport and labor costs* to decrease in high automation scenarios relative to low automation scenarios. It was also observed that the effect of sharing did not have a significant impact on this concept.
- The concepts - *operational productivity and efficiency, inventory and handling costs* tended to mildly improve in high automation scenarios relative to low automation scenarios. It was observed that the effect of sharing did not have a significant impact on these concepts.
- *Vehicle cost and shipment cost* may be expected to increase in high automation high sharing scenario. The cost of vehicle was likely to be lower in other scenarios while, vehicle cost was predicted to be the lowest in low automation and low sharing scenario.

Mobility impacts

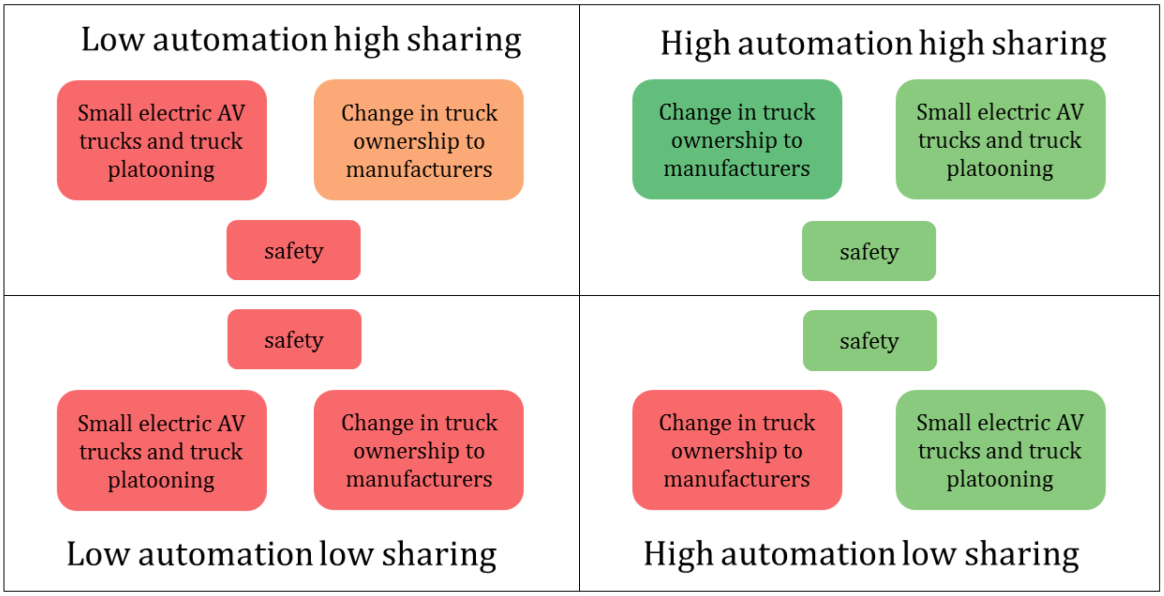


Figure 38 Mobility impacts of automated freight vehicles

Result interpretation

- *Safety* was predicted to increase in high automation scenarios relative to low automation scenarios. Sharing had negligible effect on safety.
- Increase in use of *small electric AV trucks and truck platooning* was observed in high automation scenarios relative to low automation scenarios. Sharing had negligible impact.
- *Change in truck ownership to truck manufacturers* was predicted only in high automation high sharing scenario while it was relatively unlikely to change in other scenarios.

4.1.2 Result analysis: automated passenger vehicles

The assumptions considered by experts while drawing the fuzzy cognitive maps are stated below:

- Government, municipality regulations are assumed to be positive and support towards development of AV and sharing.
- Concept *adaptivity of people to AV* refers to the degree to which people would likely adapt to travelling in higher levels of automated functionality in vehicles (level 3 and 4). Adaptivity of people to AV is assumed to be positive towards automation developments and that adaptivity towards AV causes positive tendency in *car ownership*.
- Experts believe that sufficient *pick up drop off points* can dampen *relocation concepts* and improve *last mile and Mobility as a Service*.
- *Transport modes* refers to other transport modes such as public transport, bikes which have strong cultural influence that drives last mile mobility in the Netherlands. *Transport modes*, a dummy

concept, is considered to capture the effect of public transport and biking. Biking is a strong cultural influencer to the mobility system in the Netherlands that cannot be ignored despite technological developments in automation. Experts believe that the concept *transport modes* will dampen door to door mobility trends caused by higher *levels of automation* and enhances *spatial social interaction* opportunities.

Result 1: Structural analysis

The fuzzy cognitive map for personal mobility consisted 29 concepts leading to 99 connections between concepts. The density of fuzzy cognitive map was 0.11. It was notable that density reduces as more maps are combined. To maintain a higher density, more rounds of communication and correctional feedback from experts are required. This is also a way of validating results. This fuzzy cognitive map had 1 transmitter and 0 receiver concepts. The remaining 28 concepts were ordinary concepts. The dummy concept *pick up drop off points* behaved as transmitter in this fuzzy cognitive map which is an example of the concept *AV friendly urban redesign*. Table 18 shows the characteristics of FCM indices.

FCM indices	**Value**
Number of concepts	28
Number of connections	99
Number of receiver concepts	0
Number of transmitter concepts	1
Number of ordinary concepts	28
Map density	0.11
Number of self-loops	0

Table 18 Characteristics of FCM indices - passenger

The outdegree, indegree and centrality of all concepts defined in the fuzzy cognitive map are shown in Figure 39. *Level of automation and sharing,* and *disutility of car travel* showed highest outdegree, meaning they behaved as the driver of the system. Other major drivers of the system were *car ownership, parking facilities, change in land value* and *lifestyle and business model*. Concepts with lowest outdegree were *Last mile, Mobility as a Service (MaaS), number of car trips* and *car trip length*.

Level of sharing, accessibility and *disutility of car travel* showed highest indegree of the system meaning they were highly dependent on other concepts and heavily influenced by them. The concepts *level of automation, car ownership, origin destination relocation, number of car trips, resident relocation, transport land use urban form, and last mile, Mobility as a Service* were influenced and dependent on other concepts. It is to note that *pick up drop off point* had no indegree, which means it was a pure receiver. *Relocation of retail, closeness of OD vs. quality of life, vehicle cost,* and *safety* had the least indegree.

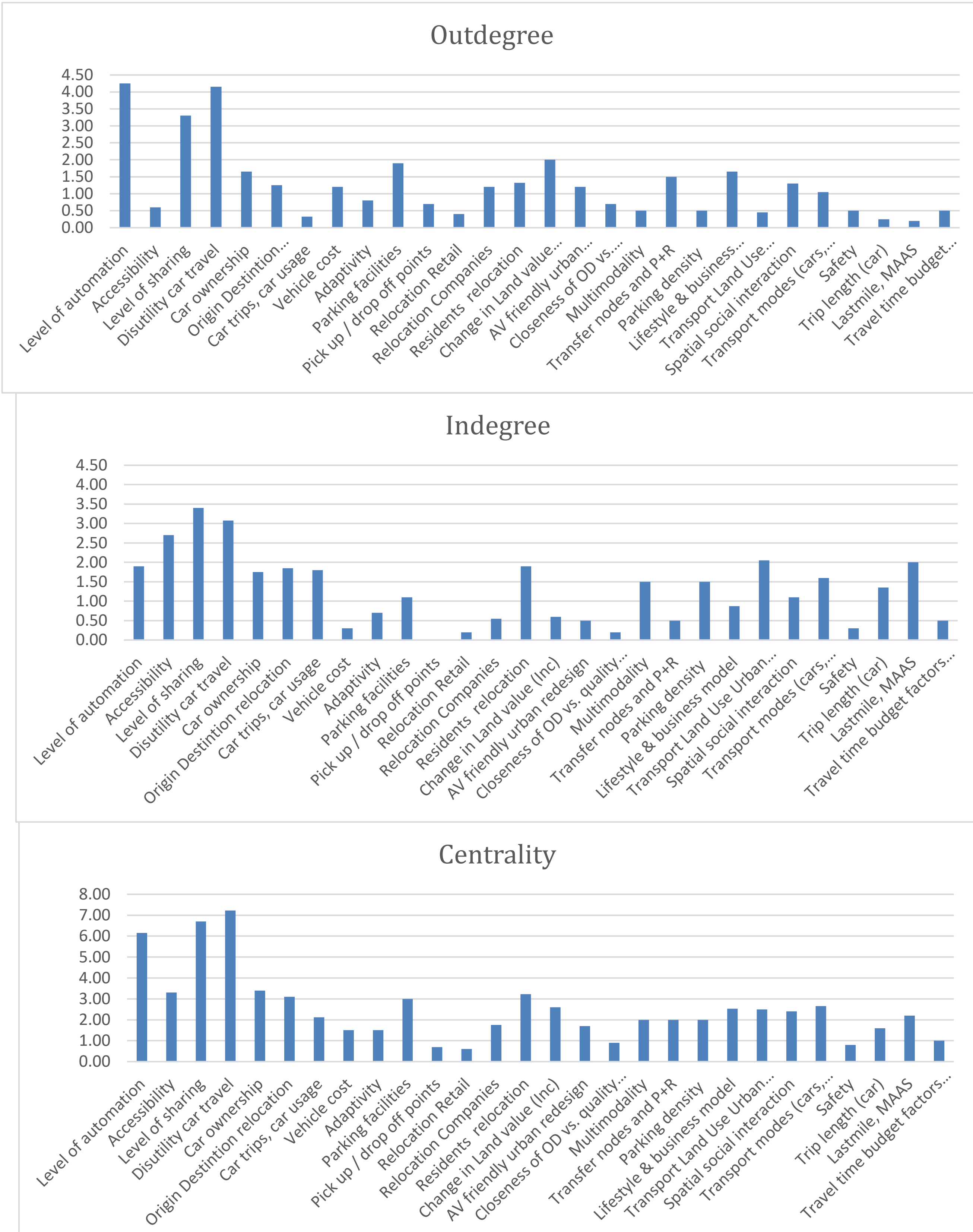


Figure 39 Outdegree, indegree and centrality of FCM - passenger

Change in land value, and transfer nodes and P+R tend to behave as transmitter as they had a high difference between outdegree and indegree. *Accessibility, last mile, MaaS, transport land use urban form*, and *number of car trips* tended to behave as receiver concepts as their indegree was higher than outdegree. *Level of automation and sharing, disutility of car travel*, *accessibility, car ownership*, and *resident relocation* were important concepts in the system. Table 19 shows the behavioral tendencies of concepts**.**

Relocation of retail, pick up drop off points, closeness of OD vs. quality of life, and *safety* were concepts that did not have high indegree or outdegree. Thus, they were relatively less important in the system. Nevertheless, they had indirect connections that influenced the degree of spatial impacts.

Concepts	**Transmitter / receiver / driver**
Level of automation	Driver
Accessibility	Receiver
Level of sharing	Driver
Disutility car travel	Driver
Car ownership	Driver
Number of car trips	Receiver
Vehicle cost	Transmitter
Pick up drop off points	*Transmitter
Change in land value	Transmitter
Multimodality	Receiver
Transfer nodes and P+R	Transmitter
Parking density	Receiver
Transport land use urban form	Receiver
Trip length of car	Receiver
Last mile, Mobility as a Service	Receiver

*means the concept is a pure transmitter or pure receiver

Table 19 Structural analysis of FCM concepts - passenger

<u>Result 2: Dynamicity of concepts</u>

Dynamicity of concepts were analyzed from iteration values of each concept. Equilibrium values were plotted against iteration values in the line graph shown in Figure 40 to analyze the changes in iteration values depicting the dynamic behavior of each concept. It showed that near-equilibrium conditions were reached within first 5 iterations. The entire system reached equilibrium in 34 iterations. All concepts started from equilibrium value 1 as set in the base scenario.

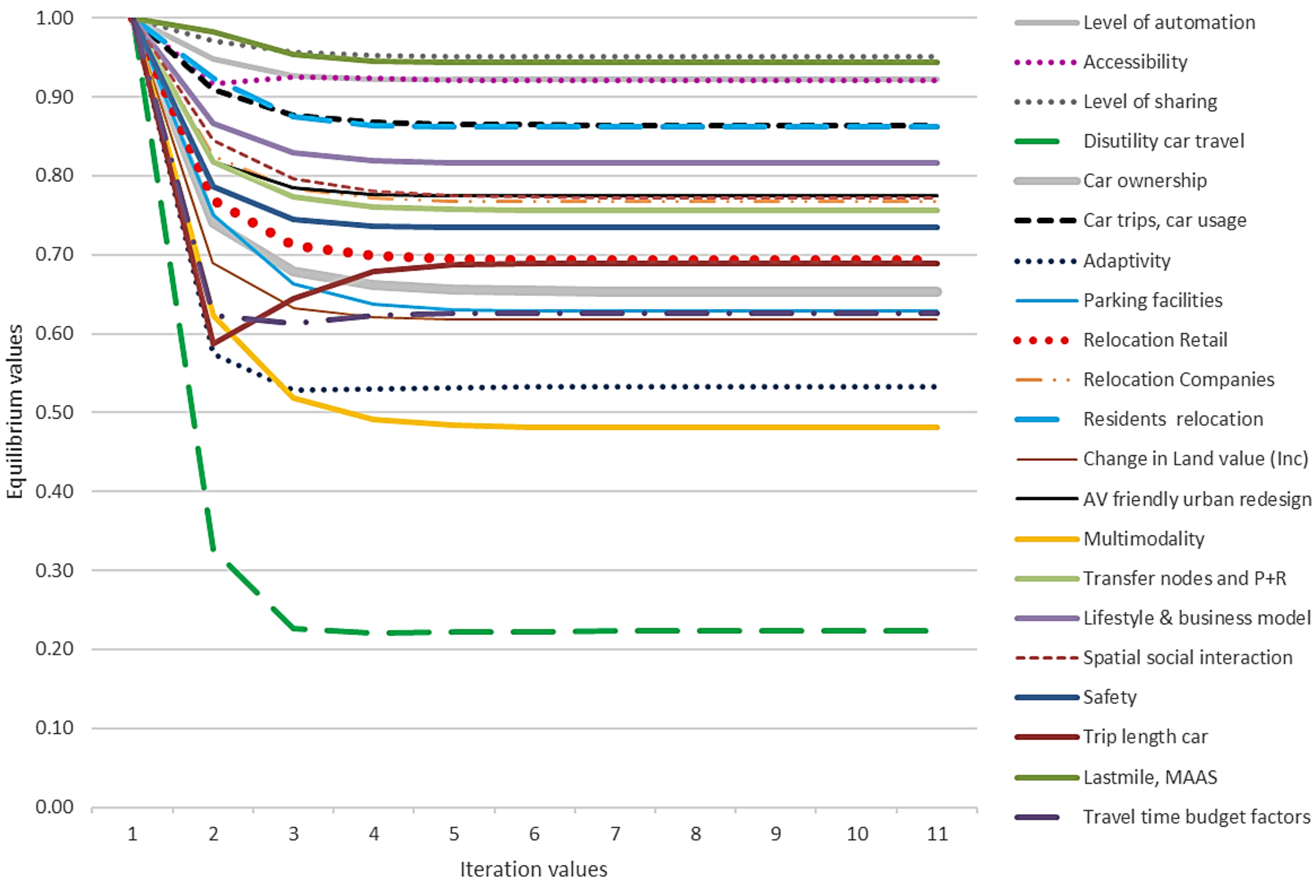


Figure 40 Modeled iteration value graph of FCM concepts - passenger

A common trend of behavior was found in most of the concepts. However, there were unique behavioral trends found in few concepts.

- *Level of sharing,* and *last mile, MaaS* stabilized with the highest equilibrium value. This implies that *sharing* and *MaaS* created relatively a higher influence on the system that was depicted in fuzzy cognitive map.
- *Accessibility* and *level of automation* stabilized at same equilibrium. However, their path towards equilibrium were different. *Accessibility* was expected to decrease before it increased to stabilize towards equilibrium. This showed its mild dynamic character in achieving equilibrium.
- *Disutility of car travel* stabilized with lowest equilibrium value relative to other concepts in the system followed by *multimodality*.
- *Lifestyle and business model*, and *AV friendly urban redesign* stabilized relatively above average (0.72). These concepts influenced the system more than relocation and mobility concepts.
- *Travel time budget* was likely to stabilize at an equilibrium above its initial decreased position. This showed mild dynamic behavior of the concept.
- It is interesting to note the behavior of the concept – *trip length of car*. It showed strong contrasting change in its behavior. It showed over 10% change in iteration value within 4 iterations.
- Among relocation factors, *relocation of residents* stabilized relatively highest. Followed by *relocation of companies* and *relocation of retail. Resident relocation* seemed to be more influenced and

sensitive to the system relative to other relocation factors. While *change in land value* seemed to be relatively less sensitive to influence in the system.

Result 3: Degree and direction of impact

The degree and direction of impact determined from FCM model is presented below. The spatial impacts on the system is summarized in the form of quadrants that represent the 4 input scenarios. The impacts perceived are grouped specific to themes for easier understanding of impacts of automation and sharing on spatial planning.

Spatial impacts

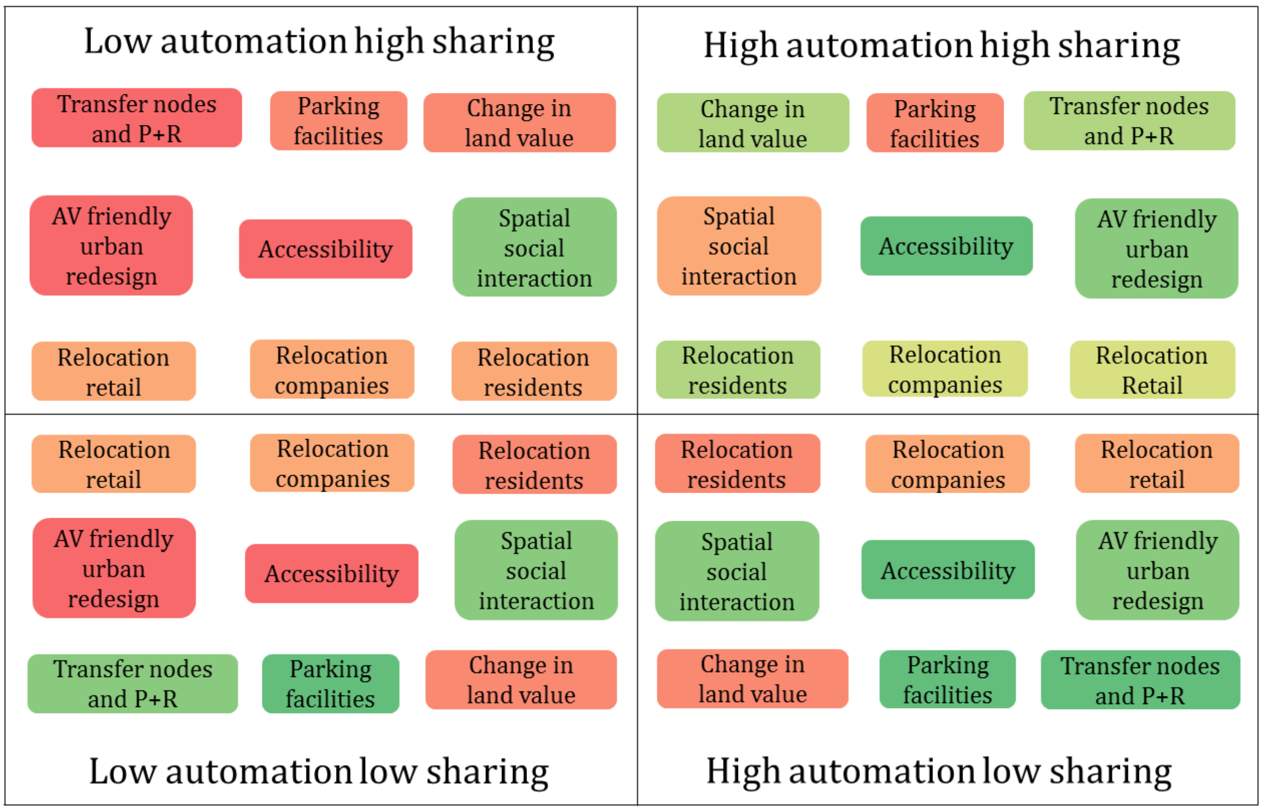


Figure 41 Spatial impacts of passenger automated vehicles

Result interpretation

➢ *Relocation of residents, companies, and retail* showed mild positive change in high automation high sharing scenario. It stayed negative in all other scenarios. This showed that relocation was only likely to occur in full automation and high sharing scenario; otherwise not.

- Similarly, *change in land value* was likely to relatively increase (become more expensive) only in high automation high sharing scenario. It was expected to be lower in other scenarios relative to high automation high sharing scenario.
- *AV friendly urban redesign,* and *accessibility* were likely to improve in high automation scenarios relative to low automation scenarios. The negative change of these concepts in low automation scenarios meant lower *accessibility* and *AV friendly urban redesign* relative to high automation scenario.
- *Spatial social interaction* was likely to reduce in high automation high sharing scenario relative to other scenarios in the system.
- *Parking facilities* was highly influenced by level of sharing. It was observed that *parking facilities* was likely to relatively reduce in high automation scenario while they seem to relatively increase in low sharing scenario.
- *Transfer nodes and P+R* was more likely required overall in all scenarios except for low automation high sharing scenario.

Mobility impacts

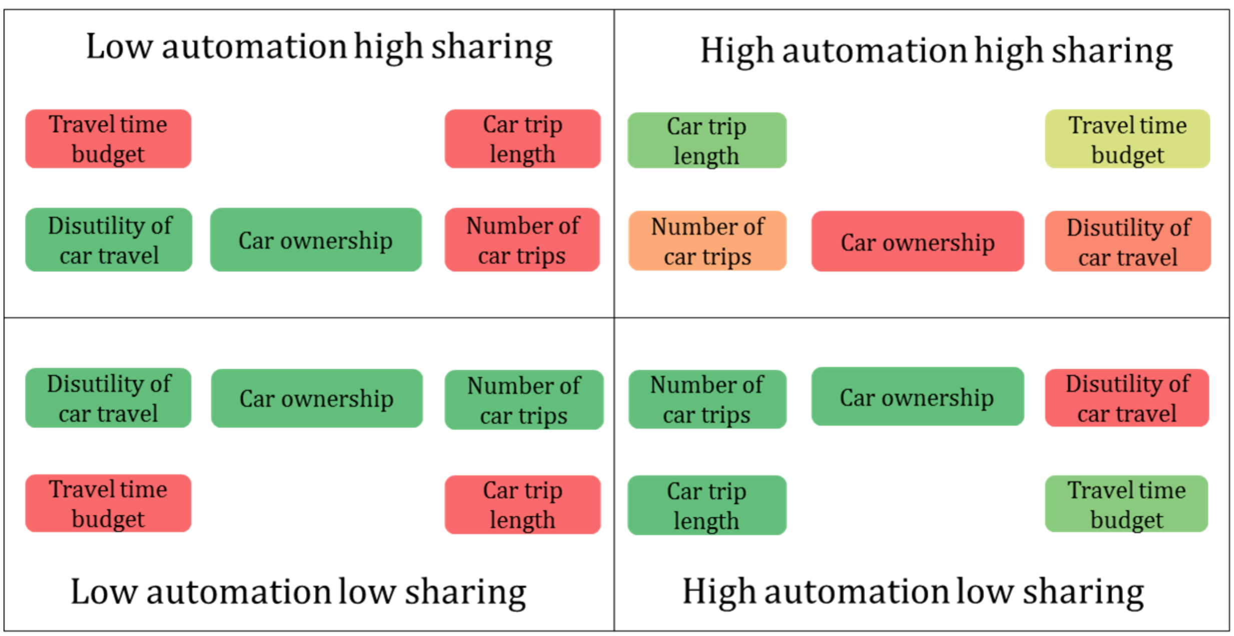


Figure 42 Mobility impacts of passenger automated vehicles

Result interpretation

- *Car trip length* might increase in high automation scenarios relative to low automation scenarios. Thus, it was highly influenced by *level of automation*. Similarly, *disutility of car travel* showed that it could relatively decrease in high automation scenarios relative to low automation scenarios.
- *Travel time budget* showed a medium-mild increase in high automation scenarios relative to low automation scenarios.

- *AV car ownership* was likely to strongly decrease in high automation high sharing scenario relative to other scenarios.
- *Number of car trips* were likely to mildly decrease in high sharing scenarios. It was notable that the model predicted the *number of car trips* to decrease more strongly in low automation high sharing scenario relative to high automation high sharing scenario.

Transport and lifestyle impacts

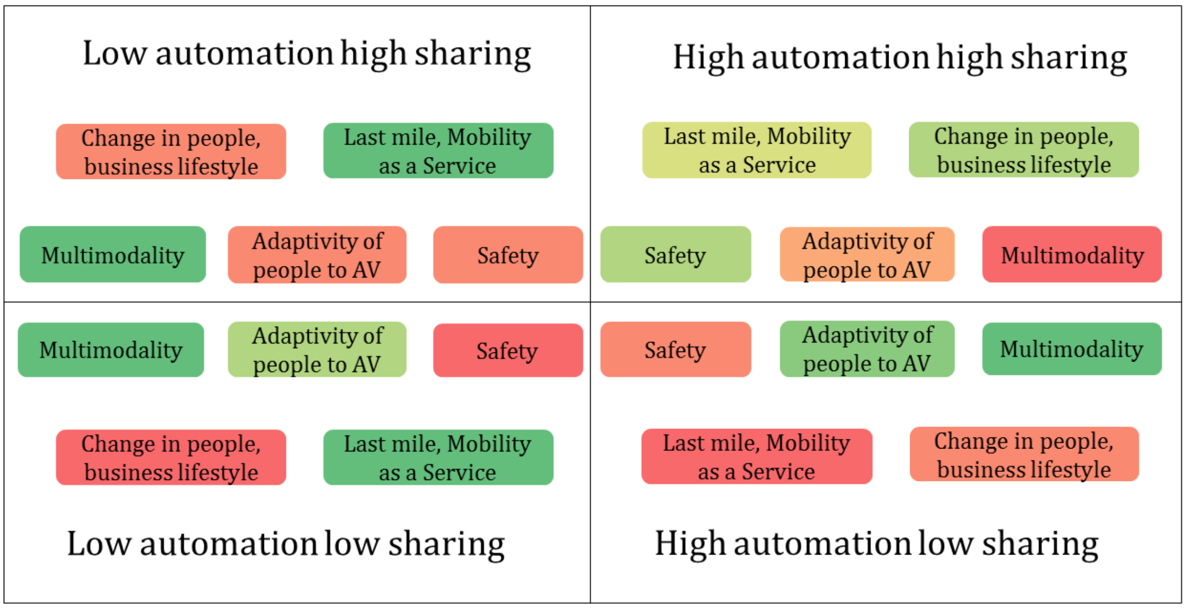


Figure 43 Transport and mobility impacts of passenger automated vehicles

Result interpretation

- Relative to other scenarios, *safety* was likely to mildly improve in high automation high sharing scenario. In relative context, safety was worse-off in low automation low sharing scenario.
- *Adaptivity of people to AV* seemed to improve in low sharing scenarios relative to high sharing scenarios. It is likely that this concept was more influenced by sharing than by level of automation.
- *Multimodality* was expected to strongly decrease in high automation high sharing scenario relative to other scenarios.
- The results also showed that *business and people's lifestyle* might have to change to adapt to transport developments in high automation high sharing scenario. Whereas, according to the model, such change might not be necessary in other scenarios.
- *Last mile and Mobility as a Service (MaaS)* was expected to improve strongly in low automation scenarios. It was interesting to note that relative to low automation scenarios, the model predicted a mild improvement in high automation high sharing scenario; and relatively deteriorated levels of last mile and MaaS in high automation low sharing scenario.

4.2 Sensitivity analysis

The variability of change was found by varying the state value of the concept with highest centrality. In this research, the experts were sometimes unsure of type of relationship (positive or negative) between concepts and wished to check the impact for both situations. These relationships were cases that needed assumptions due to lack of research, for example, people's adaptivity to automated vehicles could be positive or negative. Hence, the model was run for a positive relationship and negative relationship and the results were compared to observe the difference in results.

This revealed which concepts were most affected by people's adaptivity to automated vehicles and how important the concept was. To test such a case, the value in the FCM matrix was modified for positive and negative relationship within the value range -1 to 1. The impact of scenario was also checked by varying the strength of value in state vector within 0 and 1 for respective concepts. The concepts that showed different behavior with sensitivity analysis are explained below.

1. <u>Adaptivity of people to AV</u>

The analysis of combined map assumed *adaptivity of people to AV* to be positive towards level of automation and car ownership. However, this assumption had to be tested for its impacts if the concept was negative. Negative impact of adaptivity showed no change in results. This revealed that *adaptivity* maybe undervalued in this combined FCM. Or, it could also reveal that reduction of *disutility of car travel* was more decisive than *adaptivity*.

2. <u>Contrasting opinions on car ownership</u>

Combining maps manually helped identify contrasting or disagreement in logic that were interesting to note how expert's opinion differed. Moreover, such concepts also helped gain knowledge on uncertainty associated with them. Conflicting logic was observed during the event of combining cognitive maps. One of the experts believed that *level of automation* could have positive influence on *car ownership* (0.3) while another expert believed, *level of automation* could have negative influence on *car ownership* (-0.5). This showed how uncertain was the expectation of *car ownership* to behave when influenced by *level of automation*. Car ownership could be regulated through policy measures by the Government in practice. However, in this research, combining FCM matrix ratings led to a resultant of -0.2. This reveals that, as *level of automation* increases, *car ownership* is expected to decrease.

4.3 Result validation

Literature study revealed that transparency, plausibility and consistency were considered to be the three parameters for validating FCM results. The results obtained from FCM modelling were validated by sharing the results with the corresponding experts through email.

The experts were shared the output: (i) structure of FCM with the analysis of receiver, transmitter, and centrality of concepts (ii) the degree of impact of concepts due to 4 scenarios – high automation high sharing, low automation low sharing, high automation low sharing and low automation high sharing, and

(iii) the results of sensitivity analysis. The observation and implications of the results were explained. The experts were invited to reflect if the results from the model were in line with experts' views.

5 out of 8 experts validated the respective results, where they agreed to the results and behavior of the model. The remaining 3 experts did not respond to the email. Transparency of FCM process was gained by explaining the research process during interview process and by sharing the results with the experts. Plausibility and consistency of results were corroborated by sharing the results of FCM model with the experts. Internal consistency of the models was checked during content analysis, which ensured completeness and logic in fuzzy cognitive maps. The consistency of model results was validated through sensitivity analysis. Data validation process also ensured communicative validation thus clarifying the ideology of experts on the research topic.

The validation for combined FCM map was not straight forward as it was a result of combination of experts. Thus, combined FCM map was validated by the researcher by comparing the results obtained with results from other scientific researches.

1. Combined map validation by comparing with Wegener LUTI feedback loop.

By comparing the concept relations of combined FCM map with Wegener's LUTI feedback loop, a few contrasting points were observed. The combined FCM map revealed *disutility in car travel* to cause *relocation* and *relocation* led to increase in *accessibility*. However, Wegener's circle revealed that *disutility in travel* determined *accessibility* which further determined *relocation* as shown in Figure 44.

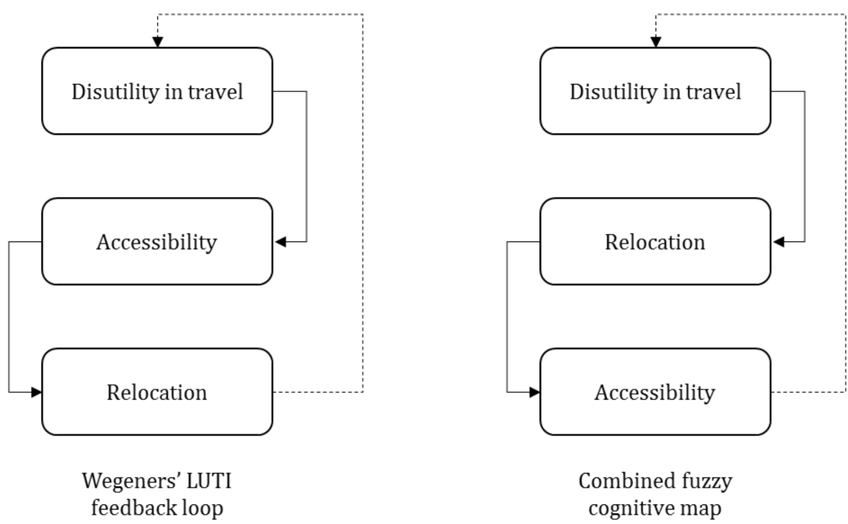


Figure 44 Comparison of concept influence pattern of Wegener's LUTI feedback loop and combined FCM map

This influence pattern in combined fuzzy cognitive map caused *accessibility* to be more of a receiver concept. However, by comparing the influence pattern of concepts with Wegener's LUTI feedback loop showed that the ideal requirement of this research was to have *relocation* concepts as receiver concepts instead of transmitter concepts.

Sensitivity analysis was carried out to test the combined FCM with adjusted influence pattern similar to Wegener's. It was found to have no change in results. This not only shows the validation of the result but also the presence of indirect loops in combined FCM map.

4.4 Conclusion

In this chapter, the results of FCM modelling were presented for two categories: automated freight vehicles and automated passenger vehicles in section 4.1. The 3 step results revealed the (i) structure of FCM, (ii) dynamicity of concepts and degree and (iii) direction of impact of the concepts. The structure of FCM revealed the character of concepts categorizing them into important, driver, receiver and transmitter concepts. The iteration value graphs showed if concepts exhibited dynamic behavior in the FCM model iterations. The degree of impact was summarized in the form of color coded quadrants. The results of degree of impact were presented in various themes apart from spatial impact. These results were additional results obtained from FCM modelling.

Sensitivity analysis was carried out for contrasting ideologies and some assumptions in this research were tested in section 4.2. The validated results of individual FCM map and a validation of combined FCM map with Wegener's LUTI feedback cycle was presented in section 4.3.

5 Conclusion, recommendations and discussion

5.1 Conclusion on research

This section provides conclusion in two parts. Firstly, the research questions defined are answered and secondly, the conclusion on research methodology is addressed.

In this research, the impacts of vehicle automation and sharing were explored and estimated. The results are concluded by answering the research question

To what extent does vehicle automation and sharing influence urban regions in the Netherlands?

The research was carried out for the case study Amsterdam. The impacts were explored and modelled for spatial, mobility and transport areas separately for automated passenger and freight transport modes. From the results of FCM modelling, it can be concluded that vehicle automation and sharing impacts urban regions mainly in high automation scenarios relative to low automation scenarios. The extent of impacts is answered through the sub research questions.

1. Through which causal paths do vehicle automation and sharing influence spatial elements?

The causal paths were identified from fuzzy cognitive maps created by experts during interview process. The causal path identified from the maps differ for automated freight vehicles and automated passenger vehicles.

For freight case it is found that, relocation characteristics depend mainly on cost factors. Increase in costs result in relocation of factories and distribution centers. However, vehicle automation reduces the flowing costs in freight:

- Inventory and handling costs
- Transport and labor costs

The map also reveals that sharing does not directly affect relocation characteristics of factories and distribution centers.

In passenger transport case, the identified spatial elements are

- Transfer nodes and park & ride facilities
- Change in land value, accessibility
- AV friendly urban redesign
- Resident relocation
- Relocation of companies and retail

The spatial elements involving relocation are primarily influenced by accessibility, disutility of car travel and travel time budget. It is observed that vehicle automation is expected to improve accessibility and sharing. Sharing is expected to reduce parking requirements that in turn reduces the disutility of car travel. The map further reveals accessibility and implement-ability of higher automation levels depend on AV friendly urban redesign. If AV friendly redesign is insufficient, it leads to rise in disutility of car travel.

2. Which are the most important factors in the identified causal paths?

The most important factors identified for freight case are the following:

- Level of automation
- Small automated electric trucks and truck platooning
- Safety

The important factors for automated passenger vehicles are

- Level of automation
- Level of sharing
- Disutility of car travel

The above factors are deemed important because of the number of influencing and dependent connections in the fuzzy cognitive map.

3. Which factors are uncertain and sensitive in these causal paths?

The iteration value graphs revealed that there were no factors showing uncertain behavior in the freight case. However, the analysis revealed that the pure receiver factor - relocation of factories is sensitive to the factors present in the causal path. This is because relocation of factories depends on the location of distribution and consolidation centers.

In passenger case, the factor - trip length of car was found to exhibit maximum uncertain behavior. Trip length of car depends on accessibility and sharing. Higher accessibility due to vehicle automation is expected to improve trip length of car whereas high rates of sharing is expected to decrease the trip length of car. Since the model simulation replicates temporal change, fluctuations in car trip length can be expected.

Combining maps manually helped identify contrasting logic in expert opinion. This revealed the sensitivity and uncertainty associated with expectation of car ownership when influenced by varying levels of vehicle automation.

4. *To what extent do the changes in vehicle automation and sharing influence spatial elements?*

There is no change expected to occur in relocation of factories and consolidation centers in any scenario. Relocation of factories and distribution centers to centralized locations occur only if the costs increase. High automation scenario is expected to reduce the costs in freight industry, thus causing no relocation. No relocation is expected in low automation scenarios. Sharing has no effect on relocation characteristics.

Overall, vehicle automation and sharing can have weak influence on land value and relocation characteristics in Amsterdam city. Weak increase in land value is expected causing relocation of residence, companies and retail from Amsterdam city to farther and cheaper locations. This is expected only in high automation high sharing scenario; otherwise no change is expected.

Vehicle automation and sharing is also expected to improve accessibility and cause medium changes in urban design of Amsterdam, requiring redesigning urban facilities to facilitate operation of automated vehicles on streets. Example: transfer nodes and pick-up drop-off points. This is expected to occur in both high automation scenarios.

Medium changes can be expected in parking facilities in Amsterdam in high sharing scenarios. Requirement for parking spaces is expected to reduce, thus allowing these spaces to be used for other purposes like buildings or recreational parks.

- Relocation of factories and distribution centers to centralized locations occur only if the costs increase. High automation scenario is expected to reduce the costs in freight industry, thus causing no relocation. No relocation is expected in low automation scenarios. Sharing has no effect on relocation characteristics.
- Weak relocation of residents, companies and retail can occur only in high automation and high sharing scenario as land value towards city center regions in Amsterdam is expected to increase in this scenario.
- Medium impact in parking spaces can be expected as parking requirement tend to decrease in high sharing scenarios. This could liberate parking space in Amsterdam that could be used for other purposes like buildings or parks.
- Medium impact in AV friendly urban redesign is expected to facilitate vehicle automation in high automation scenarios. This in turn improves accessibility in these scenarios. Additional research should be done to explore geographical locations and demand estimates for planning spatial elements concerning AV friendly urban redesign such as transfer nodes and P+R facilities and pick up drop off points.

- High automation low sharing scenario is likely to have maximum negative traffic impacts due to driving automation

High automation low sharing scenario seem to have the highest impact on mobility and traffic. This scenario shows *decrease in disutility of car travel* and *increase in number of car trips, car trip length, AV car ownership and increase in travel time budget*.

- People may adapt to vehicle automation easier than adapting to share

Adaptivity of people to AV is inversely influenced by *vehicle cost* and *disutility of car travel* that includes peoples' adaptivity to travel in automated car. The modelled results reveal that people may adapt to AV in low sharing scenarios than high sharing scenarios.

5.2 Conclusion on FCM methodology

FCM research is relatively a new method in scenario planning. This method was able to incorporate multi-perspective approach and effectively explore the spatial elements in the research topic. In this research, a new method to combine creative fuzzy cognitive maps was proposed.

- Combined maps prove to enhance reliability and accuracy of the results. The method of combining has shown successful implementation and combinability for fuzzy cognitive maps with high creativity without compromise on quality.

- It was also observed in number of cases, where combining maps had enhanced the meaning of logical concepts compared to individual cognitive maps. This shows the character of combined fuzzy cognitive map in providing holistic view on the system.

5.3 Recommendations

It is recommended that the city government should focus as much on sharing as on vehicle automation to aim for high automation high sharing scenario. Results reveal that high automation low sharing scenario provides negative impacts on mobility and traffic which would largely reduce transport efficiency and aggregate transport problems.

Parking spaces in and around Amsterdam city center are expected to be most valuable spaces in future as land value is expected to increase in high automation high sharing scenario. It may be of economic interest for the city government to regulate the parking spaces through leasing or rental schemes to private parking operators.

The model results for freight case seem to have questionable results. However, the results on passenger case seems reasonable. This clearly shows the advantage of combined map approach over individual maps. Research with more samples for freight is recommended to attain reasonable results.

Though sharing has shown to have impacts on relocation and land value through parking, experts consistently showed their skepticism on the success of sharing in practice. The city government may need to focus on sharing initiatives for societal goodness and perform detailed research for policy measures.

The results of this research may be applied for other cities with a follow up research. The same experts may be contacted and asked if they agree to the logic of FCM maps for any urban region in the Netherlands.

5.4 Discussion

In this chapter, the discussions towards FCM framework and modeling is explained.

FCM framework

Several choices are made to perform FCM modelling acknowledging practical constraints – availability of time and experts. Here, discussions involved in respective sub-steps are explicated.

Step 2: Knowledge capture

Interview vs. workshop

The most commonly used input data elicitation technique in FCM method is through workshops. (Van Vliet et al., 2010) show that participatory workshops are more suitable for quantitative models. In a workshop, a group of experts identify the concepts and develop the fuzzy cognitive map together whilst, in an interview the experts define their own mental map and concepts belonging to their expertise. The advantages and disadvantages of interview and workshop technique of gathering input data is tabulated in Table 20.

	Workshop	Interview
Advantages	Experts benefit and build on each other's ideas and knowledge leading to rich picture of the system and higher order-learning.	Interviews could help experts voice out their own ideology that they usually do not voice out in a group fearing controversy.
	Workshops require fewer contact hours with experts. Workshop results in a combined cognitive map and requires relatively less post processing, hence in overall, saves considerable amount of time.	Interviews can help to explore ideologies of each expert which provides insights on contrasting and similar views. Further, interview technique allows experts to be creative in choosing concepts and consider out of the box but plausible relationships in their mental models.
Disadvantages	Workshops may not capture every expert's views due to reasons such as: dominance of peer experts, limited opportunity to express their views.	Face-to-face interviews results in transcripts and individual cognitive maps that can be aggregated by the researcher to form combined cognitive maps. Both interviewing experts and developing cognitive maps are time consuming processes and needs post processing.
		It requires considerable effort, time, and skill by the researcher to educate, guide and interview all the experts to achieve desired results.

Table 20 Advantages and disadvantages of workshop and interview techniques of data gathering (Jetter & Kok, 2014)

In this research, due to limited availability of experts and the fact that not all experts could be present on a specific date for workshop led to choosing interview technique as knowledge elicitation purpose in this research.

Interview process:

Questions and concepts

In this research, to encourage creativity and out-of-the-box but plausible thinking of future system, the experts are urged to think of concepts that are not in the factor list presented. In order to be able to compare and aggregate cognitive maps, the experts are asked to use the concepts "level of automation", "level of sharing" by default in their cognitive maps.

Weights and rating

Every expert assigns weights to concepts they define. Though efforts are taken to classify the rating (--, -, 0, +, ++), it is to be acknowledged that not all experts have same benchmark in rating the concept connections. There exists literature on weighing experts on their credibility (Taber & Siegel, 1987), (Taber R. , 1991). However, in this research, it is assumed that all experts are considered to be equally important and valid.

Combining maps

In the case of face to face interview approach, the conventional combining technique usually works well when all experts are given the same concepts and asked to build fuzzy cognitive map from the concepts based on their expertise. However, this limits capturability of creative, plausible, out-of-the-box concepts. As a study to explore the spatial impacts of future scenarios, creativity is a key driver to the quality of research. The new methodology in combining facilitates to achieve creativity and combinability of cognitive maps, which implicates reliability and credibility of the research results.

It should be noted that not all maps obtained from experts are 100% complete in terms of establishing relationships. The experts create connections to concepts based on their knowledge and expertise. There had been countable cases where experts suspect a connection between concepts but is not sure about the strength of rating or even the direction of rating. Hence, these concepts are left unconnected than connecting erroneously. Combining maps allows ideas of experts to mingle leading to better level of completed connections.

Manual combining process helps identify logical reasoning of relationships between concepts and understand, weak (conflicting) and strong (similar) connections between fuzzy cognitive maps. This enriches knowledge about perspectives of experts towards their reasoning on contrasting future scenarios. It also helps to identify those contrasting ratings by coincidence that could cancel out with each other while combining. In contrast to combining process through software, such contrasting ratings are preserved for sensitivity analysis than letting it be cancelled out. However, the downside to manual combining process is that it takes lot of time compared to combining through software. It also leads to more simulation runs in FCM model to check sensitivity analysis.

Care should be exercised not to combine a cognitive map that is already combined. This leads to double accounting of rating in combined cognitive map. Similarly, while combining cognitive maps, care should be exercised not to duplicate connections between concepts, for instance, a direct connection in addition to an indirect connection.

Why average ratings while combining?

There are no criteria or rule that advises to average ratings of common connections while combining FCMs, however, averaging is the commonly used way to combining FCMs (Jetter & Kok, 2014), (Jetter & Schweinfort, 2011). In this research, it is assumed that all experts are equally important and hence equal weightage is given to ratings of every expert thus averaging.

FCM modelling

Squashing function in FCM model

Squashing functions are used to calculate the values of new state vector in each iteration. Thus, system's behavior in FCM modelling depends on the type of squashing function used (Jetter & Schweinfort, 2011). There are many types of squashing functions that can be used in FCM. They are binary function, trivalent function, linear function, and tangent hyperbolic function. The FCM model used in this research uses logistic function which introduces nonlinearity to the model. Impacts of different squashing functions could not be tested because the squashing function in the FCM model software could not be changed.

Logit squashing function used in this research. Van Vliet showed type of squashing function used alters the result of FCM. More research on finding the right squashing function for the right type of FCM research needs to be done.

Validation

Consensus

Literature say resolving disagreements between experts indicate model quality. In this research, disagreements are preserved to observe differences if any. Points of disagreements could indicate weak and uncertain links in the system. This can indicate further in depth research on the weak links to understand the dynamics and uncertainty of the factors in the system leading to improved plausibility of scenarios.

One expert who validated the results, echoed the concern to explain about benchmark of the degree of impact. The results obtained from FCM method classifies the degree of impact relative to the concepts declared by the expert in their fuzzy cognitive map. Hence, it is not possible to benchmark the degree of impact with respect to external environment.

Recommendations Further research

Is important to note that it is not considered that Amsterdam will always remain as an attractive magnet. For modelling relocation aspects. It makes the FCM more complex. This can only be known by further research for example through stated choice preference surveys.

Does sharing improve accessibility? In this research, not a single connection between sharing and accessibility was found in any of the cognitive map from the experts. Probably, experts are unclear about the impacts that sharing could cause. This topic needs further research.

The researcher has put great genuine effort to self-educate FCM method from experts and scientific literature to carry out this FCM based scenario study to near-perfect standards. It is never possible to rule out the possibility of insufficient expertise of the researcher to successfully conduct the FCM research study. It could also be the case that the experts had below-par level of understanding of FCM that could lead to unexpected results (Kok, 2009).

FCM needs a lot of time. Covering lot of topics in less time reduces in-depth capture. In order to capture quality in-depth concepts and relationships, ample time is a crucial ingredient for successful capture of concepts and ratings. For an insight, it is recommended to allot 2-3 days for scenario development through FCM workshop (Kok, 2009).

References

Alkim, T. (2016, July 12). Spatial impacts of automated driving. (S. Ramakrishnan Ganesan, Interviewer)

Amer, M., Daim, T., & Jetter, A. (2013). Futures: A review of Scenario Planning. *Elsevier*, 23-40.

Aura Din, M., & Moise, M. (2012). A Fuzzy Cognitive Mapping Approach for Housing Affordability Policy Modeling. In *Latest Advances in Information Science, Circuits and Systems* (pp. 262-267). Iasi: WSEAS Press.

Bachhofer, M. (2016, Nov). *FCMappers*. Retrieved from FCMappers: http://www.fcmappers.net/joomla/

Barth, M., & Shaheen, S. A. (2002). Shared-use vehicle systems: Framework for classifying carsharing, station cars, and combined approaches. In *Transportation Research Record* (pp. 105-112). Transportation Research Board.

Belloche, S. (2015). On-street parking search time modelling and validation with survey based data . *Transportation Research Procedia 6*, 313-324.

Bradfield, R., Wright, G., Burt, G., Cairns, G., & Heijden, K. V. (2005). The origins and evolution of scenario techniques in long range business planning. *Futures 37*, 795-812.

Bradfield, R., Wright, G., Burta, G., Cairns, G., & Van Der Heijden, K. (2005). The origins and evolution of scenario techniques in long range business planning. *Futures 37*, 795-812.

Centraal Bureau voor de Statistiek. (2016, November 15). *Bevolkingsontwikkeling, regio per maand .* Retrieved from CBS StatLine: http://statline.cbs.nl/Statweb/publication/?DM=SLNL&PA=37230ned&D1=17&D2=39,77&D3=118-119,131-132,144-145,157-158,170-171,182-189&HDR=G2&STB=G1,T&VW=T

Cepolina, E., & Farina, A. (2014). A methodology for planning a new urban car sharing system with fully automated personal vehicles. *European Transport Research Review 6*, 191-204.

Cervero, R., & Tsai, Y. (2004). City CarShare in San Francisco, California: Second-Year Travel Demand and Car Ownership Impacts . *Journal of the Transport Research Board 1887*, 117-127.

Correia, G. H., Milakis, D., van Arem, B., & Hoogendoorn, R. (2016). Vehicle automation and transport system performance. In M. Bliemer, C. Mulley, & C. J. Moutou, *Handbook on Transport and Urban Planning in the Developed World* (pp. 498-516). Cheltenham: Edward Elgar Publishing Limited.

Eden, C., & Ackermann, F. (2004). Cognitive mapping expert views for policy analysis in the public sector. *European Journal of Operational Research 152*, 615-630.

Eden, C., Ackermann, F., & Cropper, S. (2007). The analysis of cause maps. *Journal of Management Studies 29*, 309-324.

Enzer, S. (1981). Exploring long-term business climates and strategies with interax. *Futures 13*, 468-482.

ERTRAC. (2015). *Automated Driving Roadmap.* ERTRAC.

European Commission. (2016). *Declaration of Amsterdam: Cooperation in the field of connected and automated driving.* Minsitry of Infrastructure and Environment.

Geurs, K. T., & Van Eck, R. (2001). *Accessibility measures: review and applications.* Bilthoven: National institute of public health and the environment .

Geurs, K. T., & Van Wee, B. (2004). Accessibility evaluation of land-use and transport strategies: review and research directions. *Journal of Transport Geography 12*, 127-140.

Gordon, T. J. (1994). Trend Impact Analysis. *Futures Research Methodology*, 1-19.

Graduate school of Stanford Business. (2016). *Technological disruption and innovation in last-mile delivery.* California: Graduate school of Stanford Business.

Hiltunen, E. (2009). Scenarios: Process and Outcome. *Journal of Future Studies*, 151-152.

Huss, W. R., & Honton, E. J. (1987b). Scenario Planning - What Style Should You Use? *Long Range Planning 20*, 21-29.

Huss, W., & Honton, E. (1987a). Alternative methods for developing business scenarios. *Technological Foercasting and Social Change 31*, 219-238.

International Transport Forum. (2015). *Urban Mobility System Upgrade: How shared self-driving carscould change city traffic.* Paris: International Transport Forum.

Jetter, A., & Kok, K. (2014). Futures: Fuzzy Cognitive Maps for future studies - A methodological assessment of concepts and methods. *Elsevier*, 45-57.

Jetter, A., & Schweinfort, W. (2011). Building scenarios with Fuzzy Cognitive Maps: an explorative study of solar energy. *Futures 43*, 52-66.

Kamargianni, M., Li, W., Matyas, M., & Schafer, A. (2016). A critical review of new mobility services for urban transport. *Transportation Research Procedia 14*, 3294 – 3303.

Kamargianni, M., Li, W., Matyas, M., & Schäfer, A. (2016). A Critical Review of New Mobility Services for Urban Transport . *Transportation Research Procedia 14*, 3294–3303.

KiM Netherlands Institute of Transport Policy Analysis. (2015). *Driver at the wheel?* The Hague, The Netherlands: KiM.

Kok, K. (2009). The potential of Fuzzy Cognitive Maps for semi-quantitative scenario development, with an example from Brazil. *Global Environmental Change 19*, 122-133.

Kosko, B. (1986). Fuzzy cognitive maps. *Internatioal Journal of Man-Machine Studies 24*, 65-75.

Kosko, B. (1997). *Fuzzy Engineering.* New Jersey: Prentice-Hall Inc.

Kosow, H., & Gassner, R. (2008). *Methods of Future and Scenario Analysis.* Bonn: German Development Institute.

Koster, H. R. (2013). *The internal structure of cities: The economics of agglomeration, amenities and accessibility.* Amsterdam: Tinbergen institute, Vrije Universiteit Amsterdam.

Le Vine, S., Zolfaghari, A., & Polak, J. (2014). *Carsharing: Evolution, Challenges and Opportunities.* Brussels: European Automobile Manufacturers Association.

Lefebvre, H. (1978). *State, Space, World.* Minneapolis: University of Minnesota Press .

Levin, M. W., & Boyles, S. D. (2015). Effects of Autonomous Vehicle Ownership on Trip, Mode, and Route Choice. In T. R. Board, *Transportation Research Record: Journal of the Transportation Research Board* (pp. 29-38). Washington, DC: Transportation Research Board.

Litman, T. A. (2014). Autonomous Vehicle Implication Predictors: Implications for Transport Planning. *Transport Research Board*, 36-42.

Meijers, E. J., & Burger, M. J. (2010). Spatial structure and productivity in US metropolitan areas. *Environment and Planning A 42*, 1383-1402.

Michon, L., & Slot, J. (2014). *Amsterdamse trends.* Amsterdam: Gemeente Amsterdam Bureau Onderzoek en Statistiek.

Mietzner, D., & Reger, G. (2004). Scenario Approaches - History, Differences, Advantages and Disadvantages. *EU-US Seminar: New Technology Foresight, Forecasting & Assessment Methods* (pp. 47-66). Seville: JRC European Commission.

Milakis, D., Snelder, M., van Arem, B., van Wee, B., & Correia, G. (2015). *Development of automated vehicles in the Netherlands: scenarios for 2030 and 2050.* Delft, The Netherlands: Delft University of Technology.

Milakis, D., Van Arem, B., & Van Wee, B. (in press). Policy and society related implications of automated driving: a review of literature and directions for future research. *Journal of Intelligent Transportation Systems: Technology, Planning, and Operations*, DOI:10.1080/15472450.2017.1291351.

Mouratiadou, I., & Moran, D. (2007). Mapping public participation in the Water Framework Directive: A case study of the Pinios River Basin, Greece. *Ecological Economics 62*, 66-76.

Mumford, L. (1961). *The city in history: Its origins, its transformations, and its prospects.* New York: Harcourt Brace Jovanovich.

Onderzoek, Informatie en Statistiek. (2016). *Kerncijfers Amsterdam 2016.* Amsterdam: Gemeente Amsterdam.

Oxford dictionary. (2016, November 15). *English Oxford living dictionary*. Retrieved from English Oxford living dictionary: https://en.oxforddictionaries.com/definition/impact

Özesmi, U., & Özesmi, S. L. (2004). Ecological models based on people's knowledge: a multi-step fuzzy cognitive mapping approach. *Ecological Modelling 176*, 43-64.

Petersen, R. (2004). *Land Use Planning and Urban Transport.* Eschborn: Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ) GmbH.

Peterson, G. D., Cumming, G. S., & Carpenter, S. R. (2003). Scenario Planning: A Tool for Conversation in an Uncertain World. *Conversation Biology*, 358-366.

Pillkahn, U. (2008). *Using Trends and Scenarios as Tools for Strategy Development: Shaping the Future of Your Enterprise.* Erlangen: Publicis Corporate Publishing.

Porter, A. L., Roper, A. T., Mason, T. W., Rossini, F. A., & Banks, J. (1991). *Forecasting and Management of Technology.* New York: John Wiley & Sons Inc.

Porter, M. (1985). *Competitive Advantage: Creating and Sustaining Superior Performance.* London: Free Press.

Ringland, G. (1998). *Scenario planning: managing for the future.* Chichester, West Sussex: John Wiley & Sons.

Ritchey, T. (2003). Nuclear Facilities and Sabotage: Using Morphological Analysis as a Scenario and Strategy Development Laboratory. *44th Annual Meeting of the Institute of Nuclear Materials Management* (pp. 1-6). Arizona: Swedish Morphological Society.

SAE International. (2014, December 18). *J3016 "Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems".* SAE International. Retrieved from The Center for Internet and Society: http://cyberlaw.stanford.edu/blog/2013/12/sae-levels-driving-automation

Schoemaker, P. (1995). Scenario Planning: A Tool for Strategic Thinking. *Sloan Management Review*, 36 (2), 25-40.

Schoemaker, P. J. (1991). When and How to use Scenario Planning: A Heuristic Approach with Illustration. *Journal of forecasting*, 549-564.

Schoemaker, P. J. (1995, Winter). Scenario Planning: A Tool for Strategic Thinking. *Sloan Management Review*, pp. 25-40.

Schwartz, P. (1991). *The Art of the Long View.* New York: Doubleday.

Shaheen, S. A., & Cohen, A. P. (2013). Carsharing and Personal Vehicle Services: Worldwide Market Developments and Emerging Trends . *International Journal of Sustainable Transportation* , 5-34.

Shoup, D. (2006). Cruising for Parking. *Transport Policy 13*, 479-486.

Sivak, M., & Schoettle, B. (2015). *Influence of current non-drivers on the amount of travel and trip patterns with self driving vehicles.* Michigan: University of Michigan Transportation Research Institute.

Sołtys, J., & Smolnicki, P. M. (2016). Driverless Mobility: The Impact on Metropolitan Spatial Structures . *Procedia Engineering, 161*, 2184-2190.

Somers, A. (2015). AUTOMATED AND SELF-DRIVING VEHICLES - WHAT MIGHT IT MEAN FOR MANAGING THE ROAD NETWORK? *AITPM 2015 National Conference* (pp. 1-15). Brisbane: Australian Institute of Traffic Planning and Management Incorporated.

Stylios, C. D., & Groumpos, P. P. (1999). Mathermatical Formulation of Fuzzy Cognitive Maps. *7th Mediterranean Conference on Control and Automation (MED99)*, (pp. 2251-2261). Haifa, Israel.

Taber, R. (1991). Knowledge Processing with Fuzzy Cognitive Maps. *Expert Systems with Applications 2*, 83-87.

Taber, W., & Siegel, M. (1987). Estimation of experts' weights using fuzzy cognitive maps. *IEEE International Conference on Neural Networks* (pp. 319-326). San Diego: IEEE International Conference on Neural Networks.

Townsend, A. (2014). *Re-programming mobility.* New York: NYUWagner Rudin Center for Transportation Policy & Management.

U.S. Department of Transportation. (2015). *Benefits Estimation Framework for Automated Vehicle Operations.* Cambridge: U.S. Department of Transportation.

U.S.Department of Transportation. (2016). *Federal Automated Vehicle Policy.* Washington DC: USDOT, NHTSA.

Van Nes, R. (2016, June 2). Spatial impacts of automated vehicles. (S. R. Ganesan, Interviewer)

Van Notten, P., Rotmans, J., Van Asselt, M., & Rothman, D. (2003). An updated scenario typology. *Futures 35*, 423-443.

Van Vliet, M. (2011). *Bridging gaps in the scenario world - Linking stakeholders, modellers and decision makers.* Wageningen : Wageningen University.

van Vliet, M., Kok, K., & Veldkamp, K. (2010). Linking stakeholders and modellers in scenario studies: the use of Fuzzy Cognitive Maps as a communication and learning tool. *Futures 42*, 1-14.

van Vught, F. (1987). Pitfalls of forecasting: Fundamental problems for the methodology of forecasting from the philosophy of science. *Futures 19*, 184-196.

Van Wee, B. (2016, June 6). Spatial impacts of automated vehicles. (S. R. Ganesan, Interviewer)

Vecchiato, R., & Roveda, C. (2010). Strategic foresight in corporate organizations: handling the effect and response uncertainty of technology and social drivers of change. *Technological Forecasting and Social Change 77*, 1527-1539.

Wegener, M., & Fürst, F. (1999). *Land-Use Transport Interaction: State of the Art.* Dortmund: IRPUD.

Zmud, J., Sener, I. N., & Wagner, J. (2016). *Consumer Acceptance and Travel Behavior Impacts of Automated Vehicles.* Texas: Texas A&M Transportation Policy Research Center.

Annexures

Annex 1: Scenario planning methods

Planning beforehand helps to overcome uncertainties while executing an event. Previous planning would give detailed steps to help execute an event. However, this is not complete. This traditional planning tool does not consider the effect of second degree variable elements that influences the uncertainty of an event (Schoemaker P. J., 1995). Scenario planning simplifies the number of what–if scenarios while it considers most of the variable elements that influence the environment of an event. Moreover, it also conveys how various elements could interact with other elements under certain conditions (Schoemaker P. J., 1995). In contrast to traditional planning, scenario planning enables to explore complex environment with many uncertain variables (Schoemaker P. J., 1991) while ensuring the system is internally consistent thus providing rich picture and enabling informed decisions.

Scenario planning was used by the Royal Dutch Shell in early 1970s as a part of exploring strategic options before the great oil crisis. It helped the company to be prepared during the crisis and revive quickly. It also helped companies Electrolux, Pacific Gas and Electric, Erste Allgemeine Versicherung by being prepared for various uncertainties (Ringland, 1998). (Peterson, Cumming, & Carpenter, 2003)states "Scenario planning offers a framework for developing more resilient conservation policies when faced with uncontrollable, irreducible uncertainty". Scenario planning allows to be enlightened about the uncertainties in the system, incorporate multi-perspectives to provide a rich picture and make more informed decisions while framing policies (Peterson, Cumming, & Carpenter, 2003).

Scenarios are built in order to be educated about possible outcomes of the uncertain nature of future (Porter M. , 1985). A scenario is an internally consistent view of possible future situation. It is not a prediction rather a range of plausible situations that is likely to occur. Scenarios help to innovate the future by breaking down the mental models and providing insights on near term, medium term and long term planning. Hence, there is a potential to innovate for solutions depending on temporal requirement (Hiltunen, 2009).

Classification of scenario planning methods and techniques

There are several approaches to scenario planning. (Amer, Daim, & Jetter, 2013) summarizes the literature review on scenario planning that there are various methodologies for generating scenarios with desirable characteristics. The most cited scenario planning literature is that of Schwartz and Schoemaker (Amer et al., 2013). A Review of Scenario Planning Literature (Chermack et al., 2001) briefly explains the step by step approach of Schwartz (Schwartz, 1991) and Schoemaker (Schoemaker P. , 1995). The steps stated by both authors are summarized in Table 21.

	Peter Schwartz (1991)	**Schoemaker (1995)**
Step 1	Identify focal issue	Identify scope of project
Step 2	Identify key forces in scope	Identify key stakeholders

Step 3	Brainstorming the driving forces	Identify and map the trends in causal maps or matrices
Step 4	Ranking the key factors and driving forces based on degree of importance and degree of uncertainty	Identify and consider the key uncertainties. Including relationships among the uncertainties
Step 5	Development and selection of scenario logics	Initial scenario construction: positives and negatives
Step 6	Check sensitivity of the factors leading to scenarios and plausibility of scenarios	Check for plausibility and internal consistency of scenarios
Step 7	Examine implications of scenarios	Check for sensitivity of indicators on scenario
Step 8	Monitoring leading indicators that unfold possible scenarios	Check for blind-spots and examine plausible outcomes
Step 9		Development of quantitative models
Step 10		Choose scenarios for decision making

Table 21 Step by step approach to scenario building (Chermack et al., 2001) (Schwartz, 1991) (Schoemaker P. , 1995)

Classifying scenarios by perspective, they can be distinguished to descriptive and normative scenarios (Porter, Roper, Mason, Rossini, & Banks, 1991). Descriptive scenarios are explorative in nature whereas, normative scenarios are goal oriented. Descriptive scenarios provide insights on a range of plausible alternative future events. Normative scenario responds to concerns in planning to achieve the set goals. Further, scenarios are also classified on the characteristics of topic, breadth of scenario scope, and level of aggregation (Amer et al., 2013).

Another common distinction in scenario building methodology is based on level of complexity (i.e.) ranging from simplistic to complex, qualitative to quantitative approach (Amer et al., 2013). The extent of qualitative or quantitative approach influences the data input type. Qualitative scenario follow narratives and storylines as a part of their approach whereas quantitative scenarios extensively use statistical and computational tools (Vecchiato & Roveda, 2010). However, due to constant change and uncertainty, and cross application of scenario planning methodology in various fields, there are exists numerous scenario planning methodologies to classify and to adopt.

The existence of many scenario planning approaches can also be categorized in terms of school of thought that advocate various scenario planning techniques (Amer et al., 2013). These are (1) intuitive logics, (2) probabilistic modified trends (PMT) and, (3) the French approach of La prospective.

In brief, intuitive logic is the most commonly used scenario planning method that is used for qualitative approach where explorative research is required (Bradfield, Wright, Burt, Cairns, & Heijden, 2005). Intuitive logic was first proposed by Herman Kahn at the Rand Corporation, USA in 1960s. However, it was extensively used by Pierre Wack at the Royal Dutch Shell (Mietzner & Reger, 2004). Intuitive logics does not involve any quantitative step at any point in the methodology (Pillkahn, 2008). It should be realized that this approach strongly relies on knowledge, communication skills, credibility and commitment of the scenario team members (Amer et al., 2013).

School of Probabilistic Modified Trends (PMT) comprises quantitative scenario techniques usually matrix based methodologies. As the name suggests, it involves probabilistic modification of extrapolated trends. This school advocates two different matrix based methodologies for scenario planning, namely, Trend Impact Analysis (TIA) and Cross Impact Analysis (CIA) developed by Futures and the RAND corporation respectively (Amer et al., 2013). Both these techniques were developed on the principle that it is unrealistic to forecast an event or extrapolate historic data without considering occurrence of other key impacting events and or unprecedented future events (Chermack et al., 2001) (Bradfield et al., 2005) (Huss & Honton, 1987a). Hence, TIA uses qualitative factors in addition to traditional forecasting techniques for a robust scenario analysis (Huss & Honton, 1987b). However, it requires exhaustive and reliable time series data. It also requires the researcher to be adept with statistical and probability theory (Mietzner & Reger, 2004). In CIA, a range of causal and correlation cross impact variants are developed in a cross impact matrix hence capturing the interrelations between main influencing factors (Gordon, 1994). The shortcoming of CIA is that it needs to be contained within certain limits, otherwise could go out of control to gain infinite knowledge and robustness of the results (Mietzner & Reger, 2004). Other techniques developed for conducting CIA are Interactive Future Simulations (IFS), Interactive Cross Impact Simulation (INTERAX) and Cross Impact Systems and Matrices (SMIC) (Amer et al., 2013).

The French school - La Prospective is used for longer term planning. Created on the principle that future may be deliberately created and modeled, this approach results normative scenarios and future images that serves as guiding path for achieving set goals (van Vught, 1987). The French approach La Prospective is a combination of quantitative and qualitative approach nearly like the blend of probabilistic modified trends and intuitive logics (Bradfield et al., 2005).

Quantitative scenario planning techniques

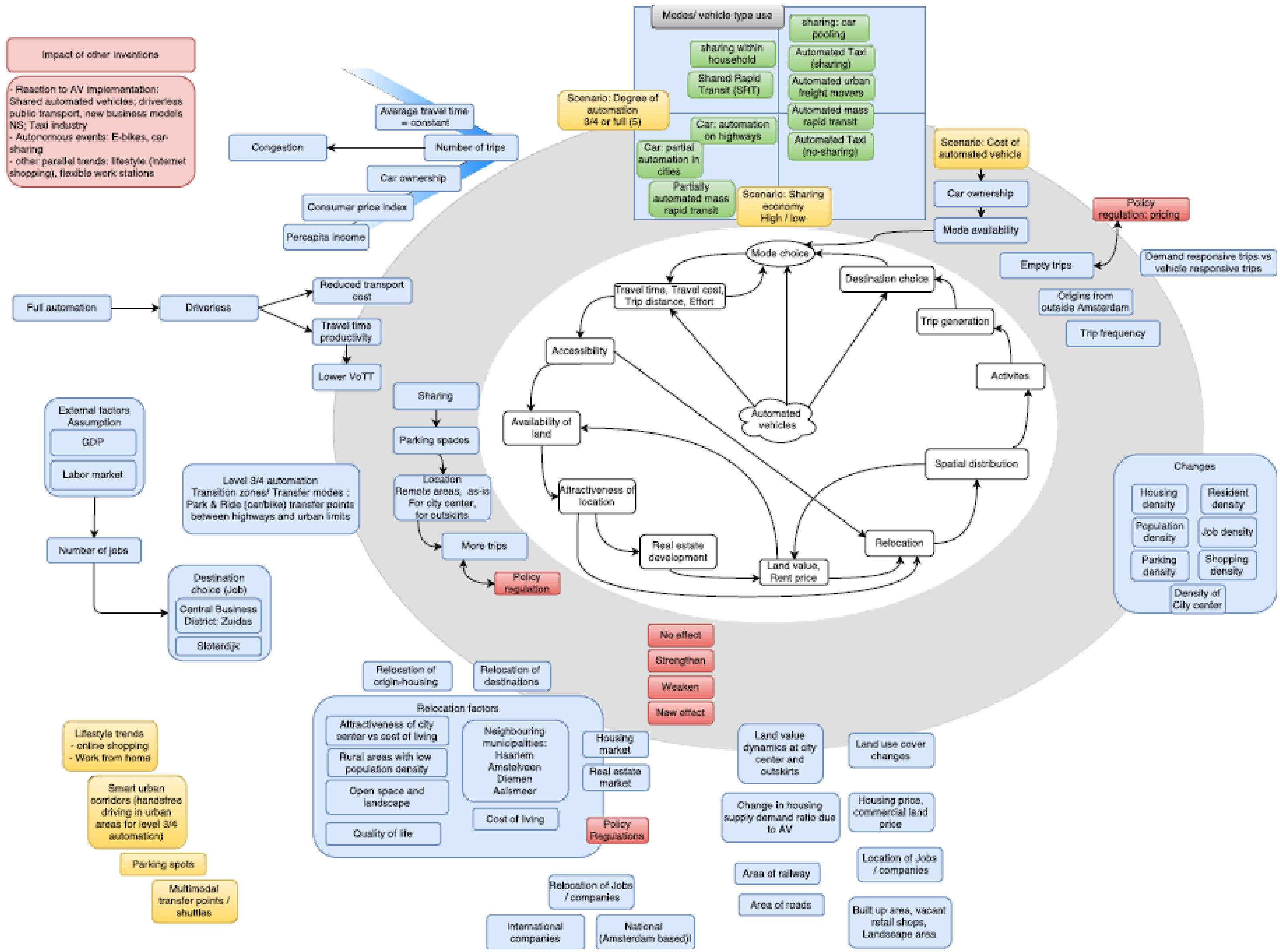
Most popular quantitative scenario planning methods summarized by (Amer et al., 2013) are Interactive Cross Impact Simulation (INTERAX), Interactive Future Simulations (IFS), Trend Impact Analysis (TIA) and Fuzzy Cognitive Map (FCM) based scenario planning.

While the approach of TIA has been discussed in the previous section, the INTERAX method uses both analytical and expert judgment to show possible future options. Through iterative process, this method explores alternative futures from the broad possible future options. This approach calls for a Delphi study with large group of experts to develop a multi-disciplinary database with broad range of long range vital strategic issues, future trends and events. INTERAX helps in understanding how conditions can branch from one evolutionary path to another and how policy can help regulate these conditions (Enzer, 1981). While INTERAX can combine the strengths of CIA and TIA, the disadvantage of this method is that the selection of combination of events to occur at the first time-step is based on random selection using user entered probabilities. There is no consideration as to the combination of events would be likely to occur (Huss & Honton, 1987b).

(Huss & Honton, 1987b) summarizes the principle behind methodology of IFS as it promotes long range perspectives and provides insights into dynamics using cause and effect relationship. It encourages innovative ideas, urges contingency planning and provides warning whenever major changes in environment is noticed. Unlike INTERAX, IFS does not require independent forecast of key factors as it does not use Monte Carlo simulation and results are generated based on level of consistency and relative likelihood of occurrence. Another advantage of IFS is that it is usually a computer based software allowing rapid analysis of sensitivity. However, the shortcoming of IFS is that the software simulates scenarios as calculated to appear at the end of the modelled temporal environment. Hence incorporation of time dynamics is not straight forward and hence the researcher needs to make explicit conditions to explore the alternative futures.

Annex 2: Mental map

Amsterdam


Impact of other inventions
- Reaction to AV implementation: Shared automated vehicles; driverless public transport, new business models NS; Taxi industry
- Autonomous events: E-bikes, car-sharing
- other parallel trends: lifestyle (internet shopping), flexible work stations
Average travel time = constant
Congestion
Number of trips
Car ownership
Consumer price index
Percapita income
Full automation
Driverless
Reduced transport cost
Travel time productivity
Lower VoTT
External factors Assumption
GDP
Labor market
Number of jobs
Destination choice (Job)
Central Business District: Zuidas
Sloterdijk
Level 3/4 automation
Transition zones/ Transfer modes : Park & Ride (car/bike) transfer points between highways and urban limits
Sharing
Parking spaces
Location
Remote areas, as-is
For city center, for outskirts
More trips
Policy regulation
Modes/ vehicle type use
sharing within household
Shared Rapid Transit (SRT)
sharing: car pooling
Automated Taxi (sharing)
Automated urban freight movers
Automated mass rapid transit
Automated Taxi (no-sharing)
Scenario: Degree of automation 3/4 or full (5)
Car: automation on highways
Car: partial automation in cities
Partially automated mass rapid transit
Scenario: Sharing economy High / low
Scenario: Cost of automated vehicle
Car ownership
Mode availability
Policy regulation: pricing
Empty trips
Demand responsive trips vs vehicle responsive trips
Origins from outside Amsterdam
Trip frequency
Mode choice
Destination choice
Travel time, Travel cost, Trip distance, Effort
Trip generation
Accessibility
Activites
Automated vehicles
Availability of land
Spatial distribution
Attractiveness of location
Real estate development
Land value, Rent price
Relocation
Changes
Housing density
Resident density
Population density
Job density
Parking density
Shopping density
Density of City center
No effect
Strengthen
Weaken
New effect
Relocation of origin-housing
Relocation of destinations
Relocation factors
Attractiveness of city center vs cost of living
Rural areas with low population density
Open space and landscape
Quality of life
Neighbouring municipalities: Haarlem Amstelveen Diemen Aalsmeer
Cost of living
Housing market
Real estate market
Policy Regulations
Lifestyle trends
- online shopping
- Work from home
Smart urban corridors (handsfree driving in urban areas for level 3/4 automation)
Parking spots
Multimodal transfer points / shuttles
Relocation of Jobs / companies
International companies
National (Amsterdam based)
Land value dynamics at city center and outskirts
Change in housing supply demand ratio due to AV
Area of railway
Area of roads
Land use cover changes
Housing price, commercial land price
Location of Jobs / companies
Built up area, vacant retail shops, Landscape area

Annex 3: Questionnaire

Questionnaire

Demographic			
Name		Occupation Organization	
Age		Home country, City	

General questions			
Knowledge areas (Expertise)			
Years of experience in field of expertise			
Projects/situations similar to spatial impact of AV			
Familiarity with Automated driving technologies	Expert	Good	Average
Familiarity with Fuzzy Cognitive Mapping tool	Expert	Have worked with it once	Heard about it

Goal:

- To explore relationships (+/-) between key concepts that has influence on spatial impact due to the prospect of automated vehicles.
- Spatial impact due to automated vehicles:
    - Spatial impact not only means relocation of residents, jobs as a result of cheaper land values; but also land use for new services, automated distribution centres, drop off/pick up points, urban infrastructure redesign as a result of lifestyle changes, travel accessibility changes.
    - The spatial impact could vary from AMS city centre level to Metropolitan region AMS or even further.

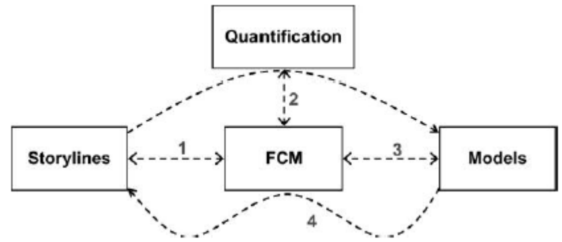
How?

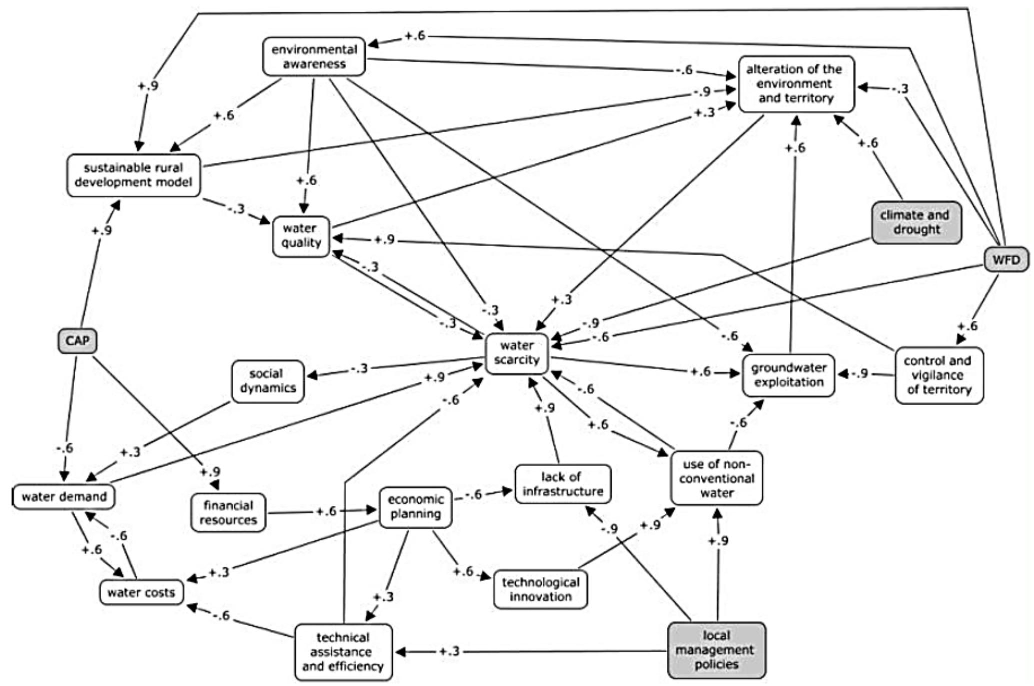
- Identify factors that help to identify key concepts
- Establish relationship between the concepts and rate the relationship [-1 to 1]
- Provide confidence level of the relationship rating [Sure, highly likely, probably, uncertain]
- Provide weight to the identified key concepts
- Identify parameters/concepts that are sensitive

- Assumptions / policies / scenarios to guide line of reasoning.

About FCM, AVs

Fuzzy Cognitive Map is a depiction of perception of a system. It involves cognitive mapping of key concepts and linking them like causal loop diagram to define relationships. The strength of relationship between 2 concepts is advocated by experts based on a fuzzy logic pattern **(-1 to 1)**. The key concepts are weighted (0-1). FCM is also used as scenario analysis tool. The quality of FCM is enhanced by including **feedback loops** and confidence of the strengths.





Example of the graphical representation of a Fuzzy Cognitive Map, as developed in the Candelaro basin in Italy. Grey boxes indicate outside drivers of the system; numbers indicate strength of the relationships. Adapted from (Khadra et al., in press).

Automated vehicles: Technologically advanced vehicles that allows automation in driving in various levels. Example: partial automation on highways (level3), self-driving vehicle (level5).
Characteristics: Improves comfort in driving for drivers, productive in-vehicle time*, a prospective for sharing vehicles, traffic efficiency, longer trips, more frequent trips, lower travel cost. Possible impacts on various categories.
Assumptions: Travel time budget exists;
Scenario 1: high automation (5), high sharing;
Scenario 2: low automation (3/4), low sharing.

Type/Auto, level	**Level 3 (low auto.)**	**Level 4 (low / high auto.)**	**Level 5 (Full auto.)**
Example tech.	Highway chauffeur	Parking garage pilot, truck platoons	Robot taxi, truck platoons
Passenger char.	Highway chauffeur	Automated shuttles, buses (last mile), limited parking automation	Fully automated in any urban/highway setting
Freight char.	Highway chauffeur	Truck platooning, last mile urban freight delivery system	Fully automated in any urban/highway setting
Environment	Truck platooning in limited	C-ITS, Controlled	Anywhere

	sections: highways	environment	

Factor pool	**Key concepts**	**weight (0-1)**	***"Drivers & Consequence"***
Automation level Implementation: Level 3 vs. Level 4 vs. Level 5 Sharing Adoption rate			
Mobility Platooning, B2B (refillers), B2C (last mile) Reliability Last mile connectivity New modes: Truck vs. automated vans etc. Electric vehicles			
Traffic Trip length Trip frequency Congestion, travel time Safety Signaling			
Spatial level -Within city center (urban-roads) -Outskirts of city center (ring-roads) -Zones in AMS (5) -Metropool region AMS (motorways)			
Infrastructure constraints - Width of streets - Parking area relocation characteristics - Urban redesign - Transition zones- highway|city - Pick up/drop off points - Upgradation of ring road networks - Urban freight distribution centers			
Legislation Parking fee Costs Efficiency (air) Efficiency (Supply chain)			

Trends Lifestyle trends -Online shopping delivery - Shops delivery, Urban sprawl			
New innovative services?			
Stakeholders			

Completing connections	
Complete the key considerations on the map, pen & paper	
Narratives	Narrate, encourages to reflect and deliberate - recording
Rating narratives	Strength of influence Confidence of strength Level of importance of the relationship Probability of occurrence
Note	Use ranges to define when unpredictable Define rating scale with intensity examples

Annex 4: Interview transcript

Experts were not sure of the difference between autonomous vehicles and automated vehicles. Though the term autonomous vehicles are used by many experts, this does not affect the data quality as the functional capabilities of automated vehicles was explained before beginning the discussion of spatial impacts.

The experts were given a sheet with various factors that relate to the spatial impacts of automated vehicles that were extracted from literature study. These were used to stimulate and steer the thinking of the experts.

First an introduction about the research and questionnaire was debriefed. The questionnaire contained information about FCM building method, rating and automation level implications on vehicles. This was followed by brainstorming session where open ended questions about familiar concepts were discussed. This is to help the interviewee to guide along the topic of discussion and help define his/her system. The entire interview was recorded and later transcribed. The transcript was sent to the interviewee for verification upon which it has been used in this research as input.

1. Expert 1

Interview

The effect of automation might be limited unless ride sharing is assumed. For ride sharing, and the same is true for car sharing, automation is not a requirement. In fact, that would be feasible tomorrow. Exception might be that level 5 automation could change the scene: in theory, automated vehicles could be available for everyone. Sharing economy and its effects can be anticipated not before level 5 automation according to a scientific paper in Transport Research Board.

- ➢ *Accessibility connects transport mode and land use according to Wegener's feedback circle. How much can a new mode (unique travel time and travel cost characteristics) impact the spatial preference?*
  - Considering level of automation 3 and 4, there is an opportunity for multimodal trips. Level 3-4 automation are expected to be able to drive without any human interference on highways. This could possibly lead to development of transition zones at off-ramps that could serve as park and ride (P+R) facility. This possibility seems more likely for activity end trips.
  - Other parallel inventions also can have influence. For example, E-bikes can now travel at higher speeds and longer distances that increases accessibility. For instance, e-bikes and level 3-4 automation can provide a multimodal transport connection for passengers.
  - Internet services, and flexible working locations like work from home could change the lifestyle trends that influence destination choice. This also has an influence on spatial location of shopping and work areas. However, automation does not play a direct role here.
  - There could also be reactions to invention of automated vehicles that can have an impact on mobility thus spatial impact. The railway service NS or metro/tram could have a different business model to prevent losing their market share to automated vehicles. The Taxi industry is expected to have a strong reaction to automated vehicles but it is not sure if this will be successful not.

➢ *What are the plausible spatial impacts that can be anticipated from automated vehicles?*

- Automated vehicles can have impacts on shopping density. The impact on relocation depends on the demand and availability of land. The area of relocation depends on attractiveness of the area. For example, Paris is more attractive than living at neighboring areas in France. Constraint of being close to job plays a more weighted role than choosing the ideal place to live. But with AV, in future, could be that residential relocation is less bound by job location.
- Goals of municipality between high density housing and land use regulations to expand decides the spatial structure of the city.
- There is a relation to closeness to previous location. This exists for household as well as office.
- Central Business District (CBD) like Zuidas needs multimodal accessibility and agglomeration factors. These characteristics are well balanced at present with the role of public transport and P+R facilities. Cities need the benefits that mass transit provides.
- The number of people the system transports is way higher than the number of cars required to transport the same number of people. High demand on existing infrastructure means space constraint to handle such demands.
- Considering the aspect of MaaS, providing demand responsive trips and ensuring vehicle occupancy rates is a challenge. Asymmetrical and symmetrical demand influences vehicle occupancy rates.
- Travel time budget notions may change which seems to have shown consistency in the past and present. With level of automation and travel time enrichment increasing, this might no longer stay constant.
- If the trip lengths could be shorter or longer. AV can enable longer trip lengths. But not too long where trains are comfortable.
- Driving automation technology can enable multimodal travel capabilities. Example automated shuttles can enable last mile transport for passengers. But competes with biking and walking which have strong modal share in the Netherlands.
- Liveliness of cities characterizes urban areas that some population groups find it attractive.
- It is possible that the land use in the rural areas could change in land use. Automated vehicles have more impact in those regions where transport modes are limited. Such areas provide quiet and green living conditions and hence may grow.
- Shared Rapid transit (SRT) have big effects on meeting travel demand. It has high likelihood of occurrence.

2. Expert 2

Interview

➢ *Comments about the research topic*

- Amsterdam is a small city. Amsterdam center is more popular than Bijlmer or other surroundings. Residents on average prefer to live in the center over moving to the suburbs. Commuting from the suburbs to the center is quite fast. So, automated vehicles are not needed to move to the suburbs. However, it will be different to move to a place 17km away, because it is attractive and green, and the car automatically drives you to work. But I don't think it will play an important role in the scale of Amsterdam region.
- I am familiar with this theory of travel time budget, but it is unclear if it will also apply if we drive in automated vehicles. Because then the generalized transport cost will go down and you might be able to use the in-vehicle time more efficiently. So, it could be that this theory will not apply under a scenario of a lot of people having accustomed to automated vehicles because they might accept them over time in travelling. So, it is uncertain. It may remain stable but it could also go up, I would hypothesize.
- AV may have mode choice effects, may have origin and destination effects, trip frequency effects which are a bit less clear. It could also be that for the parents who now bring the children to lessons need not do that anymore as they cars can drive the children automatically. Though it might save trips for parents, the consequence is that the trips that compensate would be additional trips to other destinations. That is also possible. Such effects also could be included in the model.
- I think accessibility improves as a result of which you also might have effect on trip generations. Because accessibility improves, people might also substitute destinations or live somewhere else.
- Main concern for Amsterdam is the question how policies deal with what is going to happen. I can imagine if people in large scale substitute travelling by train for travelling by AV, they won't want AVs in central urban area of Amsterdam. So probably there will be restrictions on cars in general. So, the policy response is an important issue to deal with.
- Another issue is parking, depends on if we share vehicles or not, we might have less or more parking problems. Where are they going to park? Close-by or somewhere remote, which leads to additional set of movements related to parked vehicles which could generate more traffic, congestion. Maybe the local government does not want that, and says you cannot drop someone at the railways station if the result would be a lot of movements of AV to remote parking places. So, it is a very important question for the policy makers.
- Another remark I think relates to the importance of dynamics to adaptivity. It is probably not just one scenario that will be the outcome of this conceptual model. It is probably more dynamic. If the vehicles are more expensive, then the effects on mode choice will be very limited compared to scenario with cost of vehicles being cheap. And if vehicles are cheap, we could impose levies on such vehicles if they cost so much trouble. Maybe we could implement a charge per kilometer to avoid lot of empty vehicles driving to save few parking fees. For 0.20eur per km it doesn't makes sense to park the vehicles 30 km away from Amsterdam. Adaptivity and dynamics are important concepts in this model and research.

➢ *Apart from mentioned spatial impacts (in the model), what are other possible, out-of-the-box spatial impacts that we can anticipate around dense urban cities? Both for passenger and freight. It is more likely that heavy long trucks will be automated to work only in freight and not in urban areas as clearly the automation of heavy vehicles in dense cities cause more negative impacts.*

- It could be that destinations could relocate like shops. It is difficult to visit a shop in the center but outside the center, it could also be that there is implication of autonomous vehicles.
- It could be that new services will emerge. Maybe you can send you car to pick up groceries as supposed to supermarkets delivering goods at home.
- Maybe we will have neighborhood distribution centers, because we do not want all people to send their car to pick up goods from supermarket, it leads to spoiling of the neighborhood by AVs. Maybe we will say for neighborhoods there will be designated places where all goods need to be brought to, to avoid a lot of traffic in neighborhoods. Maybe at the end of the day, people can pick it up on the way home from destination as people can be notified by message that packages are waiting. This is a spatial impact that could evolve anyway.
- Parking: maybe we will reallocate road space. For example, more space for cyclists if they feel unsafe because of all the AVs that are not directly responsible. There are people who have suggested that in central urban areas, pedestrians will always win as AVs will spot them anyway. That could spoil the advantage of the whole system. As a response, the police might fine people for doing that, which could reduce the problem.
- In spatial context, parking rates in center of Amsterdam is very expensive. For a garage, it costs about 150,000 Euros in the center. Maybe people don't need that anymore because the vehicles can automatically drive to a cheaper parking spot.
- Maybe new taxi services could emerge based on AVs. Which also means it solves last mile problem as AV can drive you to the destination. Maybe it will affect PT (tram), some people hypothesize. But the cost of travelling with AV is not known for this event to occur. Vehicle maybe expensive but costs of driver is cut. But the overall costs relative to conventional mode is still not known.
- In freight distribution, most costs are labor costs. If the freight companies switch to AVs, that cost would go down. Maybe the city might decide only electric vehicles are allowed in the center, including freight. This implies that the trucks need to stop somewhere outside the city and transfer goods to electric AVs that will deliver to central places.
- Policy aspect: currently delivering goods is restricted to time of day. These restrictions may be removed if electric vehicles can load and unload quietly. E vehicles are quieter. Maybe time of day, distribution pattern for freight might change.

➢ *Can we expect changes in spatial distribution factors like housing density, job density, etc. due to automated vehicles compared to current distribution?*

- A lot depends on policies, if we would not avoid a lot of negative externalities related to AV's, the city center will be crowded with AVs and people will not like it. It may reduce the attractiveness of center and people may move to the outskirts of town. Policy makers will not accept that and impose restrictions to avoid that.

- On the other hand, the city center could become more attractive because you do not need a car anymore, it can be parked elsewhere, maybe it pick you up at home and drive you. So those people who don't want to live in city center due to parking restriction of cars, may find it more attractive to live in the city center.
- Housing prices could therefore go up or down, could lead to selection of specific groups who can still afford to live in Amsterdam. Maybe only high income people can live at center. On the other hand, if they don't have restrictions to degradation of livability prices could also go down, leading to high income people to move out, though it is highly unlikely case.
- People have hypothesized that city center would become the place where you watch products, try cloths, but don't buy it anymore. It will be bought online. This can influence trips made.
- Tourism is important for Amsterdam. Amsterdam fears the overloaded non-western tourists that the city can't handle anymore. It could be that AVs have some relations with them. For example, via Airbnb etc., it is possible to distribute people more equally over the city, facilities with AVs, it could also help in dealing with increase in demand for tourism to stay in center or stay outside center of Amsterdam and AV bring them to center as it is cheaper. So, it could also affect the distribution and capacity of tourism.

➢ *Amsterdam is a small city, and if people choose to relocate, could it be that they relocate to Utrecht? Also, do you feel urban sprawl can occur?*
  - Urban sprawl is a concept often referring to cities becoming less compact and people living in outskirts but still travelling to center for commuting or other purposes. In the Netherlands, the cities are compact but the people commute between cities and vice versa. So, the cities are compact but the trip patterns are dispersed.
  - I don't think AVs will resolve in lot of dispersion, urban sprawl with respect to places with new houses, because of restrictive planning policy. Did not allow new neighborhoods to be developed anywhere in the open space. Probably it remains the same. It could occur that intercity travelling due to AVs. Because generalized cost going down so people may live somewhere else and work at Amsterdam. So, I expect more dispersed crisscross patterns of any travel.
  - Another expansion maybe to be driven. If it is expensive to rent a hotel room or private house like Airbnb, but AV brings you in 30mins to Hilversum, then you may decide to go there. So, interurban traffic or any purpose.

➢ *Would there be an impact on growing and dying areas in metropool region of Amsterdam due to AVs? What areas and what impacts?*
  - High pressure in whole metropool region of Amsterdam. There are few places that are not popular to live but are relatively popular than remote places like in the North. De-populating areas are not in greater metropool area but are elsewhere in the Netherlands.

➢ *What kind of changes can we expect at Central Business District i.e. Zuidas due to AVs? Or can we anticipate another CBD somewhere else in cities that could start developing?*
  - Theoretically yes, but in practice, the Zuidas, I am not sure if this would not have occurred if we would have driven less cars, maybe a bit less. But there is a clustering and image effect in those

areas. They don't evolve from calculation of cheapest place to locate offices. Therefore, I don't think that reduction in generalized transport cost (GTC) will have a lot of effects on that, also is uncertain. Based on timescale. It could be that in the north of Amsterdam, a new center will emerge. But on the other hand, due to image reasons, it is a bit hesitant to say. Because the southern part is more popular, close to Schiphol, Rotterdam and Utrecht. Hence I am not sure if new CBD will evolve thanks to AVs.

- *Land regulations of Amsterdam try to preserve green areas strictly. At present, there is pressure in demand and supply of housing market in Amsterdam. Due to lack of space, people are forced to move out if they can't pay the expensive rent. Realizing this pressure, can we expect a real estate boom in housing market to occur, acknowledging the impacts and accessibility of AVs?*
  - Theoretically you would expect that GTC relax the pressure of central urban areas with high prices. Because lower GTC means you can live further away still accessible to your destination. However, this in theory. In practice, it is not sure as we won't allow lot of AVs to travel to city center. And the public transport (train) is already good to support such commutes. Maybe we will see more AVs for park and ride. People currently don't live near a station, or commute by car, can say I travel by AV to a place where I switch to continue my trip by a metro or bicycle. The overall tendency is that the pressure on housing market will probably reduce a little as people have more options to live.

- *Online commerce is gaining importance. Upon research, it is found that number of vacant retail stores are increasing year on year. This is growing to a number that cannot be neglected anymore. However, these are very valuable land space. On the other hand, there is residential market pressure. Can we expect any change in land use type? Also, probably no new retail develops in outskirts or in center or development of shopping malls as an agglomerate?*
  - It is difficult to answer as it depends on the effect of policies. If those new shopping areas would result in deterioration of shops in suburban areas probably we will not exempt them. On the other hand, if it is a distribution center where people send AV to get their products, can we afford it as it is not shopping but distribution center. On the other hand, it can also be that the city becomes even more attractive as people only want to pick up something and they don't have to travel to center anymore. So, it could also improve livability of central urban areas. What is also important is we can also redesign urban land uses. Maybe shops located in central urban areas can move to outskirts because AVs reduce GTC as a result of which we can buy apartments in city center. This is what is done in many places in city center. This increases number of dwellings in Amsterdam. AVs could also local policy also with respect to out of town shopping malls.

3. Expert 3

Interview

➢ *What are the main drivers for freight industry? Is it the transport cost or are there other factors?*

- If you take freight, it's all about cost. Not all, there are 2 different types in freight. There is long distance and short distance (intracity). Though the long-distance goods use synchro-modality but roads are used anyways. In a scenario study by PBL it is expected that freight on roads to increase by 25% - 50% by 2050. This will be seen in big trucks because the technology is there and roadmap is being planned. So even level 3 and 4 already will have impacts. After 11 hours shift to stop the truck, the driver's resting time of 8 hours can be converted to travelling time then distance covered can be increased by 40% for the same cost. Second driver may not be necessary, and there will be minor fuel savings. So, with autonomous driving the impact is that the transport cost will go down. Which means we will see volumes changing mode from train to road. From IWW also changing to road. So, there will be a huge increase in the freight on road.
- Secondly for distribution centers there is always a tradeoff between inventory cost, handling cost and transport cost. The basic factor to decide will the lead time, which will be like 1-3 days a year. Distribution center with cost going down can have bigger reach. So instead of shipping 500km, we will see distribution centers shipping 1100km away. Which means in spatial context, there will be centralization of warehouses which in-turn will have big impact on where the location of factories is. For Holland as a distributing country it makes more sense to expect these changes.
- For urban freight, it's not only about cost but also value of time. The shipment must reach the customer when the customer prefers to receive it. For example, in construction site the vehicles should be exactly between 7.00-8.00hrs, customers want shipment delivered while they are at home, bars want their shipment when they open. So, there is lot of time definite constraints. All the urban freight will be small vans. Now we see light electrical vehicles, they are ideal for autonomous driving. DHL is testing it. As long as they drive 5-6kmph it is fine for urban use. So, I expect the impact the cost of shipment will go down. Important factor while thinking about cost is the value density (value/m^3). Most products having low value density are upstream and in downstream, looking at what goes into towns, the transport cost is very small of compared to the value of shipment. So, in these cases, reducing transport cost has no effect in the way such companies do business. However, autonomous driving will have an impact on parcel delivery to consumers because that is more efficient. This might lead to consumers shopping more online.
- Autonomous driving will make a big difference. Especially for web stores, most of the times the parcel goes to houses when customers are not at home creating loss. Big trucks have parking space problem. So, lot of time is spent in searching for parking space in a town. Using, Autonomous car combined with light electrical vehicle concept can increase productivity by 50%. Cargo bikes has already shown increase productivity.

➢ *Categorizing freight vehicles in spatial terms, truck platooning has shown promise especially in motorways, secondly, urban freight delivery vehicles like B2B, and thirdly B2C.*

- In towns, only 20% goes to customer, rest 80% trips are B2B deliveries. Retail is only 5% of urban freight. Big ones are construction 35%, garbage collection, bars, HORECA, and then stores (retail).

➢ *The markets and the sectors are like e-shopping and delivery and in future, the groceries may be delivered to home?*

- To consider is senior market. 25% of people are not mobile enough to do the shopping and only 18% have family that can take care of them. That alone is a bigger market than the e-commerce market 10years from now. There is huge need to have small time critical deliveries that needs to be shipped in town.

➢ *Pick up points have shown some growth at the present. What is the future of this concept?*

- It's a good system. Research on address intelligence by Ron van Duin showed that in certain areas it will be profitable. Because most of the times consumers are not at home. They certainly have future. Now we are tending to move from big stores to nano-stores like convenient stores that serves as smaller pickup points.

➢ *We discussed about the freight in relation with spatial road networks. There also exists an important concept which is the transition zones. For instance, a truck has to leave from the formation while entering the city limits. In future, would there be an influence on location of distribution center based on highways?*

- Yes of course. For instance, Albert Heijn is already investing in Nieuwegein. But, Netherlands at present, is not very suited for platooning. Because NL is not linked like the TENT. That will be realized soon. Once they are reliable then, it will be safe. Only 20% trucks go abroad and platooning can be used better for longer distances. To answer your question, it will surely change spatial planning. The best way to make the platooning work is if they all are going to the same address. So, we can expect lot of consolidation centers. That is what we can see happening in food and chemical industry. So, there could be big consolidation centers near manufacturing centers. And close to the cities, there could be big centers dedicated to freight operations – decoupling what goes into cities.

➢ *Size of vehicles in city centers – will there be a change towards smaller lighter vehicles?*

- Yes, but not for big retail companies. Example Albert Heijn needs full truck load every day to refill the stores. The same is the case with building materials. In urban freight, 85% is done by LCV and that will go to 90%. The rest 15% is be done by large heavy trucks. There will be no autonomous garbage trucks. Neither in these light commercial vehicles though they will be smarter.

➢ *Would last mile delivery system go electric in future?*

- Yes, 2025 zero emission is signed by many municipalities. Co2 is a major issue. Transportation industry is the only industry that has not decreased the carbon footprint. Light electrical vehicle has a great potent to minimize these emissions. And since there is the pressure to cut the carbon footprints, I am sure that electric vehicles have to be used. Big trucks can become hybrid with various fuel alternatives. But for small vehicles they don't have a choice other than electric.

➢ *How does safety concept apply in this scenario? Would it be a main driver to automation?*

- It will surely be safer. But if a human error makes mistakes, people can forgive it. But not if a system does an error. Spatial changes in city center of Amsterdam is not possible. It is very difficult. But the system of automation can change. Example the waste collection can be done at night etc. To make it AV friendly, new controlled environment has to be created. That is not easy. For instance, if we have car sharing, then there might be less cars on the road and then it might be possible to use the space in a better way. There is a big potential for last mile in urban areas.
- I am afraid that automated driving's impact on sharing is making travelling in cars way cheaper and comfortable that people might prefer road over train. Eventually the time savings in autonomous driving will be considerable compared to any other mode. Also, because there is no necessity to change modes. The constraint associated with parking, if solved by automated parking, then there is no constraint at all.

➢ *Can you explain more about impacts of level 3 automation?*

- Many trucks in Netherlands already are in level 3. The only impact of level 3 I can see is in terms of number of incidents. This is what the insurance companies are also saying. It is only in terms of safety.

➢ *Do you think there could be a new sharing service/economy in freight industry? For instance, a sharing service between DHL and Post.nl?*

- Yes, they will. But both DHL and Post.nl are both very efficient networks. They should never combine. Sharing capacity is one of the best examples of coal trailers. It is the biggest company in renting out such tipping trailer. There might be something like that but that is not autonomous driving. When there is autonomous driving, why would a company outsource truck operations? Further, why would the manufacturer sell the trucks? Rather, I predict that the manufacturing companies like Mercedes Benz and Scania will be the new transportation (trucking) companies. They have the opportunity to operate with the lowest cost possible. Only one company has to earn the profits and maybe there will be a completely different way of sharing, maybe with different partners. We will see a change in ownership of the fleet. Third party supply chain companies may still be required though. An example of this is the BMW's car sharing system.
- In towns, taxi services like Uber is more likely.

➢ *What about legislation?*

- Lobby! It will take 20-30 years. Some favorable, some unfavorable. But municipality can have its own regulations. Other legislations will be on labor conditions. That will have a big impact on regions in Europe. It sounds very simple but will take very long time to happen.

➢ *Any comments on deployment?*

- Depends on depreciation of truck. Also important is the special lanes for automated driving. Once the infra is set, the system will come into practice. Just like Euro IV to Euro V. And, the demand of transport vs. available number of drivers.

4. Expert 4

Interview

- *Which levels of automation is most likely to be implemented first?*

  - Personally, I think there are many issues with level 3 as there is an uncertainty on who takes the responsibility: the system or the driver. So, I believe more in level 2, 4 and 5. When it comes to the well-known OEMs I think they will focus on level 2 and level 4. The people movers, shuttles etc. would be interesting for certain dedicated areas and those works on level 4/level 5. So, there are two parallel paths and they will co-exist next to each other.

- *If the adoption rate of such AV needs to increase, the cost of vehicle is a main factor. There are some arguments in the internet saying the cost could increase because of technology but could also reduce because the cars can be constructed on lighter frames. What do you expect to happen?*

  - If you look at the price of Tesla models, you can get an idea of the cost of the car. The price of the car will be relatively high by few hundreds to few thousands compared to the current prices of a standard car, depending on the implemented (amount of) functionalities.

- *How do you think the automated system will work together with the conventional traffic safely?*

  - The answer is they have to. Reaching full penetration rate will not happen immediately, there will be a long transition period. I don't believe in creating new infrastructure only for automated vehicles. They should co-exist. So, the higher automated vehicles should be able to deal with lower or non-automated vehicles. That is the only solution.

- *What to you anticipate on travel cost? And if all AV can communicate with each other, the trips could be directed such that there is no or very less congestion, how much should we believe in that?*

  - We believe that full potential of AV can be reached by adding the cooperation (v2i) part. The technology is being developed to allow cars travel close to each other (0.3s) safely. If that works well, it will give benefits over fuel, efficient use of road capacity. Will it reduce cost? If vehicles platoon (or C-ACC), then there will be fuel savings hence cheaper. But it is important to see at overall level, the travel time reduction would yield benefits. However, this is assuming the modal split remains the same as it is now.

- *It requires less effort to drive higher levels of AVs. So, is it that the actual impact of travel time savings only happens in higher levels of AVs? What is your perspective?*

  - Yes, that is in the basis correct. Although C-ACC is a level 1 system, based on purely longitudinal automation in combination with V2V that already can bring substantial time savings due to more effective road usage, thus lesser congestion and better throughput.

- *C-ITS impacting reduction in congestion. Or what driver to reduce congestion?*

- For congestion, it not only depends on C-ITS but also systems like collision avoidance system etc. When would this take place? If vehicles are equipped with V2V, V2X systems, for 10% vehicles equipped with these systems, there is already some effect on traffic flow.

➢ *What are the changes required in the infrastructure to support this transition to higher level AVs?*

- I don't believe we have more space and acceptance from residents to build new infra like widening city streets. It is not possible socially and economically. What can be done is some minor changes like making intersection cooperative.

➢ *AV in city center vs car free city center?*

- It does not matter if it needs to be allowed or not but what is important is that the cars are shared. Automation, car sharing and electrification are the three key drivers for mobility changes. Right policy is very important to ensure the positive effects if not it could be negative.

➢ *Effects on parking?*

- Depends on sharing. If sharing is positive, then the vehicles are maximum utilized. So, it would be more mobile. Policies like if the car is green, safe, and it does not use parking places, then it works the best.

➢ *If sharing is not successful, then how do you see this entire system working?*

- Valet parking application will be used. Automatic parking feature to drive by its own to nearest transferia, then it can be more interesting or people to get off at doorstep and not have to walk to the parking places. Location of transferia is an important factor.
- Another concept is the multi-level parking garages. With automated parking system, we could reach higher parking density. Also, segregate type of vehicles in each level. It is almost like a warehouse. Both are different concepts, both share a common feature which is in urban city.

➢ *Are transition points necessary? Where should it be located?*

- The system should take care of the facility such that change in control is done on the fly. If there are transition zones that requires parking etc., it is very difficult to implement and bad for effectiveness of the system, throughput.

5. Expert 5

Interview

➢ *Effects of sharing*

- The impacts of sharing are not only on capacity and congestion but also on spatial impacts. The spatial impacts are affected more by sharing than the level of automation. Of course, sharing could be enabled by the levels of automation. By sharing you are decreasing car ownership. But when you see the automation capabilities, it is likely that it will increase the car ownership, which means how much will the capacity increase and how much latent demand is generated. Will this cause reduction in congestion? I am not sure it will. If driving is made easier, people will start using it more. Driving automation takes away the stress, effort required. In fact, the impact could be that why use public transport anymore? So, I don't believe that the congestion will reduce. But of course, it could also go the opposite way.
- In level 5 automation and high sharing levels, it is the most idealistic and will reduce travel resistance substantially. Which means there is less resistance to travel or travel longer distances. Basically, the travel time budget gets affected and hence the travel time budget might also change. At present, 60-70 minutes is the travel time budget which is a very strong constraint for travel demand. But in level 5, if the vehicle can arrive at the doorstep, you use the travel time fully then this is no longer a constraint. Basically, it takes away the cost and time constraint that govern the travel demand. This affects, how we travel, where we work, where we go for recreation. So, it changes the complete pattern of activities in travel and spatial patterns.

➢ *You also mentioned about Mobility as a Service (MaaS). MaaS enables sharing so how would you see MaaS and sharing's influence on each other and on the system?*

- MaaS now is ride sharing platforms. So, in fully automated system, this will fully replace the system because the vehicle is the driver.

➢ *Should there be regulatory policy to control the travel demand due to highly automated vehicles? What kind of policies?*

- I think this is the most important issues to control when level 4 and level 5 automation is available in the market. Because in level 3, the driving task still relies on the skills of the driver. But that is not the case in level 5. When there are different transport systems operating in different levels of automation. Even in level 4, there could be a situation that the driver may need to step in to take control of the system. So, until then, the driver does not use the skills. And suddenly gaining control will be difficult. Even if you have a driving license, if you don't use it for 3 years, the skills are not the same. They degrade. Higher automation reduces the driving skills. It is not possible to regulate driving license of people according to the level of automation they are using. This will be a huge risk. So, I am not actually that optimistic that we will get to level 5.

➢ *Parking in Amsterdam is quite a concern in the present. Because of lack of parking space and high parking costs. So, the question is that will automation reduce the parking woes in Amsterdam?*

- Of course, in level 5, assuming full penetration rate, then people don't have to own a car, if there is high sharing. If there is no sharing in level 5, there is no change in condition except for more people using the system. Only if level 5 is available in robot taxi, the car ownership will drop. That again depends on level of sharing and not on level of automation.

➢ *Do you think building automated parking garages in Amsterdam could also solve the problem up to a certain extent? For instance, if the narrow streets in city center are wider, then it could probably be used better like freight delivery?*

- Yeah depends. It depends on the goals of the municipality to decide. High density automated parking garages does not make a difference. In Japan, there is already the system of automated parking garage but then you cannot get down at the door step. It is still required to walk. So, I don't see a difference in making such investments.

➢ *How do you see the sharing economy trend to follow in future?*

- I think I am not very high in my expectations about sharing. At the moment, all the sharing schemes, apps have very low market share. Less than 1% or so. Of course, sharing comes with a cost which is privacy. Not all people like that. The same person may like to share for a certain purpose may not like it for another trip purpose. They might prefer to hire their own car and be fully in control to decide where to go, when to stop etc. For specific population segments living in city center for example where conditions are not very ideal to drive a car around but other modes like bikes provide a better alternative, people might not be very inclined to have a car and in this case, sharing is interesting because in this case trips can be shared. But this case is in specific spatial-economic context. The spatial conditions play a very important role in enabling car sharing. It also depends on specific population group like maybe for people in 20s might be the early adopters. I don't see elderly people as users of car sharing systems.

➢ *If the modes can change accessibility, like shuttles that can travel through narrow streets of Amsterdam, what kind of changes will the land value undergo?*

- I think the major effects could be that, automated taxis/shuttles are used as feeders of public transport. I see that intercity traffic is still more favorable because of capacity and speed. The automated taxis are very important to increase the catchment area of public transport which is now constrained to walking distance. For last mile, this concept could be important. The attractiveness of companies to be near the stations is of course linked to this last mile. If last mile becomes last 5miles or last 10miles then the spatial pattern will change. So, this will probably flatten out the differences in the land values and real estate prices. Specifically, for places which are now accessible to such train station will be more beneficial. Already, people are ready to bike about 3km to reach the train station on the first mile. So, this could change the urban landscape.

➢ *Do you think door to door level of service possible in Amsterdam?*

- I think it would be difficult to get to level 5 anyways. I would highly doubt it. Unless the technology is so good. It is important to be careful about technology optimism. If there is another Tesla accident, there it is possible that the automation tech is off the agenda. The same happened with bio-fuels. There was an optimism that the creating bio-fuels could stop our dependence on oil. Did it? No, it didn't. So, in such complicated urban condition, any kind of accident involving automated vehicles will be looked negatively in terms of acceptance especially in pilot phase.

- *What is your opinion on shared space concept / dedicated space in Amsterdam for functioning of automated vehicles?*

  - If there are dedicated lanes in Amsterdam, then it could help in safe functioning of automated vehicles as it reduces the number of interactions. But it depends on the amount of space available. I doubt if such kind of system could be implemented in Amsterdam.

- *Relocation of people due to accessibility change caused by automated vehicles?*

  - Specific population groups live close to shops, city centers, etc., that will not change. The travel time as a whole does not change. It is only the usage of the travel time that makes a difference. For companies to locate close to each other for agglomeration economies will still exist. So, I doubt if for Amsterdam the spatial structure would become very different. It might be possible for specific population groups like high income groups, can locate a bit further away with a bigger house. But I doubt if automated vehicles could bring a substantial change in spatial structure of Amsterdam.

- *Do you anticipate more housing density in outskirts of Amsterdam?*

  - It is possible for higher density housing complex in Amsterdam because that is where people want to live. So, I'd say this might even increase the housing density in Amsterdam city. The process of sub-urbanization could also take place simultaneously. Reason for not having high density housing is because there is not enough space for parking and the parking fee is high. Some people don't live in Amsterdam for this reason.

- *Real estate developers – if come up with new housing townships near by Amsterdam such that those areas are AV friendly, would it make a difference?*

  - Growth in Amsterdam has been restricted by space. Almere was built thinking Amsterdam will not be enough. But people like to live in Amsterdam rather than Almere. Having automated shared vehicles means low demand in travelling out, which means the amount of space in Amsterdam is increasing to maybe accommodate more people.

6. Expert 6

Interview

- *What is the development plan of implementing automated driving? In terms of time line or in terms of level of automation that will be implemented first.*

  - There is no master plan for implementation. There are two philosophies for implementation and that is "something everywhere" and "everything somewhere" approaches. I think both will happen. So, OEMs are following something everywhere approach and I think they will all realize that level 3 automation is not a good idea and they will skip that. So, we will see implementation of level 2 that has already happened and then it will be level 4. It could be between 5 to 10 years. The drive me project is scheduled for next year and that will be the first real world level 4 large scale field operation test with customers. If that goes well, we will see level 4 driving in some restricted areas with next 5 to 10 years.
  - A good reference to see when what will be available is from the scheme of Steve Shladover. So, it says level 5 is from 2075 and beyond. I think that is a good prediction and I tend to believe that more than other experts indicating in workshops and the media. I think there are too many believers who are too positive to want it to happen. The potential of automated driving is too large to ignore. If the road operators and municipalities can speed up the deployment process if they facilitate it from infrastructural perspective. Also from legislation perspective.

- *You mentioned that the potential of automated vehicles is too large to be ignored. What kind of challenges and problems do you think automated vehicles could solve?*

  - The usual benefits of automated driving are the extension of benefits of C-ITS, ADAS. Increasing the traffic flow in terms of safety, throughput and impact on the environment. It can become further safer, efficient and have lesser impact on environment. All these are under the assumption that it accommodates the demand for mobility as it is right now. So, there are higher order questions that we don't know if the demand for mobility goes up or down.
  - If you have Mobility as a Service (MaaS), it is omnipresent, then I may start using it more often than I am using it right now. It may increase the demand of mobility just like the bandwidth and availability of Wi-Fi. Now the tendency has moved from downloading to streaming. So, a similar mechanism could happen with mobility if it is that easy to access. Then it may have a counterproductive effect. Then there are two fundamentally different benefits of automated driving. The value of travel time is a game changer. Because then the impact of congestion is different – less important. Probably the impact of congestion that users perceive is less. The other benefit is social inclusion. The people who are not able to drive can now be mobile. However, this only happens in level 4 and level 5 respectively.

- *What are the few important challenges in implementation or percentage adoption to see automated vehicles running on roads? Also from the perspective of cost of technology and affordability?*

  - It may be right that the first few highly automated vehicles could be expensive than the rest of the production. But if there is no necessity to own it, then the cost factor is less important. I think this will happen in certain urban areas. It is not a big barrier that the initial costs are rather high. On the other hand, the automotive sector will always try to find the balance between what is economically feasible so they will also have a plan to roll out what is possible. The other game changer is Tesla's approach. Vehicles that are automation ready with sensors, and by software modifications the sensor can be used to provide higher automation capabilities.

- *What kind of infrastructure adjustments are required to enable high automation driving?*
  - This is the part of the research we are conducting. It is important to distinguish several factors. There are necessary elements to drive and driving automated. For example, asphalt, lane markings. The quality of lane markings is an element of consideration. For example, it was discovered that the system could not deal with the type of lane markings that is used in the Netherlands. At on and off ramps, there is special lane markings called block markings. So, there are two options, one is redesigning the block markings in the whole country such that the system can recognize or the alternate is to change the software of the system to recognize block markings. The solution to adjustments lies in between. The vehicles have to deal with certain infrastructure components. One non-regret investment infrastructure can improve on is C-ITS. Because it is good for ITS as well as automated driving.
- *What kind of changes would you expect in urban roads to support AV friendly vehicles as a road user? Keeping in mind the narrow streets near canals, parked cars and the bicycle users.*
  - There are two components that make automated driving simpler. Low velocity and low complexity. Urban areas have low velocity but high complexity and motorways have high velocity and low complexity. If there is an area where the velocity and complexity is low, then implementation of level 4 driving is easier. This is what happens in Rotterdam, where the level 4 automated vehicle operates on dedicated lane. There are some roads in some areas that restrict some participants like cars or busses etc. Alternatively, the software of automated driving should be developed to a very advanced level where it can handle all complexities but it is far down the road. Pedestrians and cyclists are complicated to deal with respect to automated driving of cars in urban areas.
- *The urban areas are well known for the complexities especially the pedestrians and cyclists. This could cause a major complexity in driving an automated vehicle through the city. Should there be restrictions in right of way for either the cyclists, pedestrians?*
  - It is difficult, how realistic do you think the cyclists would stick to the rules? Unless they are physically segregated. There could be a physical segregation between the lanes but that is a costly solution. I think it is extremely difficult to deploy automated driving in an urban environment because of this complexity. Also, it is difficult to program the vehicle the way it should behave. But this is not explored fully how it should be done. I would be happy to know the answers to these questions.
- *Automated cars and automated shuttles, both are vehicles with automated driving tech that help urban mobility. Which one among the two, do you see happening more? Because right now more importance is given to cars, but it seems that automated shuttles are more practical and relatively easier to implement. Also, the travel costs could be lesser as driver costs are lesser.*

- I think that both will happen, because of relative simplicity of those shuttles on dedicated tracks. It is expensive but it can be built and it is seen to be operating in some places like middle-east etc. But there is a constraint in flexibility. They cannot travel everywhere. It is not necessary to follow bus routes, instead demand responsive routes. This can play an important role in rural areas. For shuttles to be attractive 20kph to 30kph is not bad for first and last mile connections. It is also important that the automated shuttles are not to be seen as replacement as trains etc. as they are very beneficial in transporting large volumes of passengers at a time. And it is not possible to transport all those passengers in automated vehicles. That is not the answer. Another issue is that, I feel a resistance to do the last mile by pods, we are built to be move around, so there it needs to be an optimum. It is hard to compete with the current first and last mile options like walking and biking. The health benefits and good infrastructure for biking and walking makes it less favorable to use pods for last and first mile.
- But it should be known that when public transport is made free, there is a shift from biking to public transport rather than cars to public transport.

➢ *Some experts believe that without sharing, the concept of automated vehicles may not work as AV would only increase the number of trips (empty) without sharing. What is your perspective on this?*

- True, there is a large potential for combining sharing with automated driving. It also helps in the cost element of not requiring to own but use automated cars. It might take some time that the younger generation is getting used to sharing economy. This could decrease the number of vehicles that is required to support the demand and it can have major implications on the layout of the city in terms of parking spaces. In that way, it is an added benefit to have sharing. But it is not so crucial for automated driving to not happen otherwise.

➢ *Automotive manufacturers like Volvo has shown in their automation concept that a car can be able to drive by itself in AV friendly motorways and when it is exiting the AV friendly environment, it needs transition zones to change control from system to driver. Especially if the driver is not taking control at the right time. To extend further, these transition zones are a means of spatial implication and could also serve as a park and ride system to use automated vehicles on highways. What is your view on this concept?*

- I think the transition zone with park and ride concept is a good idea. In future, it can also be expected that people will start living in green areas spread out from cities. Also, the shops need the vehicles to come to the shop at the same time the shop should be accessible to customers.

7. Expert 7

Interview

➢ *What are the most common issues faced in urban planning? What is the context of urban planning on network, mobility and spatial planning?*

- High capacity and high density have a great reciprocal relationship in transport land use and urban form. In high density environment, the car does not do well, public transport does. But in low density environments the car performs better than public transport. Speed and functional mix have inverse relationship. The mix means how close to each other are different functions living working recreating. In a functionally mixed environment on average, the distances are shorter, with similar time budget, low speed reach many destination – and the other way around.
- Functional separation (e.g. Shopping malls or offices far away from homes) and fast transport (e.g. cars, trains) reinforce each other. On the other hand, high mix environment and slow transport (like walking cycling trams) reinforce each other. Combining all these elements is one of the crucial issues when you explore what could be the impact of the change of different transport systems.
- Secondly the public space. The important concepts are if it enables only planned or also spontaneous meetings. For example, people plan for social meeting or just come across each other spontaneously. It is related to certain transport function on qualitative aspect. It is less researched, less formalized but a distinction is whether transport is motorized or not motorized. This has connection with interactions if they are planned or spontaneous. Walking, cycling and to a certain degree public transport are more conducive of spontaneous meetings than the car. Facilitating meeting at cafes, joint public spaces are the ones that makes the city attractive. This is a type of consideration in terms of factors. In Amsterdam, it is more important, because it offers high quality public space to support interaction etc.
- Another discussion point is environmental sustainability, sustainable use of natural resources – climate, energy, pollution, but also health issues related to moving or not moving. It is important to understand the side effects of a new transport system, what it does to the natural environment and human health.
- Lifestyle – technology offers new choices but it also depends on how one wants to live. People can make choices and a city provides a diversity of lifestyles. That is also an important dimension of the attractiveness of cities.
- On a collective side, politics and regulations are important factors. Social justice and equity is also a factor that I would like to include. As cities are becoming less and less equal that affects all discussions on if a city should become just or less just.

➢ *In what contexts does urban planning influence especially with mobility and spatial planning? I see spatial planning as zones, levels like metropolitan Amsterdam.*

- There are various levels as you said. They Firms each have their own action spaces. For some activities/businesses the action space is mainly local, for others it is national, or even international. Also, people may have or choose to live and work in different spaces. The problem with planning is that it is very difficult to match all these different and often changing scales. As far as people are concerned, it is like about 80% live in the urban regions and the rest 20% live on a higher level. For firms, it is much more varied. So, there exists a tension between levels. New transport mode can have a lot of dynamics at different scales which can imply different things. Amsterdam has lot of people who live and work in Amsterdam. That is because there is lot of jobs, so people living outside Amsterdam also work at Amsterdam. So, the dynamics also involves people who do not live in Amsterdam. This is the same case for tourists who just visit. Planning involves all of this but is almost impossible to combine all these scales.

- *If we consider in an urban form, how can we formulate the same thinking?*

  - If you look at the urban form of Amsterdam, there is a sense of compactness but also diversity. It is a high dense high mix city. The city thus matches with low speed high capacity mode which are above all walking and cycling. In Amsterdam, their share is comparatively enormous. There are certain nodal points like the Zuidas, which have a transit oriented development system. So above the urban system, this system exists in Amsterdam. For example, American cities have the car system. The ideal car world is very low density and low mix environment with separated jobs, houses. This characteristic can be found in the periphery of Amsterdam. But the closer you get to the city, the closer you get to the low speed high capacity system. So, the two systems don't match. What happens is that people change modes between car + PT or PT + bike. The reason is that the car does not fit the dense mix city of Amsterdam. So, the crucial question is the interface between the car world (outside the city) and the city world, where car doesn't fit well. There are discussions over park and ride etc.

- *Considering the mobility aspect, there are few characteristics that differentiate normal cars and automated cars. For example, automated cars provide more comfort, will become safer and provide opportunities for travel time enrichment. Furthermore, automated cars are said to provide assistance in parking like self-parking assist function that could decrease the dis-utility of using a car in the city. There is some literature that refers to travel patterns indicating that there will be longer trips, another literature says the trip frequency will be higher and that people could possibly change from train to car. What could be the spatial implications of all these in terms of spatial relocation?*

  - From an individual point of view, why would you shift from conventional cars to automated cars, but also from public transport to automated cars. The comfort, safety, effort etc. are all arguments from an individual perspective. There are no clear collective gains. But if automated vehicles are shared, the story is different because there are gains on the parking aspect. Space gain would also apply to people shifting for individual to collective transport because of the latter becoming automated. However, if people move from walking and cycling to automated vehicles this would mean a shift from low to high speed, and (in the case of automated cars from high to low capacity. So, this will put pressure on the city transport relationship in Amsterdam. It would favor like the car did, a move towards less density and less mix. But the dynamics can also come from the other side. There already exists a dense and mixed city. People and business like it. So, they could resist more cars and they might not care about automated benefits and rather use public transport, cycle or walk. Big shift away from public transport, bicycles and walking would require cities to become less dense and less mixed. On the other hand, if people and businesses want dense and mix cities, they will not use cars, automated or not. So, it is a contrasting dynamics. It depends on whether people and businesses want dense and mix cities.

- Furthermore, there are the impacts on public space. Here it is not only quantity but also quality: I social interaction being enabled or not? And is it only planned or also spontaneous interaction being enabled? Automation technology can also be in public transport form. This scenario is very different because the social interaction aspect is not in contrast as to the car. In scenarios where even watching movies in a car is possible, no need to watch outside anymore, there is no longer social interaction and that is the end of public space. That's a big difference between automated cars and automated public transport.
- From a social interaction perspective, walking has the first rank, then is cycling, followed by public transport, last is the car. Automation will reduce the social interaction of the car even further. The only positive possibilities are that because of automation people switch from car to public transport.

➢ *The factor of interaction is very important from urban planning perspective. The concept of sharing could play a positive role for interaction?*

- Yes, sharing is very important for two reasons. Firstly, I don't think it will change the capacity issue of moving vehicles but influences freeing up parking space, and this parking space could become public space. Sharing could make a change but it highly depends on how many people use it. Secondly, there is also forced sharing. For example, in a bus, you are forced to share. You can interact, but you often don't have a conducive environment. It is a bit different from not sharing but fundamentally it is not that different. It is a different kind of public space in a bus compared to the public space outside.

➢ *Considering automated cars, automated trams, automated buses etc., Should Amsterdam city have an urban redesign in the direction of dedicated lanes or shared spaces?*

- In this discussion, it is quite paradoxical. Capacity – automated cars don't change the lack of capacity issue, and might even make it worse, if people shift from high to low capacity transport because of automation. On the qualitative side, automated vehicles are less conducive to spontaneous social interaction. Overall, they are not compatible with the city center of Amsterdam. Rather, there is a chance that the city center could be in the future a space only for walking and cycling. This could bring developments (land value) because of value of social and spatial interaction. Lesser cars and lesser public transport but more cyclists and pedestrians. In such trend, the role of automated vehicles does not play a significant role.
- The historic Amsterdam city center is very valued in its form. It is not very flexible to demolish and rebuild. So, it is place where transport has to adapt to land use characteristics which are again compact and mixed.
- Outside the city center, the situation, is a bit less extreme. However, he real contribution of automated vehicles from a spatial perspective is in low density regions, in providing a new form of public transport in low density areas. That is where public transport is becoming less and less feasible, because of too dispersed demand. The automation assistance is more useful in rural side than in dense city centers. So, inside the city is walking and cycling. And getting to the city is where

high speed high capacity transport like the train play an important role. The automated vehicles could have a role to get to stations, connecting low density areas to the nearest station (next to, of course, for trips within low density areas).

- *If we consider Rotterdam for example, would it be a same argument or rather a different argument?*

  - Partially different, partially similar. The different part is that there is more space in Rotterdam for low capacity transport like the car. Rotterdam is more diffused. It is much less concentrated. But interesting thing is the new kind of jobs and people look for this kind of environment. They are trying to develop high density and high mix 'Bakfiets buurten' in Rotterdam like Amsterdam because they want to attract higher educated people who look for environments conducive to spontaneous social interaction.

- *In highways?*

  - Automation in highways is a very interesting thing because if these cars can increase the capacity then there will be more cars on the road which will make the situation more difficult in cities. The problem of people reaching a city in cars will become even bigger. The solution is perhaps improvement in park and ride system. Within low density regions, cars could even be subsidized as there is not enough public transport. But for high density regions, they have so many negative effects.

- *In terms of park and ride and remembering the sharing concept, combining these spaces could have a positive impact?*

  - Yes, it is a good point. The combination of park and ride and automated vehicles could help develop more interesting park and ride concept, more flexible, less focus on a station as exchange can be at any place. Maybe that can be possible.

- *If so, what kind of characteristics should such spaces have to enable park and ride system?*

  - The closer you get to door to door where people get down at station and vehicles can drive itself assuming high automation. Of course, keeping in mind that there will be a shift of travelling from high density to low density regions (or the other way around), and the capacity of vehicles have to adapt in the process. Automation can also help in collaborating with other modes in an easier way.

- *How will land value change with respect to quality of life, affordability and demand? With the P+R that provides more accessibility will there be any fluctuation in land value? Will automated vehicles make different places more desirable to live compared to present?*

  - It is very dynamic. Most of the places in Netherlands are already well developed and well accessible. As mentioned earlier I do not see automated vehicles fundamentally changing the accessibility of most of them and thus their land values. The exception are low density low mix places, where automated vehicles can become a substitute for public transport, and provide a transport alternative for people who cannot drive a car (like the disabled, the elderly, or children). Here land values might be positively impacted.

8. Expert 8

Interview

- *What are the possible spatial impacts of automated vehicles on high density urban areas?*

- There is an interesting link between pick-up drop-off traffic and parking fees. It depends on level of sharing. If there is relatively low level of sharing and high parking fee, then it is easy to have the car circling. So, that will bring an extra traffic.
- I think the urban redesign factor, which is very local, is a significant one. The concepts of urban redesign conceptualized by the automobile manufacturers look amazing, but is unrealistic. Especially in high density areas. On lower spatial levels, that is very important. There will be a different kind of infrastructure. Especially, in the scenario of high automation, there will be less parking spaces in urban areas. Outside such high dense areas, the impact may not be that big.
- The location of parking can be elsewhere in high automation scenario but it is better if it is closer to the residential areas. The closer it is, quicker it is to pick up. For a very good sharing system, the car should be demand responsive, which means it needs to be close by so that the service is provided immediately. If it takes longer, it adds to disutility of people as the expectation is not met. So, parking spaces are still required to be close to destinations or origin. However, automated car can self-park so the parking could be high density parking.
- In a dense urban area, the number of inhabitants is high to maintain a shared system. But in lower densities, the sharing system may not be as robust as in high density urban areas. People will accept sharing system only if it works perfectly and flawlessly.
- I think many of the potential spatial redistribution effects will be linked to the question whether people are going to value their travel time differently? If the value to travel time is not going to change then the whole automation concept is like as it is today. The travel time budget is biological thing or psychological thing? If it is a psychological thing, it could change. But if it is a biological relation, then there is not going to be any change. On average, the travel time value of public transport is less than in cars.
- What would be a realistic travel time for people travelling in automated car? It should be looked on the values of car passengers. But there is not enough research on value of travel time for car passengers. It is just an assumption based on car driver's value of travel time. So, this whole travel time value has uncertainties around it and these are important to find the spatial responses. So, you can hypothesize on what could happen but it is not a certainty. Hence, the scenario study could shed light on it.
- It not only depends on level of automation and degree of sharing but also on how people respond, how Governments and industries respond. The report "Re-programming Mobility" by Anthony Townsend takes out of the box cases for scenarios for spatial impacts of automated vehicles. The demographics plays an important role. If the population is aging, automated vehicles could be very useful to keep this people mobile. On the other hand, the younger generation might be not open to accept new technology. That might be a hindrance. There is a whole acceptance discussion. Especially involving ethical way of making decision during emergencies.

- If it is assumed that people will mind less to travel, then there could be some interesting land use consequences. While the long-term scenario was done at PBL, it was not sure of the speed of adoption of automated vehicles. Since these scenarios are the basis of infrastructure investments, it cannot be just assumed that automated vehicles will be there. If there is a high economic growth, then it is more likely that there will be impacts from ICT and hence changes in land use patterns. So, people could take opportunity to move to places with better quality of life, to a place that is green and with lower densities. This was calculated as an extra sensitivity analysis on the scenario that was built. It was seen that this case was not that spectacular. Though it is nice to live in green area, there is only 24 hours a day and there still exist a travel time budget. But if the whole travel experience becomes more comfortable that people mind less to travel, then there could be a suburbanization trend happening.

➢ *Would the spatial policy regulations at the moment allow that to happen?*

- The policy regulations for spatial development aren't that strict. They appear to be strict. In the last 20-30 years, many houses were built in green heart region though there existed policies protecting the green heart. I think many of the developments could still be possible without drastic change in spatial policy. I don't think policy regulations is the restricting factor here. The spatial regulations are at the moment at the municipality level.
- If there is a location without well connected public transport and there are automated shuttles to solve the last mile problem, it still means there is a good quality public transport system, which is very realistic. It is an important question if driving automation will be supportive of transit oriented development. That will depend largely on the choices that the policy makers make regard to the spatial policies. The problem with spatial policies is not what they restrict but what they allow. So, if municipalities allow sprawl then it will be bad for public transport system.

➢ *There exists a high pressure for housing demand in Amsterdam and the reason to expand will be to minimize this pressure, where the land value and rent prices also play an important role. Does Amsterdam have the characteristic that no matter how much residential plots are created, the housing demand and pressure remains the same, just like Paris?*

- The characteristic in Amsterdam, Paris and London is that the inner area of the city will always be a magnet. This inner-city area is spatially restricted. So, the land value and rent prices will still be expensive. The built environment around Amsterdam will not have the same attraction as living in Amsterdam. New environments could be built outside Amsterdam but that is not the solution to the problem Amsterdam is facing. By sprawl I don't mean it in the US context but in the Dutch context.
- Overall, Mode choice depends more on the spatial characteristics of the destination than the characteristics of the origin. So, if jobs are located at places that are well serviced by public transport, and if there are woes using car mode, then the effect of automated vehicles will be limited. Hence I don't see an obvious change in job locations due to automated vehicles and/or sharing.
- Public transport has an impact from automated driving technology in rural areas. It will probably be a mobility as a service. Between urban nodes and within urban areas, there is still need of inter and intra public transport. Rail based transport will exist for mass transit. First and last mile may be

replaced by mobility as a service alternatives. The main difference is if it will use specific routes or will it be on demand at any location? That will depend on the volume, the number of users. It could be like Uber system.

- The impact on cycling and walking is interesting. Because if the local public transport accessibility is increased, it will reduce the necessity to cycling and walking.
- Amount of traffic could be less or more. No idea which way it could go! High automation low sharing could have the highest spatial stress. Sharing can help reap all the gains of automation. Sharing only works better in high density regions but automation could lead to non-high density regions that could be conflicting the ability to share.

9. Expert 9

Interview

- *General discussion on automated vehicles.*
  - Automated vehicles have many important regulations to be sorted before we start considering the impacts. For example, how does an automated car react to a person who takes a very long time to cross at junction? Or how does the car react to those bicyclists that don't indicate with their hand. This is the kind of complexity setting in urban areas.
  - The autonomy will happen very fast despite accident of Tesla. It has lot of advantageous with travel time. With the current Tesla, it is possible to look at smart phone while driving at regular intervals already. Having driven with Tesla for two weeks, I miss the feature now and I want that and I can pay for that feature. However, in cities, the application is more difficult.
  - With automated cars, there could be a big balancing problem inducing more number of trips between cities. Also, empty trips could rise and they are potentially trips that do not exist at present. Roughly 50% more miles would be driven by cars. Environmentally that is not a good system.

- *Do you think the number of cars will reduce? Assuming sharing system to exist.*

  - Yes, there will be less cars driving more miles assuming level 5 automation. If done wisely, there could by just half the number of cars that do about 4 times more miles. Which also means a new car will be required 4 times sooner which is also good for the car industry. The cities like automated cars, car industry wants automated cars and citizens will use automated cars.

- *Could AV enhance multimodality?*

  - Level 5 automated cars could enhance multimodality. Everyone believes future is multimodal, I believe future is monomodal. Cars would pick up and drop off at door step. The mode transfer is very inefficient and uncomfortable. If there is a service that transports from A to B directly and cheaply, then multimodality will not work. I do not believe in multimodality. But the comfort is that a person can work in train during the travel. If this feature could be achieved in monomodal trip, and even if I have to pay, I would prefer the car trip. If this modal shift is in large scale, then there is a problem.
  - Only 10% of car trips are train trips. The number of passenger miles done by car is 10 times more than that done by train. So, extra 10% on road especially on rush hours is quite a problem. I believe Uber will give a better system. If we have Uber system, then the spatial effects will be very similar to that of automated driving system. In California, the public transport is not good and hence Uber has become a mode of transport for many commuters. If the service of public transport is not good, then this trend can be seen in Uber like systems with automation as well. Cost per kilometer in public transport in Netherlands is about 30 cents per kilometer. If the cost with automated cars with sharing system is lower than this, then the mode will shift. Uberfied system has similar spatial consequences of level 5 automation. The only difference is the physical driver that transports you.

- Level 3 and 4 will also lead to safer traffic, all the disadvantages from traffic will reduce. Getting caught in traffic jam may not be annoying anymore. This is because you know the time that will take to reach the destination.

➢ *Philosophy of spatial differentiation*

- The rounded kerbs that differentiate two transport mode spatial areas but not restrict other modes when necessary on using other spaces. It is a philosophical item that works very well in Amsterdam. This is common for the paths differentiating tram way and car roads or bike paths. This concept is very important for running of automated vehicles. Theoretically it will not be possible for modes to interfere to such lanes but if need be, they can in practice. In cities, there is not enough space for dedicated transport infrastructure. Shared space concept is vital. It classifies and clearly differentiates responsibility of users.
- So, there are two spatial reasons on how to facilitate automated cars. One is shared space that works very well even in dense urban areas. It also has good throughput and is safe. Another is how will cities emerge if automated vehicles are used. This differs especially if there is sharing or not. Automated vehicles and sharing have an overlap of synergy. The main difference comes when the car can provide door to door transport. If there is something like snap car in Amsterdam, like a car ever 500meters that everyone could share, it will be fine. High sharing could have balancing problem. However, this will not be a problem with level 5 automation as cars can self-drive.

➢ *What would be the impact of AV on parking space?*

- When we assume to have high automation scenario, I think that we will require 20% - 30% more parking space. Though parking centers could be with high density, probably the car modality will be more interesting attributing to more parking space requirement. This would change if there exists high sharing. Especially with households having more than 1 car. People want to have guaranteed mobility very close by so that they can access at any moment. Rich people could follow this trend.
- In Amsterdam, even if 5% of commuters drive to work with fully automated cars, the roads will be nearly blocked due to high volumes of traffic. Traffic from other cities towards Amsterdam could worsen. Especially when car modality is more attractive than public transport. And hence parking space or space required for pick up drop off points could increase.

➢ *Impact due to cost of automated public transport and modal change?*

- Yes, that is correct. Automated driving technology eliminates driver cost. However, this will make a difference only if the travel cost is less than 50 cents per kilometer with door to door service. That is mobility as a service which will be less than 50 cents per kilometer. Owning a car could be just 10 cents per kilometer. Uberfication also works like concept of MaaS.

➢ *Impact of new transport modes like automated people movers or automated shuttles, WePods?*

- The question is why does not Renault Twizy sell? People want a bigger car. References from blog of Brad Templeton are very interesting. They speculate the probable mobility and urban spatial effects of automated vehicles. He claims that a car can be extremely cheap and does not need airbags etc. And he suggests that new modality for just 1 or 2 passengers would pop up.

- *What infrastructure constraints do you foresee for automated vehicles, example width of the street, parking area redesign or reallocation of parking space especially near canals.*
    - Canals are to be enjoyed with the view rather than parking the cars by the canals. The space needs to be given back to the people. The assignment is to give city back to the people. To facilitate meeting of people and to keep them mobile. There exists travel time budget but mobility is much required by people. The solutions should contribute to this factor.
- *If cars are to be available at a place as soon as someone needs it, then the parking zones needs to be close by. Spatial concerns of such parking zones?*
    - Automated shuttles could be slow due to interaction with other traffic and ensuring safety, unless there is dedicated infrastructure which is a constraint. The cost of the driver is low, there are comfort, speed and time gains but to compete with system like Uberpool which costs 30 cents per kilometer is a challenge to compete with mode like these.
- *What is your opinion on thought on the concept of transition zones for automated cars just at the end of highway and beginning of city for example near on / off ramps?*
    - There could be a way around without such specific infrastructure.
- *Regulations for automated cars, taxi in urban areas*
    - The Roland Berger report that suggests that the future income is going to be in robot car companies. I do not believe in that. I would invest in ICT application and facilitator services. Even if there is sharing, there will be individual driving. I would rate individual driving to be most attractive followed by Uber and then automated driving taxis.
- *Spatial concerns of pick up drop off points for commuters*
    - Yes. In Schiphol, it was found that there needs to be more drop on drop off points for future mobility. Drop off points should be located where destination traffic is high. Origin is also drop off points. Not every building will be needing a pick up drop off point. Space allocation is important.
- *Urban freight distribution*
    - It is safer to test in automated driving technology in freight, the industry moves to cost minimization and package doesn't have feelings. So, such small automated freight delivery vehicles make more sense.
- *Impact on distribution centers*
    - Classical small shops could pop up that helps in the last mile delivery of parcels with the automated urban freight vehicles. Storage capacity is a variable based on demand but that is a trend I would foresee.
- *Automated vehicles vs. electric cars vs. sharing?*

- Sharing and electric cars are not a good marriage. What if vehicle that you pick up only has 25 miles of charge left? And charging takes time. Electric cars need reserved parking spot, needs to be punctual, reliable and they are factors why sharing concepts collapse. Both are individually good systems but they both don't go together.

10. Expert 10

Interview

- *How do you hypothesize that the mobility of AV can impact accessibility, infrastructure and spatial pattern?*

  - Depends on system but level 5 will increase accessibility for certain groups of people and with respect to impacts on travel time. The analysis which we did showed that the impact could go either way. Congestion could increase or decrease. It will improve capacity but also attract new drivers. These two are contradicting and influences travel time.
  - The key concepts for mobility is level of automation, level of cooperation, dedicated infrastructure, level of acceptance of AV by the people, regulation, level of service and safety. Comfort with relation to value of time, sharing, quality of other and new modes, municipal transport and spatial policies, and new market entries like Uber, Google associated with ICT.

  Cause and effect relationship for all identified concepts was drawn as a cognitive map on paper. Relation between the concepts were established and rated.

- Urban freight distribution infrastructure requirements for example parking?
  Answered through FCM.

Annex 5: Concept meanings

Spatial concepts	**Context**
Transfer nodes and P+R	An integrated spatial area that provides high density parking facility and allows passengers to transfer from one vehicle to the other, or, one mode to the other. Apart from traditional Park and Ride (P+R) concept of using car for last mile, this concept also supports using bike for last mile and automated cars with sharing for main travel.
Parking facilities	Spatial area that government allots to enable parking cars for every neighborhood.
Change in land value	Change in land price in urban areas of Amsterdam
AV friendly urban redesign	Changes to present urban form by facilitating new AV supporting facilities such as *transfer nodes and P+R*, *pick up drop off points*, *automated high density parking facility*, *lane markings*.
Spatial social interaction	It is based on the fact that people are social animals and urban design in cities supporting opportunities for social interaction improves liveliness and attractiveness of the city. Example: City square, neighborhood parks, markets. The expert believes that higher levels of automation could limit the level of interact-ability and that sharing does not necessarily improve the same.
Relocation residents	The degree to which residents choose to relocate to sub-urban areas with better quality of life and cheaper land area.
Relocation companies	The degree to which companies choose to relocate to relatively cheaper area.
Relocation retail	The degree to which retail shops choose to relocate to relatively cheaper area.
Accessibility	Accessibility refers to the ease of being able to reach a location.

<u>Meanings of mobility concepts:</u>

Mobility concepts	**Context**
Level of automation	Denotes the levels of automation with level 3 representing low automation, level 4 representing high automation and level 5 representing full automation, automation levels in accordance to SAE levels of automation.

Level of sharing	Denotes level of sharing between low and high. Sharing represents any mode of car sharing that includes sharing a car per private party at a time and carpooling.
Safety	Refers to transport safety.
Adaptivity of people to AV	Refers to the degree to which people would likely adapt to travelling in higher levels of automated functionality in vehicles (level 3 and 4).
Change in people, business lifestyle	The relative change in lifestyle of people and businesses adapting to expected benefits from travelling in higher level AVs.
Disutility of car travel	Disutility in car travel such as congestion, travel time, parking fee, transport costs, availability of parking spots. It does not include disutility in sharing such as car-pooling.
Car trip length	The length of trips expected by travelling in automated cars.
Number of car trips	The number of trips expected from usage of automated cars and normal cars.
Car ownership	Number of automated cars expected to be owned.
Multimodality	A characteristic of travel using multiple modes to reach a destination.
Travel time budget	Average time budget allocated for travel per day
Last mile, Mobility as a Service	Last mile denotes the last stretch of travel to the destination from a transport hub like train station or bus stop. Mobility as a Service (MaaS) aims to provide multimodal travel ensuring seamless door-to-door mobility at any instant through subscription packages and information and communication technologies (ICT) platform.

Dummy concepts are concepts that are included in the map that improve logic in cause and effect relationship especially when the describing term is too broad. They are also used to collectively represent multiple concepts as a single concept for the ease of drawing fuzzy cognitive map by the experts. These concepts do not add value itself as a model result. Hence, they are not mentioned in the model results. Dummy concepts: *changes in transport land use urban form, origin destination relocation, thought of OD relocation vs. quality of life* used to represent multiple concepts as a single concept in the cause and effect relationship.

Dummy concepts	**Context**
Pick up drop off points	This is a spatial concept that represents an example of the concept *AV friendly urban redesign*. These are spatial areas conceptualized to be located strategically at nodes that facilitates automated cars to pick up and drop off passengers.

Origin Destination relocation	This is a broad spatial concept that collectively represents *relocation of companies*, *relocation of retail* and *relocation of residents*.
Closeness of OD vs. quality of life	This is a spatial related concept that serves as residents' choice for relocation to sub-urban areas with better quality of life or relocation close to the existing destination location.
Transport land use urban form	It is a spatial concept used to represent the current spatial structure. This concept is covered under AV friendly urban redesign.
Vehicle cost	Cost of automated car.
Parking density	Number of cars that can be parked in a unit area.
Transport modes	Other transport modes available for people to make a choice to travel.

Annex 6: Personal reflection

I had my set of goals and ambitions before starting my master thesis. I wanted to research about the future of mobility, gain top level expertise in the research and the research methodology, and possibly try to make my research useful for the society by contributing to future research in this field. Through the master thesis, I also wanted to achieve some level of personal development. I wanted to be able to endure and perform during high pressure situations, to be able to manage stress and turn it to my positive advantage, and to not be afraid of failures in order to achieve success while being creative. Most importantly, I wanted to learn and manage the work-life balance. Overall, I considered my master thesis to be something more than just the research itself.

After my kick-off meeting, I found that my research was highly time intensive and work intensive, even more than I imagined it to be. This was especially when I figured out that conducting workshop for FCM was impractical and instead, I had to do it through personal face-to-face interviews. I took this challenge as an opportunity to deliver quality and insightful results for the society.

There was a constant reminder of responsibility in using a fairly new research methodology, FCM, without availability of much help. This tested my ability to work independently. I spent most time learning the research method from scientific journal articles. However, just the learnings through numerous scientific journals on FCM were not enough. My meeting with Dr. Kasper Kok from Wageningen University helped me reflect my knowledge into practice. The time pressure peaked several times during my research. The most important instance was during the data acquisition for FCM, as not all experts communicated in a timely manner, passing the time delays to my modelling and validation phases. This process alone consumed one-third of my thesis duration. This has been highlighted as one of the drawbacks of using FCM methodology for research works like master thesis.

The second biggest time consuming process was combining fuzzy cognitive maps, which is a consequence of interview approach. This took a lot of effort and time to combine the maps manually. In addition, it led to discovering the fact that there is a need for a methodological process to strategically combine fuzzy cognitive maps to achieve highest combinability leading to more reliable results. Due to lack of literature on combining maps, it let me to be innovative and propose a method to strategically combine the fuzzy cognitive maps. I was able to show that through the proposed method, the highest combinability could be achieved.

Would I choose to use FCM method again if need be? It is very clear that FCM is a resource intensive method. It needs time, group of dedicated and willing experts to participate in the process. Moreover, FCM is new and there are considerable literature gaps that needs attention to make this method versatile. However, FCM possesses the unique quality of being able to model scenarios without requirement of data sets that may not be available. Also, FCM is effective in exploring the causal relationships in a system allowing researchers to understand the dependencies and dynamics involved. My answer is I would use FCM to only to the extent of exploring the causal relationships in a system. And certainly, I would not recommend FCM for time bound research works like master thesis. In other words, I feel FCM is more appropriate for PhDs rather than master thesis.

I learned the importance of mental attitude and mental preparation to stay positive and keep trying until I succeed. This helped a lot to progress during the many bottlenecks I encountered while working with FCM. The time delay in my research came with opportunities. One such is the Dutch Hyperloop Challenge organized by Connekt in cooperation with Hyperloop One. I may not be the best in managing my interests, but this challenge really caught my attention as it was the perfect competition for MSc. TIL students. I, Bon and Ani stepped up, and competed for the best. During this stage, I gave more importance to the challenge and learned that being a perfectionist is not always ideal. However, I was able to demonstrate that one of my strengths was being innovative. We won the runner's up of the Dutch Hyperloop Challenge. Though I spent nearly 2 months on working for the challenge, it paid off through a career opportunity at Hyperloop One – a company that envisions to change the future of mobility.

I was driven not only by my personal goals but also greatly by the motivation provided by all my supervisors. They really helped me to see the positives during the bottlenecks and their appreciation gave me a lot of positive energy. During the entire master thesis, I had pushed my limits to new heights which has helped me become a confident engineer. Looking back at my ambitions and goals during the start of this research, I feel I have accomplished most of them and even more.