Mobility-as-a-Service from a health perspective

Exploratory research into the potential health impacts of MaaS

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J. Krantz

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by

Juliette Krantz

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Student number:	4172140	
Thesis committee:	Prof. Dr. Bert van Wee	TU Delft, TPM, Transport & Logistics
	Dr. Jan Anne Annema	TU Delft, TPM, Transport & Logistics
	Dr. Ir. Niels van Oort	TU Delft, CiTG, Transport & Planning
	Drs. Martin van Oosten	Arup
	Ir. Laurens Tait	Arup

Preface

This report is written for the TU Delft Master Program Transport, Infrastructure and Logistics and the technical consultant Arup. More than half a year ago I started my internship at Arup Amsterdam and together with the master planning team we came up with a slightly less intuitive, but very topical topic for my thesis: Mobility as a Service in relation to health. Challenging, because MaaS is a relatively new concept and the topic of health was completely new to me back then. No surprise that these last past months have been challenging sometimes, but mostly very educational and unique in many different ways. Writing this report helped me remember that I really enjoy working on more complex, indirect and slightly less intuitive fields of research, and I hope this is something I can continue working on in the future.

During my thesis I came across many interesting people and I was surprised and overwhelmed by their enthusiasm and willingness to help. I would like to thank everyone that contributed to my research and special thanks to Arup for offering me the chance to write this thesis, my colleagues for the great support and fun at the office, and especially my supervisors Martin van Oosten and Laurens Tait and project manager Hanna Ratilainen, the people who made time for an interview, the reviewers Orla O'Halloran, Loes Geelen and Hanna Ratilainen and my thesis committee from the TU Delft.

It was intense, I enjoyed it, and in some ways it changed my own travel behaviour now that I am more aware of the health impacts associated with my own travel choices!

Thank you,

Juliette Krantz

Executive summary

Due to current, ongoing mega trends, such as continuing urbanisation, a growing economy and expanding population size, the interest for health is increasing as the pressure on urban environments is growing (EPA, 2017; Sochor et al., 2015). These ongoing trends induce negative effects in the urban transport system, for example through congestion and air pollution, all of which affect health. Even though transport is a significant determinant of health in cities, it is often not considered as a focus point for establishing health improvements. This research explored the possibilities for health impacts for the rise of a relatively new mobility concept; Mobility-as-a-Service (MaaS).

MaaS anticipates to induce significant changes in the transport sector by offering a multi-modal service as convenient alternative for private vehicle use and ownership. Hietanen, one of the founders of MaaS, describes the concept as "*a mobility distribution model that delivers a transportation need to its users through one single digital interface, by integrating and bundling different transport modes into mobility packages"* (Hietanen, 2014). The concept holds the promise to contribute to current urban mobility issues and at the same time has potential to impact a wider variety of sectors beyond transport, such as health (Kamargianni et al., 2018; Moving Forward Consulting, 2016). MaaS developments are evolving quickly and without consideration to the wider (negative) effects, outcomes on urban mobility will influence liveability in cities and health of their residents. However, no research has been executed on the health impacts associated with the changes MaaS can bring. Therefore, the following research question was formulated:

"What could be the impacts of MaaS on health within urban environments?"

Due to the explorative nature of this research, it was not the intention to provide conclusive evidence on the impacts of MaaS on health, but this study aimed to help create a better understanding of the high level relations and pathways to health gains. A qualitative approach was adopted using a range of mixed methods, of which a conceptual framework linking the introduction of MaaS to health was one of the main outcomes. The framework was tested as part of a health impact assessment to determine the contribution of MaaS to health in terms of potential directions, likelihood and timing of health impacts. The Dutch urban environment was chosen as case study to demonstrate the scale and distribution of health impacts. Outcomes of this assessment were used to provide for a more informed discussion on service design to incorporate health gains and decrease the risk for negative outcomes. In doing so, the research was divided into four main research phases;

1. Collecting information: researching the links between health and urban transport
2. Analysis and conceptualisation: linking MaaS to urban transport, travel behaviour and health
3. Testing the framework: health assessment and discussion on service design and stakeholders
4. Conclusions and recommendations: the main conclusions, limitations and recommendations

- *Collecting information: researching the links between health and urban transport*

An extensive literature study was done to identify the main relations between transport and health, later on used as base for the framework. Five key health impact areas were defined for transport to impact health: *physical activity, traffic safety, environmental stressors, accessibility* and *equity*. Parallel with the literature review, a multidisciplinary set of interviewees was approached, selected purposively with a view to represent a variety of experts from both urban transport and health sectors. Several semi-structured interviews were conducted to get an understanding of how MaaS will change the urban transport system, travel behaviour and health impact areas.

- *Analysis and conceptualisation: linking MaaS to urban transport, travel behaviour and health*

The provided evidence base on health and transport was used to identify and analyse main ways in which MaaS can influence health impact areas by changing the urban transport system in terms of travel behaviour. Key components that may comprise a MaaS service (Figure 0-1) can improve travel experience and level of service of multi-modal transport, leading to improved access to (public) transport and lower travel resistances in terms of travel time, travel cost and effort. These improvement have potential to improve multi-modal travel and make MaaS a competitive alternative to car ownership and private vehicle use. This creates an opportunity for health benefits associated with improved multi-modal travel (e.g. reduced stress and increased feelings of control) and from a mode shift from car based travel to alternatives (e.g. reduced emissions and congestion).

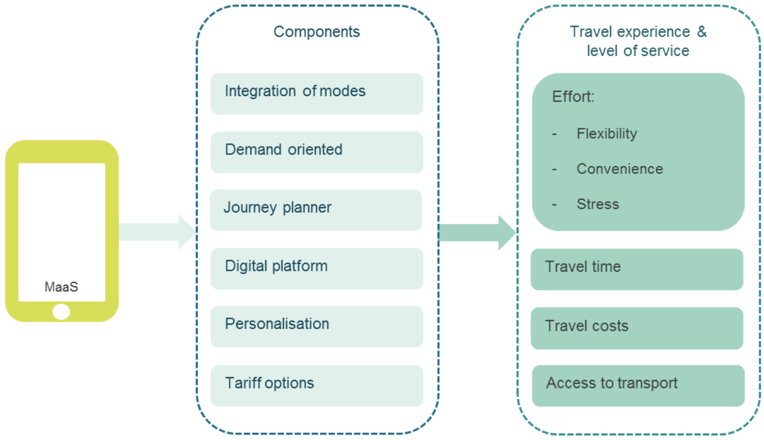

Figure 0-1: MaaS components influencing travel experience & level of service

Available research and literature, explorative interviews and empirical data from MaaS pilots (UbiGo, Smile and Whim) are analysed and showed that MaaS can change travel behaviour in terms of:

- Reduced car ownership and private car use
- Increased multi-modal travel patterns
- Changes in total number of trips made
- More considered travel choices
- New attitudes towards modes
- Changes in route choice

These directions will most likely induce a new modal split and new number of trips made, preferably to a scenario in which public transport and active mode users continue their current behaviour and former car users start shifting towards more multi-modal travel patterns. However, there is potential for a negative scenario when the use of car-based services among former public transport and active mode users turns out higher than anticipated because of MaaS making these services easier to access. Nevertheless, studies so far have shown that the positive direction prevails (Kamargianni et al., 2018).

Based on the links between the urban transport system, health impact areas and health determinants, a conceptual framework was constructed (Figure 0-2). The conceptual model departs from the notion that the health impacts of MaaS mainly arise from changes in travel behaviour through mode choice, choice to travel and route choice. In addition to the more obvious dimension of physical health, also mental health and social health are parts of potential health impacts of MaaS.

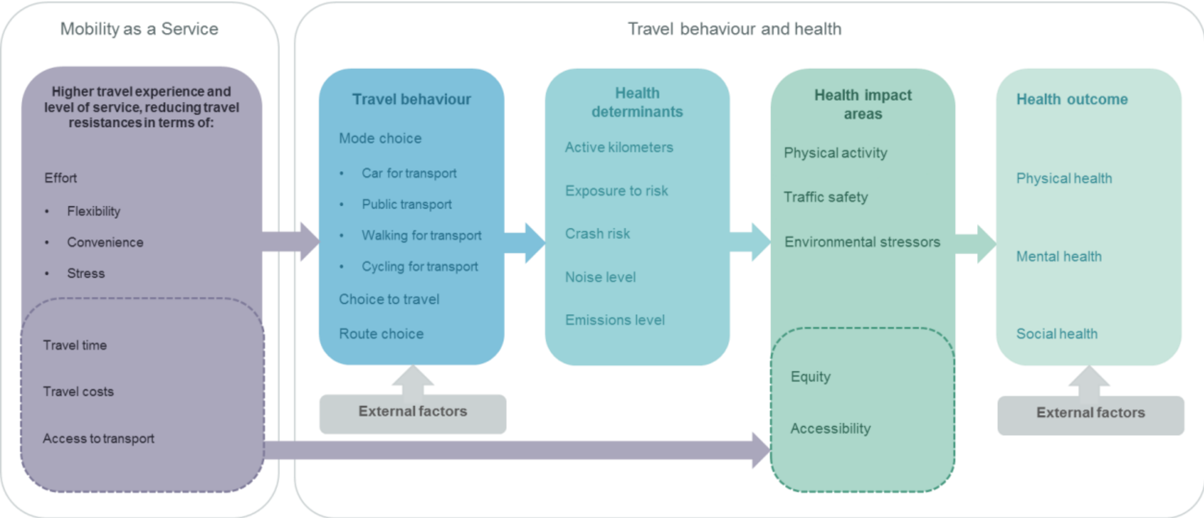

Figure 0-2: Conceptual framework

- *Testing the framework: health assessment and discussion on service design and involved stakeholders*

The framework was tested by performing a health assessment to analyse the nature, likelihood and timing of impacts on the health impact areas (Figure 0-3). This assessment showed that MaaS can establish positive health impacts; on the short-term especially in terms of physical activity via an increased demand for active modes and public transport, and also in terms of improved access to various destinations. In the long haul, change can be expected in terms of traffic safety, environmental stressors and equity. However, impacts on equity are highly dependent on the design of the service and the aim of the MaaS operator.

Health impact area	*Nature*	*Likelihood*	*Timing*
Physical activity	▲▲	Probable	Short term
Traffic safety	▲	Probable	Long term
Environmental stressors	▲	Probable	Long-term
Accessibility	▲	Probable	Short-term
Equity	≈	Speculative	Long-term

Figure 0-3: Summary of health impact assessment results

Furthermore, scale and distribution of health impacts were estimated in a case study for the Dutch urban environment. Data on modal split suggests that between city centres and surrounding municipalities MaaS has potential to contribute to healthier travel behaviour, as current shares of public transport and active modes are low and car use is high. Furthermore, research (Bingen, 2017) showed that Dutch inhabitants most likely to adopt MaaS already have high use of active modes and low use of private cars. Uptake of MaaS by this group can result in some, but lower health improvements, even creating a risk for negative impacts, for example in terms of increased use of ride-sharing services. To generate health gains on a larger scale, MaaS must be adopted by car owners willing to modify their travel behaviour towards more multi-modal patterns, which will likely be more difficult.

The health assessment was brought to further use by providing for a more informed discussion on MaaS service design and stakeholder positioning in the MaaS ecosystem to enhance the chance for positive health impacts. For package design the main trade-off was to create a package that is both appealing to consumers, incentivises healthy behaviour and is interesting from a MaaS operators' perspective. Research (Ratilainen, 2017) shows that among consumers a package with public transport as backbone is preferred, which is in line with the preferred package from a health point of view. The pro health package therefore aims to incentive the use of public transport, complemented with active modes and occasionally car-based services. Such a MaaS service is preferably driven by, or in collaboration with, a public entity rather than a commercial third party. Another possibility is that a public entity establishes conditions and guidelines to ensure that the opportunities provided by MaaS are in line with broader objectives regarding health. Without clear regulations set by national and city governments, some of the negative impacts of MaaS can become a threat to various health aspects.

- *Conclusions and recommendations: the main conclusion, limitations and recommendations*

This thesis used a conceptual framework and health assessment to show MaaS has the potential to contribute to positive health outcomes in urban environments. MaaS services can be used as an entry point for different stakeholders to deliver health improvements at the individual and societal scales. It will require, however, further attention and investment in the design of the service from the diversity of stakeholders influencing mobility and health processes. Government will likely need to play an active role in service design to achieve positive health impacts. There is a clear risk that poorly conceived MaaS designs will produce negative outcomes in important parts of the urban system, for example: congestion, emissions, stress, accessibility, and decreased social interaction. Any negative impacts on the urban system have health implications. Based on this study and the main conclusions, recommendations are proposed on the use of the framework, for incorporating the potential for health benefits during MaaS service developments and for further research:

The framework can be used during further development of MaaS services and ecosystems when designing for health impacts. The core of the framework and presented pathways, focussed on travel behaviour and health, can be used to define the nature of impacts for new transport projects on health. It is believed that the framework can be used for different transport related projects of varying scales and in different research areas, e.g. as a checklist to ensure that decision makers consider the opportunities and risks. The following recommendations are proposed to the public sector to enhance the change for a healthy MaaS service:

- Start MaaS pilots with a health focus
- Set regulations and regulatory frameworks
- Facilitate partnerships between health care companies and MaaS
- Accelerate innovative mobility services with MaaS
- Design infrastructure that facilitates healthy behaviour

For further research, the following recommendations are proposed:

- Evaluate the share of consumers choosing for packages or pay as you go subscriptions
- Estimate potential for health impacts in rural areas
- Test the effects on travel behaviour from a healthy MaaS design
- Quantify results from the health assessment

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List of abbreviations

AM	Active Mobility
AV	Automated Vehicle
CDC	Centres for Disease Control and Prevention
dB	Decibel
DRT	Demand Responsive Transport
EV	Electric Vehicle
HIA	Health Impact Assessment
Ministry I&W	Ministry of Infrastructure and Water Management
KiM	Kennis instituut Mobiliteit
KPI	Key Performance Indicators
LoS	Level of Service
MaaS	Mobility-as-a-Service
NO_2	Nitrogen Dioxides
PM	Particulate Matter
PT	Public Transport
RIVM	Rijksinstituut voor Volksgezondheid en Milieu
UCL	University College London
UU	University Utrecht
VKT	Vehicle Kilometres Travelled
WHIASU	Wales Health Impact Assessment Support Unit
WHO	World Health Organization

1. Introduction

Due to the continuous increase in urbanisation, economic growth, and population growth, the demand for transportation is increasing, resulting in higher levels of congestion, emissions and noise pollution, among others (EPA, 2017; Sochor et al., 2015). Transport is therefore seen as one of a range of social, environmental and economic factors outside of health and medical care which are known to impact health (Kavanagh et al., 2005). This research explores the possibilities and impacts on health of a relatively new mobility concept, called Mobility-as-a-Service (MaaS). The concept holds the promise to contribute to some of the current urban mobility issues and at the same time has potential to impact a variety of sectors beyond transport, such as the environment, society and health (Kamargianni et al., 2018; Moving Forward Consulting, 2016).

Nowadays, urban mobility is considered as one of the major challenges for the future of cities; it contributes significantly to the attractiveness of cities, being a precondition for economic prosperity and wellbeing, but also poses some immediate threats to both individual and societal health. Daily commute choices play an important role in maintaining a healthy population and urban environment, but also raises health concerns regarding traffic safety, exposure to air and noise pollution and increase of unintended side effects such as obesity, heart diseases, stress and dementia (Public Health Ontario, 2017; Bassett et al., 2008; Mindell, n.d.).

Focus on the wider health impacts of urban mobility is needed, but discussions and frameworks, for example the 5E structure by van Oort et al. (2017), often do not consider health as main focus point. This is starting to change, as the work by the World Health Organization (WHO) has increased the understanding of policy makers and others on the impact of environmental and social factors on health and the role of professionals outside of the healthcare sector in determining the health of populations (Mindell, 2015). The European Union formulated specific objectives regarding mobility and health, trying to address the obesogenic environment by stimulating active mobility (Commission of European Communities, 2005).

From a transport perspective, the quality of health and the urban environment can be improved through various transport related areas. The introduction of the mobility concept MaaS in 2014, defined by Kamargianni et al. (2018) as *"[…] a user-centric, intelligent mobility management and distribution system, in which an integrator brings together offerings of multiple mobility service providers and provides them to end-users through a digital interface, allowing them to seamlessly plan, access and pay for door-to-door journeys.",* could potentially be a means to do this. The service provides an opportunity to support active lifestyle objectives and impact various other health areas (Kamargianni et al., 2018; Move Forward Consulting, 2016; Karlsson et al., 2016). The main aim of this mobility concept is to provide an alternative for car ownership and private vehicle use by offering a service to consumers that makes multi-modal transportation more easy and convenient to use.

1.1 Knowledge gaps

The body of knowledge that describes the effects of transport on the population and environment is growing (*discussed further in* chapter 4). The increasing awareness that transportation systems have a high impact on health and wellbeing creates a dilemma for governments and non-governmental organisations that try to seek innovative policies and programs to improve public health while at the same time accomplish their primary transportation objectives (CDC, 2014). Even though planners, engineers, and designers are increasingly aware of the relationship, the implementation of high quality transportation systems that consider health within urban regions can be challenging, as it also requires a convincing business case.

The hope and ambition is that MaaS can contribute to the quality of the urban environment and health by promoting people to make more considered decisions during their travel (Ministry of I&M, 2017). Research and studies on the links between health and transportation are available, but the ways in which MaaS can be linked to these relations has not yet been studied.

MaaS holds the promise for a paradigm shift in transport, where MaaS can offer travellers easy, flexible, reliable, well priced and environmentally friendly travel options as an alternative to owning and using a private vehicle (Li and Voege, 2017). MaaS can stimulate a shift away from ownership-based transport to access-based transport via sharing systems (Saidla, 2017). Replacing car ownership and usage by alternative transport modes is seen as one of the most effective measures when it comes to increasing sustainability and MaaS may motivate people to make this transfer (Ministry of I&M, 2017). On the other hand, MaaS may also induce negative impacts on health as the promotion of ride-sharing among MaaS users can decrease liveability in cities by worsening congestion. An example is the city of San Francisco where the total vehicle kilometres travelled increased due to the introduction of ride-sharing services, e.g. Uber and Lyft. More people started using ride-sharing services for short trips with an average distance of 4 kilometres; a distance that could be travelled by foot, bike or bus, but now leading to more congestion (NRC, 2018; Clewlow, 2017).

Research in London, Amsterdam and Sydney showed that former public transport users more often use car-based service when having a MaaS subscription (Kamargianni et al., 2018; van Oort and Veeneman, 2017; Alonso-González et al., 2017). When a MaaS service attracts more former public transport users than car users, the sustainability effect can become reduced and even negative (Jacobs, 2017; Holmberg et al., 2016), also affecting health. Furthermore, there is a possibility of increased vehicle kilometres when (automated) vehicles are used as personal vehicles, resulting in an increase in congestion and energy consumption (Holmberg et al., 2016). Other research argues that the implementation of sharing systems is an opportunity: research by Gould et al. (2015) envisions MaaS as a way to decarbonise the transport sector by reducing the use of private, fuel-based vehicles and encouraging the diffusion of electric vehicles as part of sharing systems in cities. The gradual electrification of road transport can be a strategy to increase urban health, as it reduces transport-related oil dependency, local emissions and noise pollution (Weiss et al., 2015). However, this does not solve the problem of congestion.

To start moving towards a healthier population and environment in urban areas, the need to shift away from conventional transport methods is recognised among researchers. Some cities have tried to face the challenge of urban mobility, but a holistic approach is needed to achieve synergies between different modes of transport (Sochor et al., 2015). It is uncertain based on existing literature and research to what extent and in which direction MaaS can change travel behaviour (Kamargianni, 2016), and therefore impact urban health.

The bigger picture has to be understood to determine what factors have the biggest impact on health (Cavoli et al., 2014). It is therefore important to identify and link MaaS to transport and health indicators to see how a change in one area can have a spillover in other areas. Some researchers see MaaS as the solution to many problems regarding urban mobility, but even though attention is growing and activities and research on MaaS are ongoing, quantifiable evidence on costs, benefits, and influence on travel patterns and travel behaviour is limited (European Commission, 2017). In conclusion, the possible health impacts of MaaS have not yet been studied despite the potential for both a positive or negative outcome. The relations between MaaS, transport and health are undefined and the impacts require research before the service adds to urban mobility issues and induces more negative effects on health.

To sum up, the following gaps are identified:

- So far, research on MaaS has been limited to, among others, conceptualisations of MaaS, the framework and associated terms (e.g. Jittrapirom et al., 2017; Holmberg et al., 2017; Karlsson et al., 2017), MaaS business models (e.g. Aapoaja et al., 2017), the MaaS ecosystem (e.g. Kamargianni & Matyas, 2017) and studies on the market potential, steps for implementation (roadmaps) and regulatory requirements (e.g. MaaS Scotland, 2018; MuConsult, 2017; Li and Voege, 2017; Karlsson et al., 2017; Moving Forward Consulting, 2016). Empirical data on how MaaS can change travel behaviour is limited as only one pilot has been thoroughly evaluated; the UbiGo pilot (e.g. Sochor et al., 2014; 2015; Karlsson et al., 2016).
- The potential impact of Maas on health provides a new perspective to analyse and evaluate the concept, which is in line with the increasing interest for health improvements from sectors beyond the traditional health and medical-care. Health is not often used as perspective to analyse new mobility concepts despite the significant impact transport and travel behaviour can have on health, which stresses the need for synergy between both disciplines.
- Potential impacts from MaaS on health can turn out both positive and negative, so an understanding of the bigger picture is required. For now, the direction and extent in which MaaS can influence health is uncertain and requires further research.

1.2 Research goal, research question and sub-questions

This study aims at closing the gaps mentioned in the problem definition in section 1.1. The main goal of this research is to better understand the links between MaaS and health through explorative researching the concept and its main elements and inter-relationships with health. Based on this research goal and problem definition described above, the following research question is formulated:

"What could be the impacts of MaaS on health within urban environments?"

To be able to answer the research question, different sub-questions are formulated. Within chapter 2 these sub-questions are linked to the research methodology and the outline of this research. To answer the main research question above, the following sub-questions are formulated:

1. *What are the main characteristics of Mobility-as-a-Service (MaaS)?*
2. *How do urban transport and travel behaviour influence health?*
3. *How can the introduction of MaaS change urban transport?*
4. *How can MaaS change travel behaviour?*
5. *Via which pathways can MaaS impact health?*
6. *What is the potential impact of MaaS on health?*
7. *How to design MaaS to generate positive health impacts?*

This research provides added value in two ways: scientific relevance and social relevance. The study is scientifically relevant as it links two scientific fields; the MaaS concept has not yet been analysed from a health perspective. The bigger picture regarding the links between health and transport has to be understood to determine the impact of MaaS on health. From a societal point of view, the analysis of MaaS from a health perspective is interesting as the service enable the reduction of private car use, resulting in less congestion, air pollution and noise pollution (Sochor et al., 2015). The potential of MaaS to improve health within cities is therefore socially relevant and interesting for governments and municipalities, as it provides potential to contribute to their broader objectives regarding accessibility, social inclusion and liveability.

1.3 Scope

This thesis is conducted to identify and analyse the health impacts of MaaS. Because of the exploratory nature of this research, it is not the intention of this study to provide conclusive evidence on the impact of MaaS on health, but it aims to help create a better understanding of the relations and potential impacts. This study therefore focusses on the high level relationships between health, transport and MaaS: because MaaS is novel and health is a complex study area. To make sense of the complex study area of health and transport, it is chosen to focus mainly on changes in travel behaviour induced by MaaS. Furthermore, personal characteristics such as socio-demographic factors, capabilities and personal behaviour (e.g. smoking and diets) are not considered.

The urban environment is chosen as focus area since research has demonstrated that MaaS is most beneficial for people living in urban areas (Holmberg et al., 2016; Sochor et al., 2014). The chosen research area for the case study is the urban environment in the Netherlands. Health standards and ambitions are location-dependent and also travel behaviour and transport infrastructures can differ strongly between countries and even between cities; walking and bicycling is more common in the Netherlands than for example in other, especially non-European countries such as the United States and Australia (Bassett et al., 2008). Also, health impacts may vary; fatality risks for cyclists are six times higher in the U.S. compared to the Netherlands (de Nazelle et al., 2011).

1.4 Technology in Sustainable Development annotation

During the master program Transport, Infrastructure and Logistics, I started with the annotation Technology in Sustainable Development (TiSD). To graduate with the TiSD annotation, this thesis combines the fields of transportation and sustainable development. This means that the main research question tries to elaborate sustainable development to a next level in the transport sector. Sustainable development is defined as development that is good for nature, people, and at the same time economically profitable. Also, sustainable development is the kind of development that meets the needs of the present without comprising the ability of future generations to meet their own needs. This research focuses mostly on the people and nature aspect of MaaS via the potential influence on health and the environment. Technology also plays an important role in sustainable development. The technology used in MaaS has potential to contribute to a more sustainable and healthy planet as it could, among others, play a role in automation, electrification and sharification of the transport sector. It can contribute to the environment, for example, by decreasing emissions, creating more accessible cities that are less car centric and promoting the shift from ownership to user ship. Appendix F elaborates on the impacts of MaaS on sustainable development and a sustainable transport system.

1.5 Outline

The outline of this research is visualised in Figure 1-1. Chapter 2 begins with a brief introduction and review of the MaaS concept, the used definition, the main components comprising the service and the stakeholders in the MaaS ecosystem. In chapter 3 the methodology is described which is used to collect the needed information and data to analyse the MaaS concept in terms of health impacts and to provide an answer to the main research question. Chapter 4 elaborates on the definition of health, the main health dimensions and the effects of transport on health, mainly extracted from available scientific literature. Chapter 5 explores how MaaS can change multi-modal travel in terms of travel experience and level of service. How MaaS can change travel behaviour, potentially towards more healthy behaviour, is analysed in chapter 6. Chapter 7 contains the conceptual framework, which is used to perform a first health assessment in chapter 8. A discussion is included in chapter 9 to explore how MaaS can be designed to have the highest health impact. The report concludes in chapter 10 by reviewing what the study has done, providing a summary on important findings, discussing the limitations of the research and giving recommendations for further research and use of the framework.

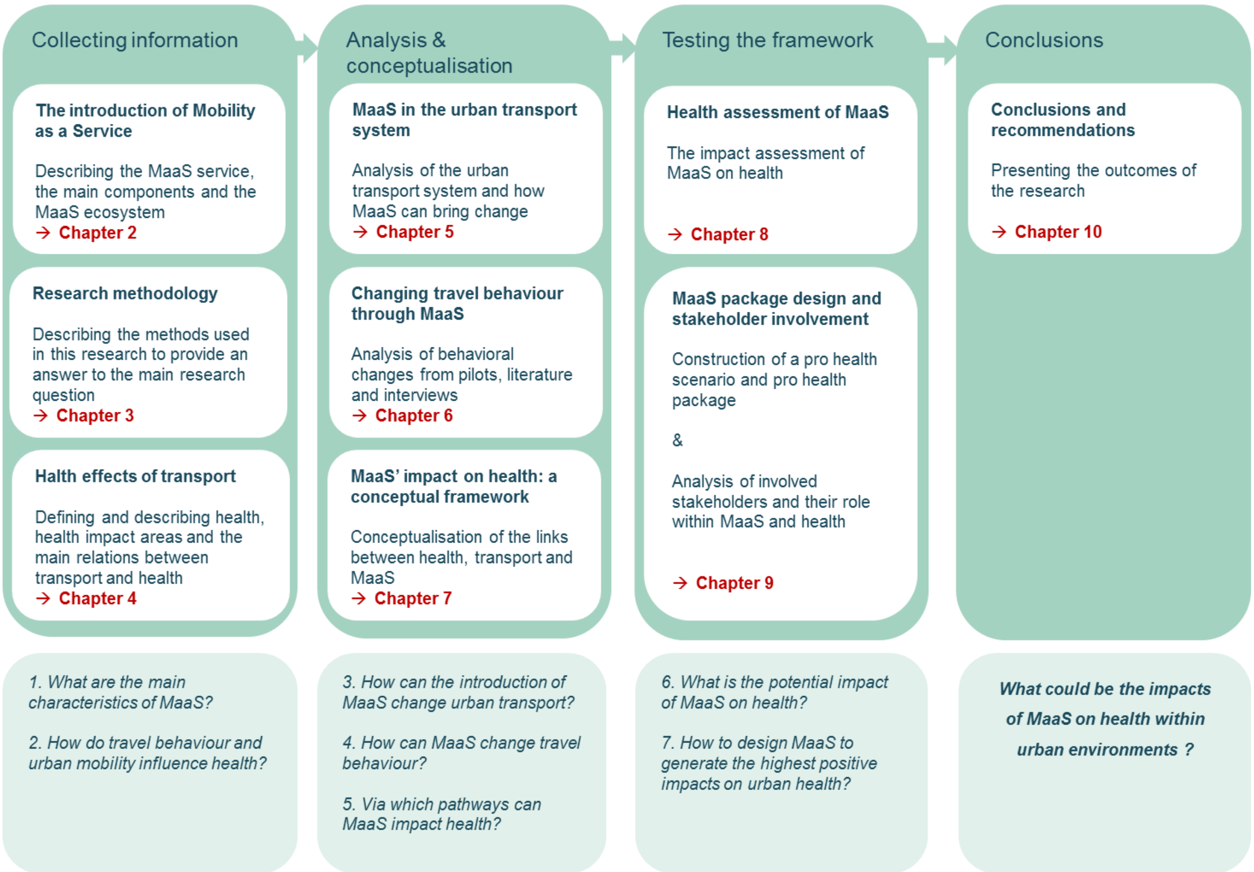


Figure 1-1: Research structure

COLLECTING INFORMATION

Information is gathered from literature review, academic research and expert interviews on the concept of MaaS, health, and the effects of transport on health.

2. The introduction of Mobility as a Service

MaaS as a relatively new innovative mobility concept anticipates to induce significant changes in the transport sector. This chapter answers the sub-question: "*What are the main characteristics of Mobility-as-a-Service (MaaS)?".* Hence the novelty of the concept, there is a certain level of ambiguity surrounding the definition and what components comprise a MaaS scheme, despite the summaries about MaaS that have been provided by, e.g. Jittrapirom et al. (2017), Kamargianni et al. (2016) and Holmberg et al. (2016). This chapter provides a definition of MaaS (section 2.1), followed by an overview of main components a MaaS service may comprise (section 2.2) and the involved stakeholders (section 2.3), ending with a conclusion (section 2.4).

2.1 Definition of MaaS

The growing pressure on urban mobility systems has increased the demand for innovative solutions that increase efficiency and tackle current urban mobility issues. A trend gaining a lot of attention in many industries is that of sharing. With the rise of Netflix, Spotify and AirBnB as examples of this trend, a somewhat similar shift also reached the transportation sector in the form of shared mobility services with the introduction of car and bike sharing systems. In combination with the new possibilities emerging from ICT, such as the Internet of Things and 'big data', the concept MaaS has started to receive considerable attention.

Despite MaaS being a buzz-word in the transport sector, there is still a high degree of ambiguity surrounding what MaaS is and how the concept has to be defined. Different sources sometimes offer conflicting definitions and presented and tested MaaS schemes comprise different components (Jittrapirom et al., 2017). Many researchers and experts do not give a strict definition of MaaS and Kamargianni et al. (2016) and MuConsult (2017) state that MaaS schemes should be categorised on the base of integration level. Kamargianni et al. (2016) distinguish four types of integration, ranked from most basic level to the most advanced level;

1. **Ticket integration:** different modes can be accessed via a single ticket
2. **Payment integration:** one account is charged for the use of mobility services
3. **ICT integration**: journey planning and booking is accessible in one application
4. **Mobility package integration**: mobility tool that allows customers to pre-purchase usage of various modes for a longer period of time as one product

This research 'defines' MaaS at the most advanced level of integration and uses the definition given by Hietanen (2014), one of the founders: "*MaaS is a mobility distribution model that delivers a transportation need to its users through one single digital interface, by integrating and bundling different transport modes into mobility packages".* Within this definition, the different levels of integration can be distinguished; it is about the **integration of transport modes** through **ticket** and **payment integration**, offered in **one digital interface** by the **integration of ICT** *and* about the bundling of these modes into **mobility packages** for its end-users.

The most common offered transportation methods within MaaS include bike-sharing, (urban) public transport, car-sharing, ride-sharing, taxi, and car rental (Kamargianni et al., 2017; MuConsult, 2017). Beyond the urban environment the service can include long-distance buses and trains, flights, and ferries (Jittrapirom et al, 2017), but these modes are not within the scope of this research.

2.2 Core components

Besides the ambiguity surrounding the definition of MaaS, what constitutes a MaaS concept also differs. Several MaaS schemes are implemented throughout the past years and research by Jittrapirom et al. (2017) compared these concepts and schemes, resulting in an extensive set of key characteristics. These components are similar to the ones described by MuConsult (2017) and Kamargianni et al. (2017), and should, preferably, be considered separately when analysing how MaaS changes travel behaviour (ibid.). The component lists are presented at Appendix D and from this list the key components that can change the way people travel are shown in Figure 2-1 (authors own). The description of these components is included in Table 2-1. These components have potential to improve travel experience of multi-modal transport, cut down on travel costs, reduce travel time and therefore reduce dependency on private cars, among others (Kamargianni et al., 2018).

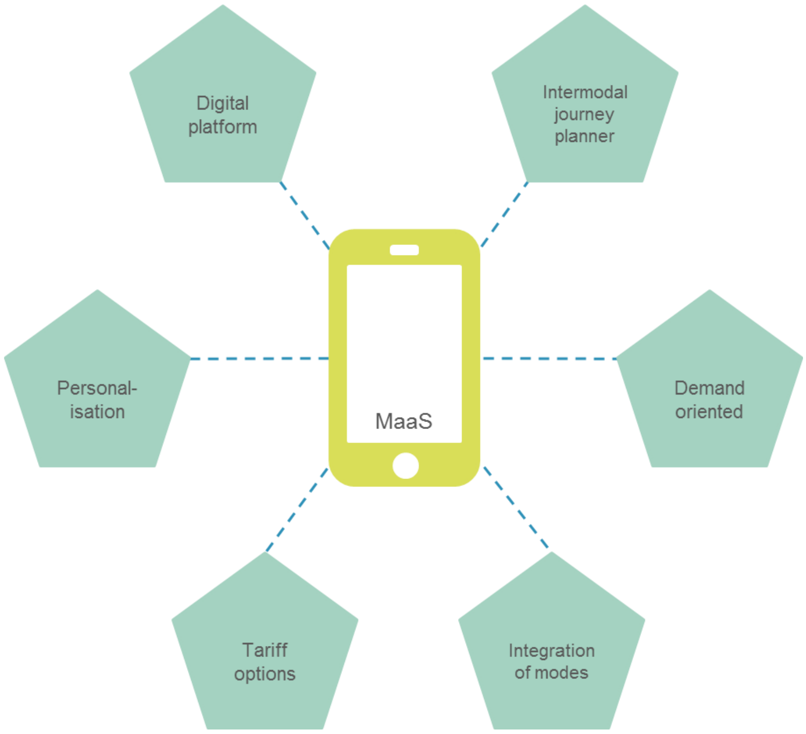


Figure 2-1: MaaS components

Table 2-1: Description of MaaS components

MAAS COMPONENT	DESCRIPTION
Integration of modes	Integration of modes from private and public providers to improve multi-modality and facilitate the users in their intermodal trips.
Intermodal journey planner	Trips can be planned within one intermodal digital trip planner that assembles information from various modes and uses real time information to update users on their trips; pre-trip and during the trip.
Personalisation	The system provides end-users with specific, customised travel recommendations to their profiles, preferences and past behaviours.
Tariff options	The platform offers two types of tariffs in accessing the service; a mobility package or a pay-as-you-go option.
Demand oriented	User-centric paradigm seeking to offer the best door-to-door transport for its user via multi-modal trip planning.
Digital platform	One digital platform that provides access to planning, booking, smart ticketing and payment. Ticket and payment integration means that when one smart card or ticket is used to access all the modes taking part in the service and one account is charged for the use of those services

2.3 The MaaS Ecosystem

Since the MaaS concept is still evolving innovations around MaaS are ongoing and stakeholders and their roles within the development of MaaS keep changing (Holmberg et al., 2016). Both public and private stakeholders in the transport system are investigating their roles in the development (Smith et al., 2018). Research by Kamargianni and Matyas (2017) provides a holistic framework of the MaaS ecosystem, showing the stakeholders engaged with the system (Figure 2-2). For the sake of scoping, this study focusses on the core business of MaaS which comprise the following stakeholders (further description can be found in Appendix C):

- **MaaS operator**; public authority or private firm
- **Transport operators & mobility service providers**; sell transport capacity to MaaS operator
- **Customers / users**; individuals, companies, or both
- **Data providers**; offer data and analytic capabilities to the MaaS operator

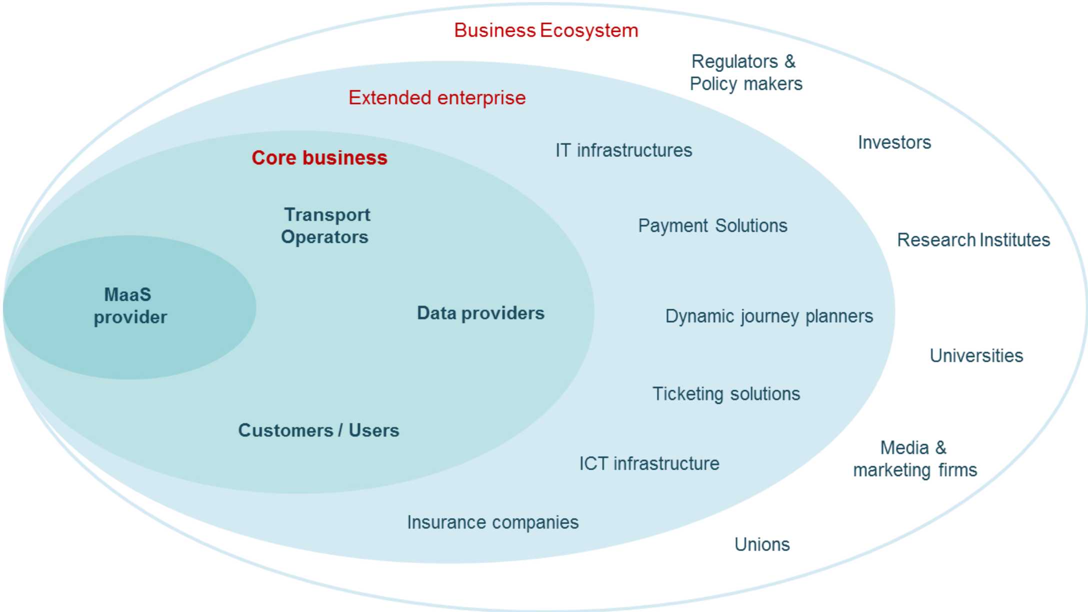


Figure 2-2: MaaS ecosystem (Kamargianni and Matyas, 2017)

2.4 Conclusion

This chapter answered the sub-question: "*What are the main characteristics of Mobility-as-a-Service (MaaS)?".* MaaS, being a relatively new mobility concept, is still surrounded by a high level of ambiguity. This research chose to use the definition provided by Hietanen (2014), to define to concept on the highest level of integration. In short, the MaaS service is about the integration of transport modes through ticket and payment integration, offered in one digital interface by the integration of ICT *and* about the bundling of these modes into mobility packages for its end-users. Through combining various components and technologies, MaaS aims to substitute private car use and car ownership with more convenient multi-modal travel options. Most influential stakeholders engaged in the MaaS concept are the MaaS operator, transport operators and mobility providers, data providers and consumers. Together they form the core business of MaaS.

3. Research methodology

This thesis studies how the concept of MaaS can have an impact on health. Since the study area is quite novel and no previous research has been done in this area yet, an exploratory research is conducted using mixed methods. Due to the exploratory nature of this research it is not the intention to provide conclusive evidence on the impacts of MaaS on health, but instead, aims to help create a better understanding of the relations and the potential directions for impacts.

The research was divided into four main phases that each answered some of the sub-questions, in order to answer the main research question in the main conclusion. The following four phases are defined:

1. **Collecting information**: researching the links between health and urban transport
2. **Analysis and conceptualisation**: linking MaaS to urban transport, travel behaviour and health
3. **Testing the framework**: health assessment and discussion on service design and stakeholders
4. **Conclusions and recommendations**: the main conclusion, limitations and recommendations

An overview of the main methods used within these phases is presented below in Figure 3-1. This research started with identifying the knowledge gaps described in the introduction. The blocks in the figure represent the used methods and the descriptions between them describe the next step.

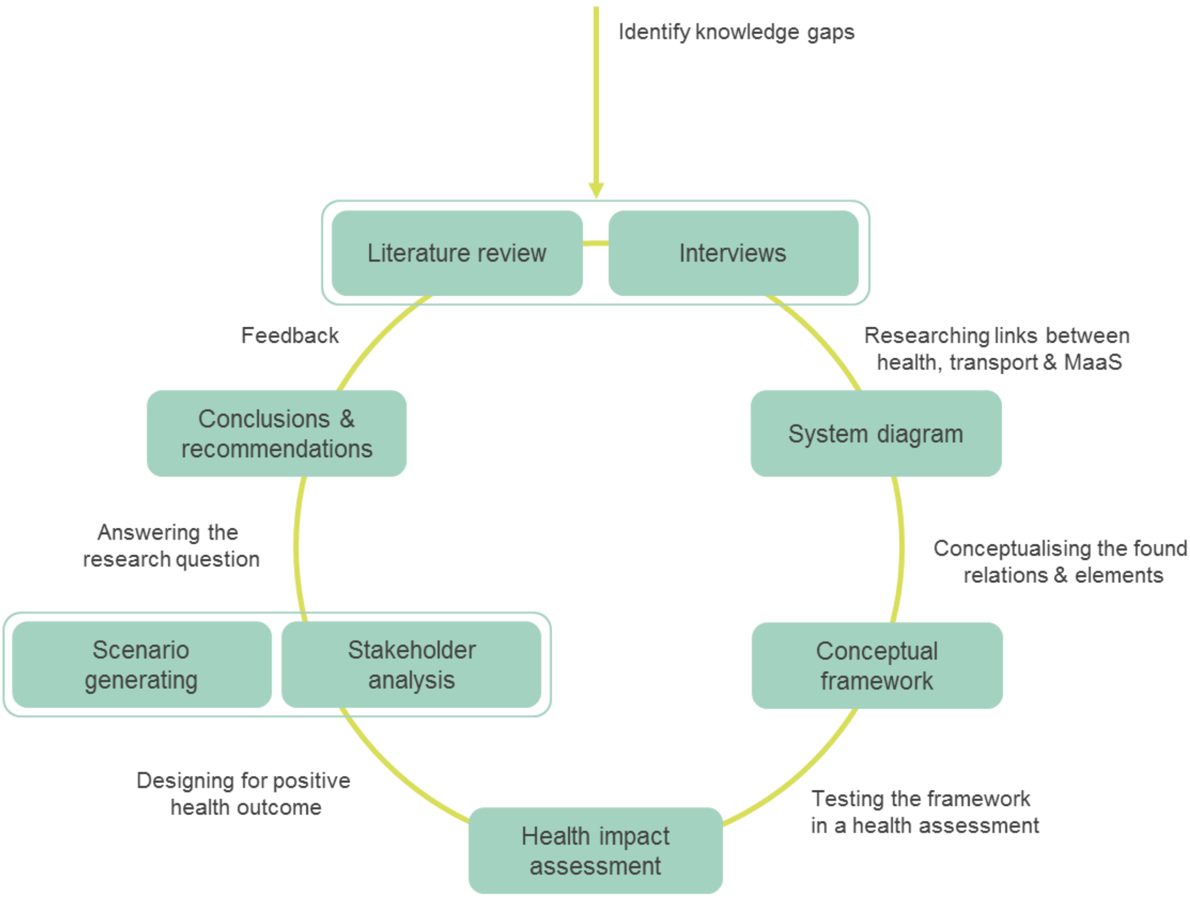


Figure 3-1: Methodology structure

3.1 Collecting information

After having defined the research goal, research questions, scope and methodology in the first chapter, information was needed to answer the first sub-questions. In the first phase of this research information was collected in two ways: a literature study was performed and interviews with experts from health and transport fields were conducted. Information and data were gathered on the inter-relationship between transport and health and on the MaaS concept. References to the expert interviews and literature are interchangeably used throughout the main text in this document. Interviews are referred to in the format of (Krantz interview, 30th of August 2018) and other references as (Krantz, 2018).

3.1.1 Literature study

The literature study aimed to give an up-to-date and structured overview of the literature in the field of health, urban transport and MaaS. Main research topics for the literature study were the existing links between transport and health, and the MaaS technology. The literature review was performed to:

- Identify the main gaps in literature (section1.1)
- Facilitate in giving insight in the state of knowledge on MaaS (chapter 2)
- Get a clear understanding of what health is (section 4.1)
- Assist in identifying the main relations between transport and health (section 4.2)
- Analyse the main directions for changes in travel behaviour (chapter 6)
- Provide an evidence base for the conceptual framework (chapter 7)

A systematic literature search was performed in a structured way based on screening and selection of relevant studies from databases available to the author (SCOPUS, Science Direct, Google Scholar, TU Delft) and accompanying snowballing as well as expert interviews lead to the majority of usable literature.

The first part was to find theory on how the transport system influences health. Combinations of the following keywords were used during this search: “health”, “urban health”, “individual health”, “societal health”, “physical health”, “mental health”, “social health” and “urban mobility”, “urban transport” and “travel behaviour”. Then the influence of MaaS on travel behaviour and the urban transport system was researched by combining the previous keywords regarding mobility with “Mobility as a Service” and “MaaS”, and by extending the initial list with the five health impact areas that were identified after the initial search; “physical activity”, “air pollution”, “equity”, “accessibility” and “traffic safety”.

Literature on the effect of MaaS on travel behaviour is limited and therefore this explorative research also looked into the impact on transport and health of MaaS-like concepts and concepts that are included in MaaS schemes, for example the concepts of car/bike-sharing, ride-haling (e.g. Uber and Lyft), and more local innovative initiatives where integration of modes is the core of the service.

3.1.2 Explorative interviews

In line with the explorative nature of this research, interviewing experts from different fields was chosen as one of the main methods to gather information and data. MaaS is still a relatively new concept with limited available literature and data, especially regarding the ways it can impact travel behaviour. Various experts were approached to get a multidisciplinary set of experts' opinions, selected purposively with a view to representing a variety of experts from both urban transport and health sectors. Unfortunately, no experts have been found with knowledge on both health and MaaS, which emphasises that the research area is new and exploratory research is needed.

From the health sector interviewees were approached whom have been involved in projects regarding health and sustainable development in urban environments. The selection represents the view of the public sector (Municipality of Utrecht), health knowledge institutions (RIVM), academia (University of Utrecht) and sustainability consultants (Arup). The interviews were conducted to gain more insight in health in urban environments, the main relations between urban health and urban transport, and to get the first set of experts' opinions on if and how MaaS can contribute to health in urban environments. From the transport sector, experts were approached with expertise in urban transport and/or MaaS. The set of interviewees represents knowledge institutions on mobility (KiM), academia (TU Delft, Radboud University Nijmegen, University College London), MaaS operator (MaaS Global) and transport consultants (Arup, MuConsult). Focus was on the MaaS concept in general as perceptions still vary, the ways MaaS can change travel behaviour and the potential of the service to influence health.

Table 3-1: Interviewees field of expertise

Interviewee	Cities	Health	Urban transport	MaaS
Leendert van Bree				
Dick Ettema				
Hanneke Kruize				
Ellen Peeters				
Susana Saiz				
Maria Montero				
Anne Durand				
Henk Meurs				
Maria Alonso-González				
Sampo Hietanen				
Maria Kamargianni				
Ryan Falconer				

Table 3-1 holds an overview of the interviewees expertise and Appendix A includes a more extensive description of who they are. The following twelve experts were interviewed:

1. Leendert van Bree (worked for RIVM, PBL, associate professor in healthy urban living at the UU)
2. Dick Ettema (Associate professor Human Geography and Spatial Planning at the UU)
3. Hanneke Kruize (RIVM, focus on projects regarding health in urban environments)
4. Ellen Peeters (Senior advisor healthy urban living for municipality of Utrecht)
5. Susana Saiz (Arup, sustainability consultant working on health and the environment)
6. Maria Montero (Arup, strategic sustainability planner)
7. Anne Durand (Transport researcher at KiM, currently focussing on MaaS)
8. Henk Meurs (Professor in mobility and spatial development & CEO MuConsult)
9. Maria Alonso-González (PhD student at TU Delft on Demand Responsive Transport)
10. Sampo Hietanen (CEO MaaS Global and founder of MaaS)

11. Maria Kamargianni (Head of MaaSLab, lecturer University College London Energy Institute)
12. Ryan Falconer (Arup, Cities leader of Transportation Consulting in Toronto)

With respect to each expert's field of study, a list of interview questions was made from the general list of questions at Appendix A. The interviews were performed in a semi-structured way and recorded, transcribed and summarised at the end. When the interviewee accepted the summary as representative to the conversation, it was used as empirical data. Coding was used to merge answers to questions belonging to the same research theme. All interview summaries were collected in a separate document, *Empirical data from interviews and conversations*, which is available on request. The given answers are paraphrased or cited throughout the main text of this report, according to the theme they belonged to.

3.2 Analysis and conceptualisation

The theoretical base from the first phase of this research was used as input for the second phase, which is about defining and conceptualising the existing elements and links between health, transport, and MaaS. The goal of this phase was to identify the potential for health impacts through building a framework that can be used to assess the health impacts of MaaS in the third phase. Two main method were selected: construction of a system diagram and a conceptual framework.

3.2.1 System diagram: urban transport system

Within this second phase of the research the urban transport system, focussed on health, was defined and visualised by means of a system diagram to:

- Analyse the position of MaaS in the current urban transport system (section 5.1)
- Link paths and highlight important interactions between health and MaaS (section 5.2)
- Identify main health determinants for the framework and health assessment (section 5.3)
- Provide a base for the conceptual framework (chapter 7)

This method is capable of analysing large and complex systems as it provides a way to create an overview of the transport factors important in the urban transport system and their link to health. Mapping of these relationships and impact areas is a useful way of visualising the potential health impacts of a concept such as MaaS, since the diagram linked paths together and highlighted important interactions (WHIASU, 2011). However, the system diagram should not be seen as a causal diagram, since many of the relations between MaaS and health are not based on causality, but are mostly derived from cross-sectional studies and observational research, for example cohort studies (Geelen review, 18th of June 2018; de Nazelle et al., 2011).

3.2.2 Conceptual framework: MaaS and health

A conceptual framework was made to make sense of the complex relationships between health, the urban transport system and the introduction of MaaS. The construction of a framework is a useful tool to integrate knowledge across different disciplines in this study: of health, urban transport and MaaS. The framework is constructed based on the outcomes of the first and second phase of this study and used to:

- Integrate knowledge across the disciplines of transport, health and MaaS (section 7.1)

- Formalise the pathways between MaaS and the health impact areas (section 7.2)
- Discuss the strongest and weakest relations between MaaS and health (section 7.3)
- Provide a framework to test for the impacts of MaaS on health (used in chapter 8)

The conceptual model thus provides an explicit method to structure how the variables in the system of health and transport are related, by making a simplified representation of the links between urban transport, the introduction of MaaS and the health dimensions.

3.2.3 Validation

Multiple experts in the field of health, transport and MaaS were approached for reviews to provide feedback and validation of this study.

- 14th of June: Loes Geelen – Health focus: Loes Geelen is an senior advisor on healthy environments and an expert in health impact assessments and odour nuisance.
- 18th of June: Arup Dublin office – Orla O'Halloran – MaaS focus: Orla O'Halloran is a consultant at Arup in Dublin, Ireland and has experience in environmental consulting and intelligent mobility.
- 22nd of June: Arup Amsterdam – Hanna Ratilainen – MaaS focus: Hanna Ratilainen is a consult in Arup Amsterdam and has done here master's thesis on MaaS. For Arup she is working as mobility consultant and has worked on a project for MaaS Global.

3.3 Testing the framework: health assessment and discussion

Within the third phase, the conceptual framework was tested by performing a health impact assessment on MaaS. This first exploration was done to use the pathways in the framework to assess MaaS' health impacts and to provide for a more informed discussion on how to design a health improving MaaS service. The discussion explored the potential design of a pro health package and the possible positioning of the involved stakeholders within the MaaS ecosystem to enhance the chance for positive health impacts.

3.3.1 Health assessment

Health impact assessment is a method used to estimate the potential positive or negative impacts of a project, programme or policy on health. The assessment structure provided by the Wales Health Impact Assessment Support Unit (WHIASU) was adapted and used to perform a first estimation of the health impacts of MaaS. Traditionally, health impact assessment favours more quantitative, epidemiological methods to collect and analyse data, but in the case of MaaS these resources are limited. The range of health impacts from MaaS were, therefore, assessed in a qualitative way.

The following steps are performed:

1. **Screening & scoping** – decide whether to undertake a HIA, determine focus, select determinants
2. **Impact identification** – identifying potential impacts to health
3. **Impact assessment** – assess the potential impacts to health
4. **Recommendations** – aim to maximize the potential health benefits and mitigate negative impacts

The first two stages of screening and scoping were performed during the first phase (collecting information) and second phase (analysis and conceptualisation). The third step, impact assessment, is performed in the third phase by testing of the conceptual framework. The recommendations step on how to enhance the chance for health benefits is performed by discussing package design and involvement of stakeholders. These discussions are described in the next section.

3.3.2 Discussion: scenario's and stakeholder analysis

This section discussed the design of a pro health scenario, pro health MaaS package and the involvement of stakeholders to optimise the positive impacts of MaaS on health, based on the outcomes of the first health assessment. The lack of available data on how MaaS can change travel behaviour required that scenarios were made based on assumptions from previous research and literature. Because of time constraints and limitations in available empirical data on package design, the package design is explored by means of a discussion.

A stakeholder analysis was executed to explore and discuss the stakeholders that play a role within the development of MaaS as a potential health enhancing mobility concept. This analysis was performed to analyse which stakeholders are crucial in designing for a healthy scenario and package. First, stakeholders were identified, followed by an analysis of their objectives, problem perception, power and instruments within a MaaS ecosystem. This analysis was conducted based on the information from literature on the MaaS ecosystem and on the expert judgement of interviewees.

4. The health effects of transport

Be it car, public transport, bike or walking, travel choices can impact health and wellbeing in the urban environment. With nearly 70% of the world's population living in urban areas by 2030, the health and quality of life of this population will determine the global future (Arup, 2016). This chapter brings together the main impacts of transport on health by answering the sub-question: "*How do urban transport and travel behaviour influence health?* To be able to answer this question, knowledge is required on the how transport impacts health. Firstly, an introduction on health and the used definitions is given (section 4.1), followed by an explanation of the health dimensions and the transport areas that influence health (section 4.2). This chapter ends with an answer to the sub-question in the conclusion (section 4.3).

4.1 Defining health

A first broad, useful and universal definition of health is given by the World Health Organization (WHO) in 1948, defining health as:

"[…] a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity".

This definition describes health as a presence of something positive and it uses the classical way of thinking about health and by focussing mainly on protecting health from externalities (van Bree interview, 20th of February 2018; Arup, 2015). It takes into account the three domains of health; *physical health*, *mental health* and *social health.* The WHO definition has positive elements, such as its breadth, and has been widely used during the last decades. During the interviews, many interviewees referred to the WHO definition: Ettema (Ettema interview, 21st of February 2018), Montero (Montero interview, 16th of March 2018), Kruize (Kruize interview, 28th of February 2018) and Saiz (Saiz interview, 28th of February 2018). However, some believe that the definition is outdated and has shortcomings that limit its usefulness (see Witt et al., 2017; Charlier et al., 2017; Huber et al., 2011). However, Ettema (Ettema interview, 21st of February 2018) states that it is useful to analyse and define each one of the health dimension by itself. For this reason, health is defined by analysing each dimension and the main relationships that define them from a transportation perspective.

Health can be impacted via several physical, mental and social diseases, illnesses and conditions. The health outcomes considered in this research are selected based on the links, found in literature and during the interviews between the health impact areas (see section 4.2) and the diseases, illnesses and conditions shown in Figure 4-1 (made by author). Appendix B provides more information on how each disorder links to the health impact areas. Maintaining an optimal level of health requires a balance between these three dimensions of health (Goodacre et al., 2013). To be able to analyse and assess the effects of MaaS on health further on in this study, the three health domains that together determine the health status of people are explained briefly in the next sections.

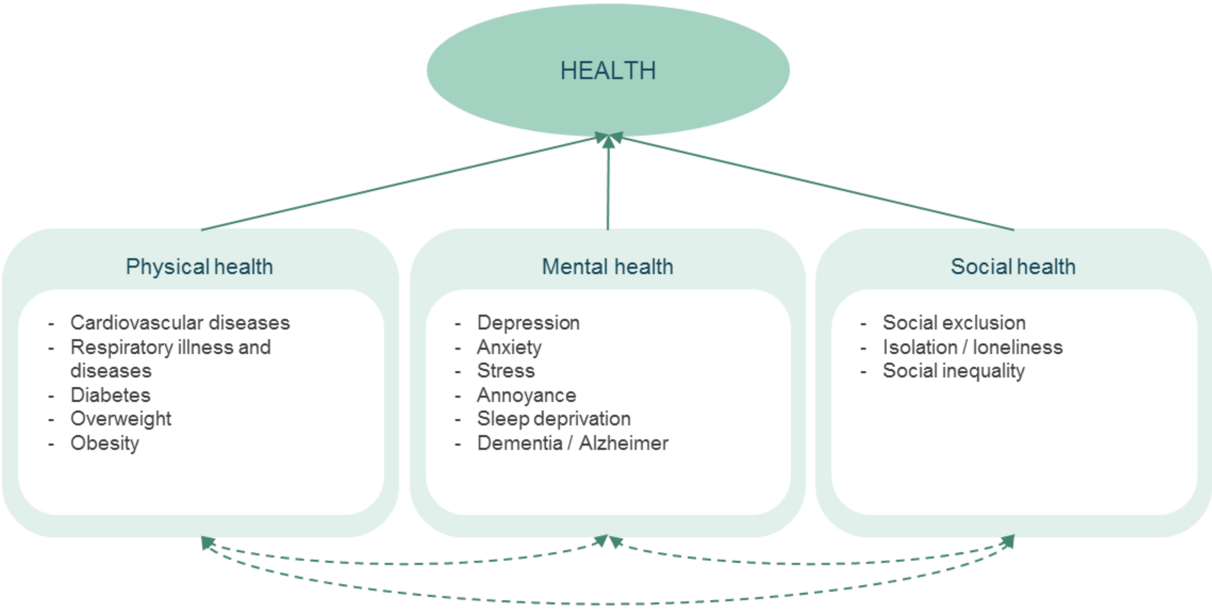


Figure 4-1: Health dimensions and their diseases, illnesses and conditions

4.1.1 Physical health

Physical health is often seen as the first dimension of health and relates to the physical body and its functioning. It is the most visible health dimension as some of the most obvious signs of being unhealthy appear physically through diseases, conditions and disabilities. The WHO (Goodacre et al., 2013) gives physical health the following definition: "*Physical health relates to the efficient functioning of the body and its systems, and includes the physical capacity to perform tasks and physical fitness.*"

4.1.2 Mental health

Mental health is a positive concept which is defined by the WHO (2014) as a "*state of wellbeing in which the individual realizes his or her own abilities, can cope with the normal stresses of life, can work productively and fruitfully, and is able to make a contribution to his or her community*." The WHO defines mental health not merely as the absence of mental illness but as a basis for overall wellbeing, because the absence of mental illness does not equal the presence of mental health.

4.1.3 Social health

The following definition of social health is given by the WHO (Goodacre et al., 2013): "*Being able to interact with others and participate in the community in both an independent and cooperative way"*. The term social interactions is used in research by Boniface et al. (2015) as a collective term to describe social health. The social factors that are most influential to health, are defined by Boniface and colleagues (2015) as *"[…] social exclusion, social capital, social cohesion and social networks collectively*".

4.2 Health impact areas

Impacts on health may be direct, obvious and intentional, whilst others are indirect, difficult to identify and unintentional, which makes it complex to analyse the multiple, interrelated effects from transport on the different health dimensions (WHIASU, 2011). Therefore, impacts of transport on health are not considered in isolation but rather in broader terms and in wider determinants of health (Boniface et al., 2015). To structure the complexity between transport and health, a set of health impact areas is used:

- **Physical activity:** bodily movement produced by skeletal muscles that requires energy expenditure. Active mobility can provide physical activity throughout the journey (WHO, 2017).

- **Traffic safety:** accidents and collisions during transport that cause unintentional deaths and harm, impacting actual safety in form of accidents and perceived safety of travel behaviour.

- **Environmental stressors**: referring to both air pollution that affects air quality in cities (NO_2 and PM) and noise pollution through traffic.

- **Accessibility**: accessibility of goods, services and social contacts which are important for one's health. Accessibility refers to the ability and ease of reaching certain destinations and activities by means of transport modes, at various times of the day (van Wee et al., 2013).

- **Equity**: mostly vulnerable people are more affected by negative health effects caused by for example affordability, accessibility and availability of transport modes, which in turn can worsen social inequity in a population.

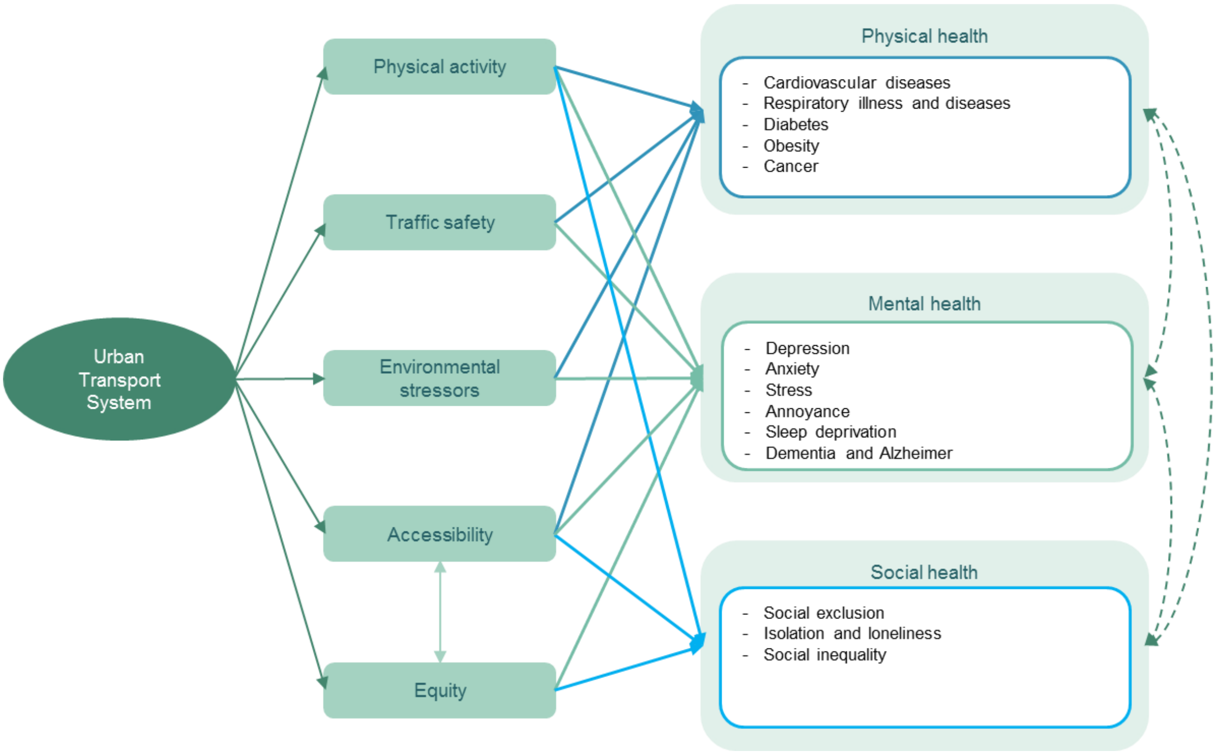


Figure 4-2: Main links between urban transport, travel behaviour and health

These five areas are adapted from other impact areas used throughout literature and research (e.g. van Wee and Ettema, 2016; U.S. Department of Transportation, 2015; Cohen et al., 2014). Other areas sometimes considered are stress, frustration and the influence of the built environment and infrastructure on health (Arup et al., 2018), however, to not add to the complexity, these factors are not chosen as main impact areas.

Considering these different health impact areas, the relations between transport and health are complex; impacts can be positive or negative and can operate in combination as well as in competing ways (Boniface et al., 2015). For example, cyclists are presented to higher exposures of emissions because they breathe in the pollution caused by cars. However, research has shown that the benefits associated with physical activity from cycling exceed the risks of inhaling emissions or getting into a traffic-associated collision (Mueller et al., 2015; de Hartog et al., 2010). Research that ignores this complexity might draw the false conclusions (van Wee and Ettema, 2016). To make sense of the complexity between the identified health impact areas and the health dimensions, Figure 4-2 is constructed based on existing literature (e.g. Khreis et al., 2017; Mackett, 2011) and from the interviews. The figure shows how the health impact areas influence the three health dimensions by increasing the risk of certain diseases, illnesses and conditions. Appendix B holds the relations and references.

The following sections elaborate further on the defined health impact areas and how these relate to the health outcomes in terms of illnesses, diseases and conditions. Even though all links are accepted as valid influencers of the three different healh dimensions, some are backed by academic studies whilst others are based on less extensive research methods from cohort studies and hypothesis.

4.2.1 Physical activity

Physical activity is defined by the WHO (2017) as "*any bodily movement produced by skeletal muscles that requires energy expenditure – including activities undertake while working, playing, carrying out household chores, travelling and engaging in recreational pursuits".* Globally, physical inactivity is the fourth leading risk factor for mortality and a major cause of non-communicable diseases (Gerike et al., 2016). In the Netherlands, only half of the population meets the recommended level of physical activity, which for adults corresponds to 150 minutes of moderate intensity throughout the week (RIVM, 2017).

A large share of the health benefits from regular physical activity can be achieved through active mobility. Active mobility is the term referring to transport modes that provide physical activity during transport, such as cycling and walking alone, or in combination with public transport, which involves walking and/or cycling during access, egress and transfers (Mackett, 2011). Forms of active mobility can fulfil health requirements for physical activity (WHO, 2017; Cohen et al., 2014), which is shown in research by Eisenmann (2018).

The contribution of cycling and walking to physical activity, and hence to health outcomes, has been recognised explicitly in literature (WHO, 2014). The contribution of these active modes to physical health and overall health can lead to lower risk of cardiovascular diseases (Mackett, 2011; Chida, 2008), significantly reduce the risk of colon cancer (Hou et al., 2004), decreases likelihood of obesity and high cholesterol (Kwasniewska et al, 2010; Basset et al., 2008). Even relatively small increases in physical activity are associated with some protection against chronic diseases and improved quality of life (High Speed Two (HS2) Limited, 2013).

Although the health impacts of active transport are dominated by the benefits of physical health, mental health also benefits directly from active mobility. Research on travel modes by Ettema and Smajic (2014) has shown that levels of physical activity involved in walking increase mental health, indicating that trips involving physical activity lead to an increase in happiness. Physical activity is, for example, an effective anti-depressant and walking can reduce the risk of stress and anxiety, resulting in a positive impact on mental health and happiness (Arup, 2016., North et al., 1990). Social health in terms of social interactions is also affected by the use of active modes as their users interact in different ways with the social environments through which they travel (te Brommelstroet et al., 2017).

4.2.2 Traffic safety

There is a significant, direct link between health, road traffic safety and casualties caused by road safety issues. Traffic crashes, and the injuries and fatalities caused by them, occur frequently and therefore road traffic is a leading cause of morbidity and mortality around the world. Worldwide up to 50 million people are involved and injured in road casualties and each year 1.25 million people are killed. Around half of this group are pedestrians, cyclists and motorcyclists (WHO, 2015). The chance of getting involved in a traffic accident depends on different factors, e.g. on mode choice, driving behaviour, vehicle type, traffic laws and transport infrastructure (Otero et al., 2018; van Wee et al., 2013). Another factor is travel speed, which is directly related to the number of traffic casualties (Mackett, 2011). Furthermore, risk factors for casualties related to active mobility are highly context specific due to large differences between countries when it comes to culture and intrastucture (van Wee and Ettema, 2016).

Research indicates that per capita crash rates tend to increase with per capita vehicle travel (Litman and Fitzroy., 2018). Research by Jacobsen (2003) has shown that increasing the number of people walking and cycling in an area improves road safety for all road users, as motorist take more care when driving in such areas. This is related to the *safety in numbers* effect, an effect that refers to the phenomenon that the more people cycle and walk, the safer cycling and walking becomes per person (de Nazelle et al., 2011). According to Mindell (2017), the question whether this effect is causal is left open in research. However, policies that increase the number of active travellers appear to be an effective measure to improve traffic safety, as stated in research by Jacobsen (2003).

Besides the direct links between traffic safety and health in terms of physical harm, there is also an indirect link between health and road traffic safety relating to safety perceptions that people can have regarding certain modes of travel (Cohen et al., 2014). The amount of walking and cycling people engage in is related to feelings of safety, which are directly related to traffic speed and traffic volumes (Jacobsen, 2003; 2000). Road traffic injuries are associated with long term psychiatric consequences (Kavanagh et al., 2005). Traffic unsafety can, therefore, create negative traffic perceptions which can deter travellers from choosing to cycle or walk (Jacobsen et al., 2009).

4.2.3 Environmental stressors

Environmental stressors in this research consist of two dimensions, namely air pollution and noise pollution. Both air pollution and noise pollution are transport externalities that can affect health adversely.

- *Air pollution*

Exposure to air pollution caused by traffic forms a direct risk to health (Mackett et al., 2015). Research has shown that it can lead to premature death, lung diseases, cardiovascular diseases, eye and throat irritation, and even to cancer, among others (Cohen et al., 2014; Jongeneel et al., 2008). The extent to which these effects occur depends on the duration of the exposure, the intensity and the personal characteristics of the person exposed (van Wee and Ettema, 2016).

The main health damaging pollutants released via emissions from road traffic are nitrogen dioxides (NO_2) and particulate matter (PM10 and PM2.5). Particulate matter and nitrogen dioxide from traffic can cause or worsen respiratory diseases, lung diseases, and disorders of the heart and blood vessels (Arup, 2016) and there are some indications that pollution can cause neurological diseases, such as autism (GGD Amsterdam, 2017).

Particulate matter is one of the worst forms of air pollution caused by motorized traffic, which arises during combustion and as result from wear on tyres and brake pads. Numerous scientific studies have linked exposure to this pollution to a variety of problems, mostly heart or lung diseases and conditions (EPA, n.d.). Especially PM2.5 is harmful because these particles can get deep into lungs and into the bloodstream (ibid.). Nitrogen dioxides arise during combustion and traffic is the main source of this matter (RIVM, n.d.). Research showed that nitrogen dioxide can be harmful to airways and lungs, trigger asthma and is even a human carcinogen (Cohen et al., 2014).

- *Noise pollution*

Next to air pollution in the form of emissions, motorized traffic is an important source of noise pollution in the urban areas. Noise pollution is defined as "*the constant stream of sound generated by motor vehicles, freight trucks, transit and service vehicles and can be detrimental to nature, wildlife and discourage human activities"* (Arup, 2016). Noise pollution can lead to a variety of health issues, relating to both physical and mental health. In terms of physical health, noise pollution can lead to impaired hearing and stress, increasing the risk of other health problems, for example hypertension (Arup, 2016; Mackett, 2015., Cohen 2014). Research by Halonen et al. (2015) found that long-term exposure is associated with a higher population risk of cardiovascular diseases, all-cause mortality and morbidity. The WHO and other research organisations have also concluded that there is sufficient evidence saying that noise pollution influences mental health through sleep deprivation, annoyance and changes in sleep quality (Cohen, 2014; Jongeneel et al., 2008).

4.2.4 Accessibility

The accessibility of essential destinations and areas is a main determinant of health. Accessibility refers to the ability and ease of reaching certain destinations and activities by means of transport modes, at various times of the day (van Wee et al., 2013). Examples are access to goods, healthy food, health-care services and recreational facilities (WHO, 2017; Mackett, 2014). Furthermore, access to work and social contacts, commercial services, public amenities, and education are relevant (WHIASU, 2011).

For physical health the accessibility of places that offer health care, healthy food and nutrition are of high importance, but also the accessibility of recreational facilities to perform physical activity. Access to green space is especially important as it can improve health, particularly mental health (de Nazelle et al., 2011). Accessibility to opportunities is also important from a social health perspective as it allows individuals to participate in society, for example by providing access to employment (van Oort, 2017; Mackett, 2015). Inaccessibility of certain places and social contacts, can lead to social exclusion and limitations in social capital, both negatively impacting social health (Boniface et al., 2015).

Accessibility poverty is defined by Lucas et al. (2016) as "*the difficulty of researching certain key activities, such as employment, education, healthcare services, shops and so on – at reasonable time, ease and cost".* As the definition of transport poverty by Lucas et al. (2016) states, accessibility is not only about physical access to destinations and transport modes, but also about travel time, ease of travel and costs of travel.

Research by Boniface et al. (2015) also argues that accessibility does not only refer to proximity and availability of transport modes, but also to provision of information and other aspects such as safety. This indicates that insufficient accessibility might also lead to social inequity (ibid). Accessibility poverty is more likely to affect some groups more than others. For example, people with higher incomes tend to travel longer distances, implying a better accessibility of certain destinations (Mackett, 2015). This shows that equity considerations are important as access to essential destinations is unequally distributed over different population groups. The next section describes in more detail the equity aspect.

4.2.5 Equity

The last main link between transport and health relates to equity. A basic definition of equity (Miller, 1999) is: "*the distribution of benefits and costs over members of society".* As such, equity can actually be considered for each health impact area described above, however, in the context of this study, equity refers mainly to providing all people and communities with equal access to services and opportunities that promote their health. Transport has to involve the needs of different population groups, each of whom have different characteristics, needs, abilities and priorities (BC centre for disease and control, 2017). Interventions that are not responsive to the unique needs and barriers of vulnerable groups may exacerbate health inequities, as access to transport for these groups may be higher. Both positive and negative health effects caused by transport are often distributed unequally and negative effects fall hardest on vulnerable population groups or communities, such as low-income, children, elderly, women, disabled or people with poor health. When they are affected by negative health effects, this can create social inequity (Cohen et al., 2014; U.S. Department of Transportation, 2015).

Research by Ciommo and Shiftan (2017) stresses the importance of improved access to transport, and thus to key activities, from an equity perspective. They use three main indicators for equity in transport:

- **Travel affordability**
- **Accessibility to key activities**

- **Access to transport**: access to transport depends on access to certain modes in terms of number of available modes and travel time, among others

According to research by Mackett (2014), there are differences in the accessibility of transport between the different groups in the community, which have implications for health. Accessibility of transportation, and especially public transport, can contribute to socially inclusive cities by creating a safe and healthy society with equal opportunities for all inhabitant (van Oort, 2017). Low-income groups and other vulnerable groups are more likely to rely on public transport as their main mode of transport, which makes access to public transport particularly important to improve equity (PHSA, 2018; BC centre for disease and control, 2017). In general, it is difficult for traditional public transport to serve trips in low density areas and short operating hours, circuitous routes and long headways contribute to dependence on driving, with the result that those without cars are negatively affected by low levels of access and personal mobility (Arup, 2018). Low-income groups are at risk of transport poverty because budgetary limitations may inhibit the use of a car, or public transport (Martens, 2013). Active mobility may well provide a feasible alternative for low income households where budgetary limitations may inhibit the purchase or regular use of a car (ibid.).

4.2.6 Individual and societal health impact

As mentioned in some of the sections above, health can be seen from an individual perspective but also from a societal point of view. However, individual behaviour influences not only the health of the person itself but also the health of the community through the impact on the physical environment. Transportation interventions or policies that focus on increasing active mobility have a large individual health benefit for the active traveller by increasing their physical activity. Smaller, but societal health benefits could accrue through reductions in environmental stressors and traffic safety. In case of assessing the effectiveness of a transport intervention, such as MaaS, these two key dimensions are inter-related but have to considered.

4.3 Conclusion

This chapter gathered information from the expert interview and literature concerning health and transport to provide an answer to the sub-question. "*How do urban transport and travel behaviour influence health?".*

Health is defined according to the definition by the WHO and the three dimensions of; *physical health*, *mental health* and *social health,* since maintaining an optimal level of health requires a balance between these three dimensions. The links between the three health dimensions and transport are categorised according to five health impact areas; *physical activity*, *traffic safety*, *environmental stressors*, *accessibility* and *equity*. A mode shift to more active transport can lead to, for example, higher levels of physical activity, less air pollution and noise pollution, higher mental health and increased social interactions, impacting both individual and societal health. However, some health impacts might also be conflicting: increased accessibility to the transport system – a desired impact on an individual and societal scale – may result in an increase in the number of trips made – possibly a desired impact on an individual level but an undesired impact on a societal scale with negative implications for emissions as well as congestion, for example.

When the health impact areas are considered during transport related developments and innovations, such as the MaaS concept, transport provides various opportunities for health improvements. The next phase identifies the potential impact of the MaaS concept on the health dimensions.

ANALYSIS AND CONCEPTUALISATION

Analysis and conceptualisation of the main pathways between the introduction of MaaS in the urban transport system, changes in travel behaviour and the health outcomes, through the construction of a conceptual framework.

5. MaaS in the urban transport system

The previous phase described the links relating transport to health, resulting in a set of five health impact areas and focus points for health improvements through transport. This chapter identifies via which factors and relations the introduction of MaaS can bring changes to the urban transport system and affect the previously defined health impact areas. This chapter answers the sub-question: "*How can the introduction of MaaS change urban transport?"*. First, an analysis is performed on how the MaaS service can influence travel experience and level of service (section 5.1). Then, a system diagram is constructed to visualise the links between MaaS, the urban transport system and the health impact areas (section 5.2). Based on these analyses, an overview of identified health determinants is presented (section 5.3), followed by a conclusion (section 5.4).

5.1 Changing travel experience and level of service

The main components that comprise a MaaS service were introduced and briefly described earlier on (chapter 2) and this section discusses how these components influence travel experience and level of service of multi-modal travel. The concept of travel experience is used, as defined in the research by van Wee et al. (2013), to describe how MaaS can establish change in the urban transport system. Travel experience is determined by travel resistances, such as travel time, travel costs and effort, and to this list access to transport is added (see Figure 5-1, authors own).

Combined within a MaaS service, these components can make multi-modal transport a more convenient alternative to private car use and ownership, and, therefore, bring change to the current urban transport system and people's travel behaviour. The next sections describe how the MaaS components can influence travel experience and level of service of multi-modal transport.

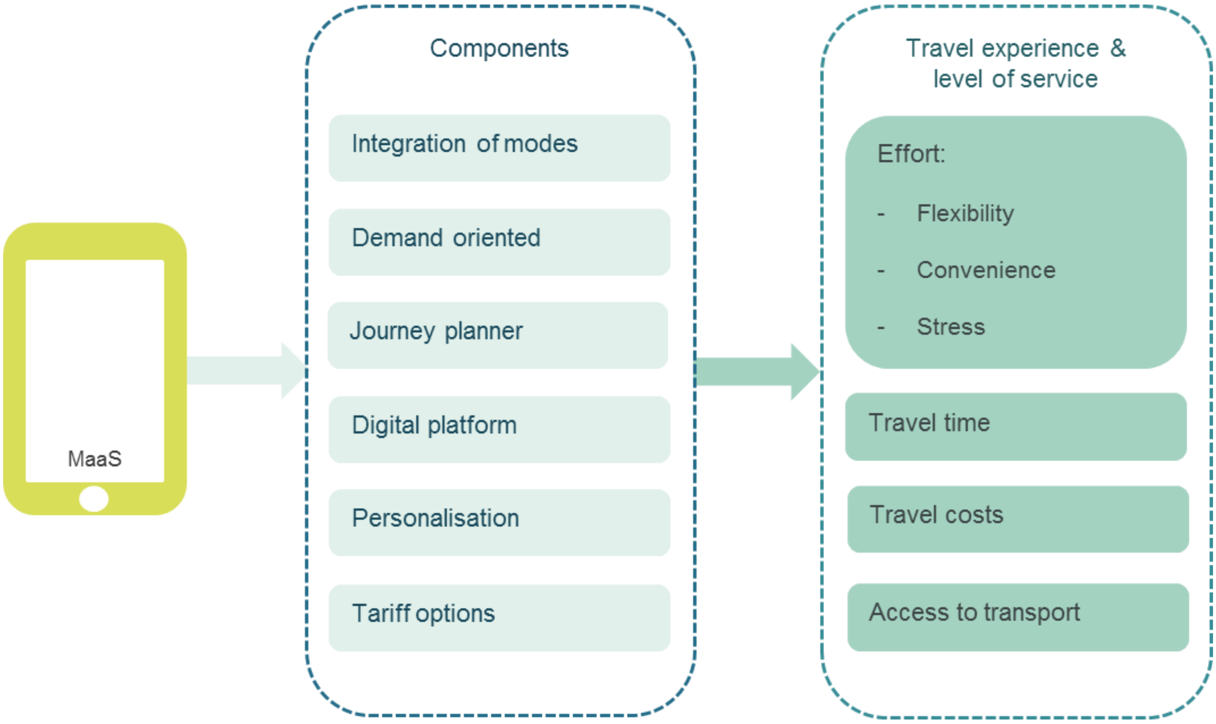


Figure 5-1: MaaS components influencing travel experience & level of service

5.1.1 Access to transport

Both physical access and perceived access to transport have good potential for improvement through the introduction of MaaS, as MaaS can improve the efficiency of the current public transport system (Arup, 2018); increase the number and variety of modes and travel options available through integrating private and public sector operated services; and offer better options for the first and last mile part of the multi-modal trip (Kamargianni interview, 13th of April 2018).

The integration of both public and private modes creates additional choices for the MaaS user, which is positive in terms of mobility services being more available (Falconer interview, 24th of April 2018). The potential of having a wide variety of travel modes available may also increase the perception of accessibility, as shown in one of the first MaaS pilots called UbiGo. Karlsson et al. (2016) describe this as:

> *"The service made participants feel that they had more transportation alternatives available to them. The alternatives also become more 'mentally' accessible due to having to reflect on one's travel needs in order to set one's subscription level, as well as having to choose one's mode for the next trip from a list in the app."*

The integration and bundling of public and private modes creates an opportunity to facilitate transport services as feeder services to the existing public transport network; enabling access to other parts of the transport system and improving connectivity within cities (Arup, 2018). As stated in research by Smith et al. (2016): "[…] *it becomes an increased accessibility to the opportunity to travel".*

However, this is not a definite impact of MaaS, according to O' Halloran (O'Halloran review, 21st of June 2018), as MaaS in itself does not create new services or dictate that certain transport modes are used as feeders to the existing network or as first- or last-mile solutions. How both public and private services are used depends largely on the design of the service, requirements set by authorities and the aims of the MaaS operator regarding the service, which are discussed later on in this research (*see chapter 9*).

Potential for better and faster access to transport can also be established through integrated ticketing and payment technology. Ticket and payment integration can increase accessibility to (public) transport, as it can lead to easier and faster transactions (Kamargianni et al., 2016). Integrated ticketing can achieve user benefits, in particular from reduced boarding times (KonSULT, 2014). The opportunity for integration of smart-card technology in a MaaS service was also take away a barrier to access and travel by public transport.

5.1.2 Travel time

Reductions in journey time are expected through MaaS, mainly due to the potential for ticket integration, integrated payment systems and real-time travel information, leading to better interchanges between modes (Kamargianni et al., 2018). Research by Moving Forward Consulting (2016) considers this a result of MaaS' focus on the whole journey experience, instead of separate parts of the trip chain. The full integration of planning information and availability of real time information provides users with intermodal combinations that can decrease travel time (Kamargianni interview, 13th of April 2018). Furthermore, the availability of real-time and intermodal travel information can be used by the service to proactively inform users on upcoming delays and possibilities for congestion avoidances, by offering alternative route options to establish time savings and reduce congestion (Kamargianni et al., 2018; Arup, 2018). Real time information on, e.g. operating capacity of transport modes can also lead to time savings and route optimisation by redirecting travellers and reducing waiting times and delays (Kamargianni interview, 13th of April 2018). This is also mentioned by Meurs (Meurs interview, 27th of March 2018), who states that MaaS has potential for *rush hour avoidance* when redirecting users.

5.1.3 Travel costs

Depending on the design of the MaaS service, the included modalities and the aim of the MaaS operator, cheapest modes and routes can be proposed to users, potentially leading to cost savings (Kamargianni et al., 2018). Empirical evidence from the UbiGo pilot supports this claim, as it showed that among the first participants travel cost reductions were seen (Karlsson et al., 2017; 2016).

The bundled mobility packages offered by the MaaS operator to the consumer could establish overall cost reductions and better value for money (Kamargianni et al., 2018; Moving Forward Consulting, 2016). Packages are considered a case of product bundling, which is defined by Guiltinan (1987) as *"[…] the practice of marketing two or more products or services in a package for a special price"*, implying cost savings. In addition, research (Arup, 2018) states that cost savings can be expected because the service enables pay-for-use and, therefore, consumers no longer need to own a car or pay for parking or other incidental costs.

Opportunities for travel costs reductions increase when automated vehicles are widely introduced, according to Alonso-González (Alonso-González interview, 4th of April 2018), since the lack of driver will reduce costs considerably. Initial costs of automated vehicles are large, but when they have settled down, cost reductions can emerge, says O'Halloran (Review O'Halloran, 21st of June 2018). Moreover, automated vehicles, similar to electric vehicles, are expensive for individuals to own and hence, cost savings related to these vehicles can only be felt when automated vehicles are shared publicly (Review O'Halloran, 21st of June 2018). The potential for cost savings may, thus, also be the result of users' ability to share mobility services more easily in MaaS (Moving Forward Consulting, 2016).

Some experts believe that MaaS could relieve households of the costs associated with car ownership, which is, according to research by Kamargianni et al. (2018) estimated to £2,802 a year. Alonso-González (Alonso-González interview, 4th of April 2018) mentions that MaaS can decrease the price of owning a car; meaning that it is cheaper for consumers to use MaaS that offers the same services as a private car, than actually owning a private car. This is supported by various other studies, e.g. Arup (2018) and Moving Forward Consulting (2016).

Even though some expect MaaS to be cheaper than owning a car, it is not very likely that the service will be cheaper than paying for public transport, according to others (O'Halloran review, 21st of June 2018; Kamargianni interview, 13th of April 2018). Travellers that already use the bike or public transport cannot expect a cost decrease as a result of MaaS (Decisio, 2017). Therefore, MaaS might be cheaper than owning a car, but it is not necessarily cheaper than availing of the current transport system and its existing payment mechanisms, implying that MaaS in the form of packages might be a luxury service.

5.1.4 Effort

A major factor in the choice to use a private car is the effort, or hassle, involved in multi-modal travel by public transport. The use of MaaS can lead to more hassle-free interchanges: better control over disruptions, personalised mobility packages, providence of integrated ticketing and payment, and/or providence of access to new services. When less effort is involved in travelling by public transport it becomes a more convenient travel alternative. The following three factors described below play an important role in making multi-modal transport require less effort for the user, as they can make it more hassle-free and easy:

1. Flexibility

MaaS can offer flexibility, defined as the possibility to choose the most appropriate solution for a specific situation, which is one of the particular strengths of MaaS, according to Sochor et al. (2016). This is confirmed in a study by MaaSLab (Kamargianni et al., 2018), which demonstrates that flexibility is one of the main perceived benefits of MaaS among potential users; the results show that people are willing to use MaaS when they believe that the service can offer them flexibility in their daily mobility.

Meurs (Meurs interview, 27th of March 2018) argues that by offering more flexible and tailor-made transport than traditional transport does, MaaS can change the urban transport system and make travel easier. This is supported by Karlsson et al. (2017), whom argue that MaaS can offer more flexibility than is the case with present public transport, as a result of the possibility to better integrate new technology and data analytics. More flexibility is created regarding mode choice and travel routes because MaaS offers its users multiple travel alternatives (Ettema interview, 21st of February 2018; Karlsson et al., 2016). MaaS proponents also suggest that especially the inclusion of privately operated services improve this flexibility (Smith et al., 2018).

2. Convenience and seamless travel

MaaS can increase convenience of multi-modal travel for its customers and enable more seamless travel between multiple transport modes (de Cani, 2018; Arup, 2018; Kamargianni et al., 2018). One of the reasons for this is due to an improvement in interchanges, according to Catapult research (2016), which can help in promoting a shift away from private car use to more multi-modal travel. Research by Kamargianni et al. (2018) states that:

> *"The hassle-free interchanges, the better control over disruptions and the personalised mobility packages would increase the convenience and comfort levels and hence make travellers more satisfied with their journeys."*

Furthermore, ticket integration and payment integration can lead to easier and faster transactions and less ticket purchases, increasing the convenience of using certain modes (Kamargianni et al, 2016). The MaaS pilot in Ylläs, Finland has showed that users found mobile payment more convenient because it eliminated the need to use cash (Karlsson et al., 2017). Overall, interoperable ticketing and new payment systems have encouraged the use of multi-modal travel by providing more fluid and convenient transfers (de Cani, 2018; Khreis et al., 2017).

Lastly, MaaS can offer real-time information and journey planning to the travellers during pre-trip, wayside and on-board. Offering personalised, real-time information can remove some inconvenience, for example waiting times and buying a ticket for the trip itself (Kamargianni interview, 13th of April, 2018). The service provides this information via one single, simple interface, which takes away the need for multiple applications to receive information users need for their trip (ibid).

3. *Travellers' stress*

Commuting can be a major cause of stress due to its unpredictability and perceived loss of control (Lancee et al., 2017). Several factors that influence traveller stress are frustration, fear of a potential accidents, route uncertainty and loss of control. These factors can lead to feelings of discomfort, annoyance, frustration or fear. Also route uncertainty is an important factor for stress (High Speed Two (HS2) Limited, 2013).

MaaS has potential to reduce travellers stress and provide users with stress-free travel planning by providing better information and more alternatives in case of disruptions and, thus, higher route certainty and feelings of control (Kamargianni et al., 2018; Li and Voege, 2017). Moreover, MaaS creates an opportunity to offer *rush hour avoidances* through the providence of better and more personalised travel information, which can decrease stress since feelings of control are especially low during rush hours (Lancee et al., 2017).

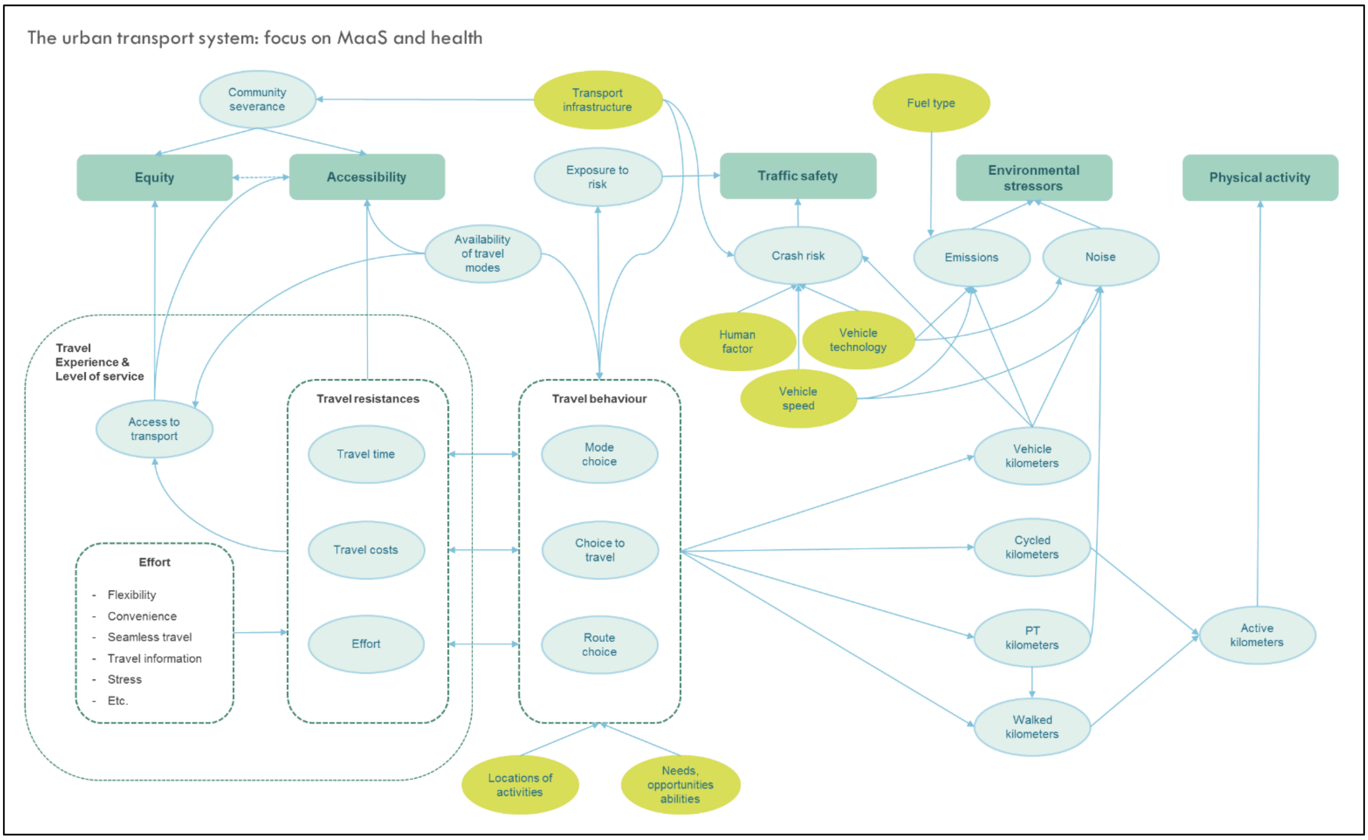
Furthermore, the use of real time travel information and personal data within journey planning creates the opportunity to offer optimal trip advice to travellers and a better user experience (Kamargianni et al., 2016). Travel information also gives customers the chance to plan their time better to reduce stress during travel and reduce the psychological anxiety associated with waiting for public transport as well as uncertainty and frustration (Khreis et al., 2017). Inclusion of real time travel information may induce a behavioural change towards increased use of public transport from car use (KonSULT, 2014).

5.2 The urban transport system

The previous section described in what potential directions MaaS can influence travel experience and level of service related to multi-modal travel. To understand if, and how, these changes influence the health impact areas is analysed by means of a system diagram. This diagram (Figure 5-2) provides a simplified representation of how the urban transport system links to the key health impact areas. Mapping of these impacts and relationships is in general a useful way of identifying the potential ways for health impacts of a project, since the construction of a relationship diagram can link paths together and highlight interactions between variables and factors (WHIASU, 2011).

The diagram depicted in Figure 5-3 highlights the factors within system that can be changed through the introduction of MaaS, which are: access to transport and the travel resistances (travel time, travel costs and effort), as described above. These factors directly relate to choices in travel behaviour and the areas of equity and accessibility. More detailed descriptions of factors and relations in the system diagram are provided at Appendix E. Appendix E also includes more background information on the methodology of constructing a the system diagram and shows and explains the functions, structure and build-up; to show and make sense of how the factors, variables and elements are related within the diagram.

Figure 5-2: The urban transport system



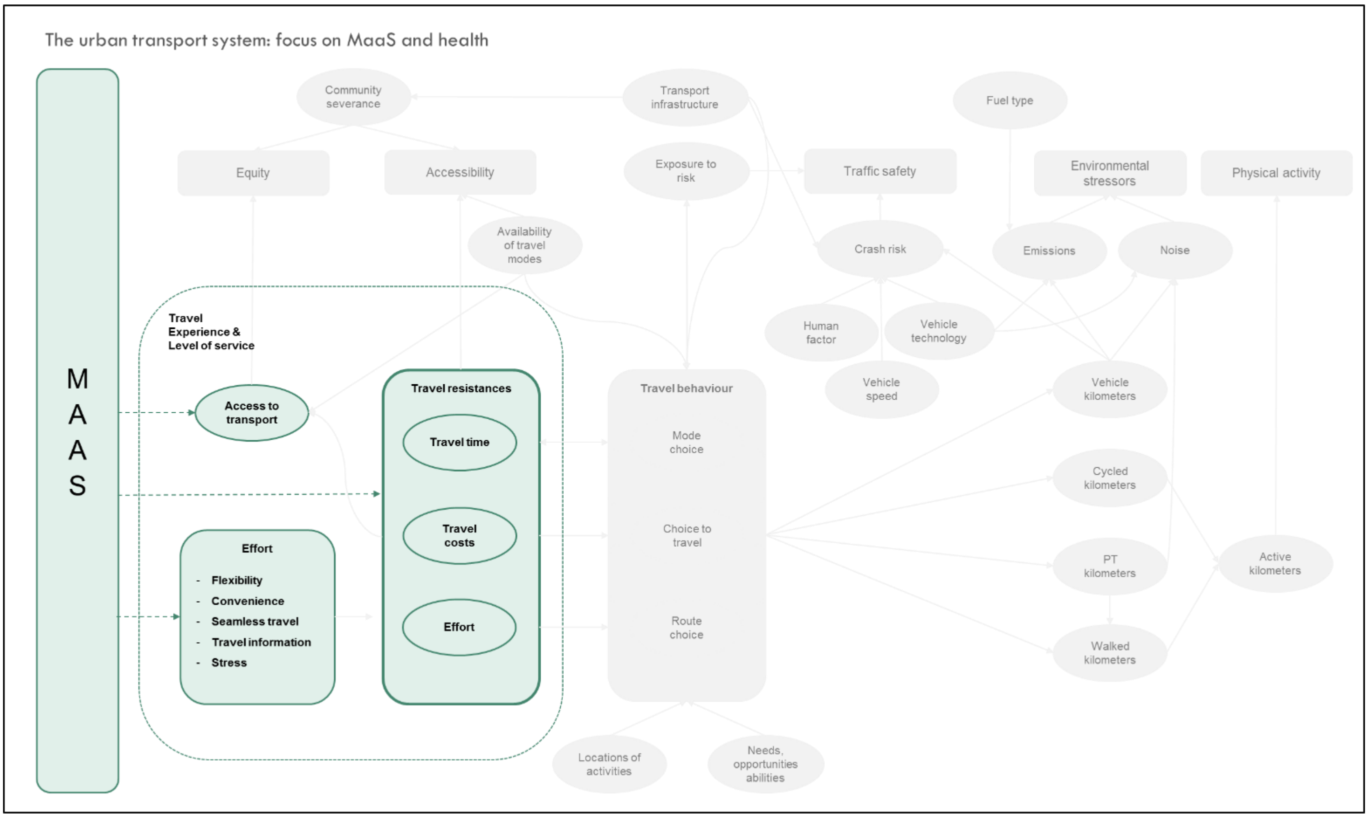


Figure 5-3: The introduction of MaaS in the urban transport system

5.3 Health determinants

In addition to providing a way to link factors in the urban transport system, the system diagram is used to identify the main health determinants of the health impact areas. Table 5-1 contains an overview of the health impact areas on the left and the health determinants in the middle, which, likewise, have their own determinants. References in the right column provide the references to literature and research on these links and determinants. The main influential health determinants identified are active kilometres, exposure to risk, crash risk, emissions, noise, travel time, travel costs, effort, and access to transport. These health determinants are later on used in the conceptual framework and as indicators during the health assessment of MaaS (section 8.1).

As can be seen in the table, the areas of accessibility and equity are mainly determined by the same factors since these areas are highly interrelated. The main difference is the factor of travel costs used as determinant for equity (di Ciommo and Shiftan, 2017).

Table 5-1: Main indicators of health influencing transport areas

HEALTH IMPACT AREAS	MAIN HEALTH DETERMINANTS & DETERMINANTS OF HEALTH DETERMINANTS	REFERENCES
Physical activity	• **Active kilometres** ○ Cycled kilometres ○ Walked kilometres	Eisenmann, 2018; Doorly, 2017; Mackett, 2011; Bassett, 2008.
Traffic safety	• **Exposure to risk** ○ Vehicle kilometres driven ○ Active kilometres travelled ○ Public transport kilometres ○ Number of trips • **Crash risk** ○ Human factor ○ Vehicle technology ○ Vehicle speed ○ Transport infrastructure	Otero et al., 2018; Schepers et al., 2014; Van Wee et al., 2013; Jacobsen et al., 2009; De Nazelle et al., 2008; Jacobsen, 2003
Environmental stressors	• **Emissions** ○ Vehicle kilometres travelled ○ Vehicle technology ○ Fuel type ○ Travel speed • **Noise** ○ Vehicle kilometres travelled ○ Vehicle technology ○ Travel speed	Karlsson et al., 2017; Jongeneel et al., 2018
Accessibility	• **Access to transport** ○ Availability of travel modes • **Travel time** • **Effort**	Di Ciommo and Shiftan, 2017; Lucas et al., 2016; Boniface et al., 2015; van Wee et al., 2013
Equity	• **Access to transport** ○ Availability of travel modes • **Travel costs** • **Travel time** • **Effort**	Di Ciommo and Shiftan, 2017; Lucas and van Wee, 2016.

5.4 Conclusion

This chapter answers the sub-question: "*How can the introduction of MaaS change urban transport*?". MaaS can improve travel experience and level of service of multi-modal travel through lowering travel resistances associated with multi-modal travel. One way is by improving access to the (public) transport network as a result of integrating public and private modes, offering-real time travel information, intermodal journey planning and integrated ticketing and payment systems, among others.

MaaS also has a positive impact on other travel resistances: travel time, travel costs and effort. The service has good potential for reductions in travel time, and to a lesser extent reductions in travel costs. A third travel resistance involved in multi-modal transport is the factor effort, which is a major reason for people to use a private car. MaaS can reduce the effort involved in multi-modal travelling by increasing flexibility, convenience and lowering travellers' stress, all through more hassle-free interchanges, better control over disruptions and real time travel information. Altogether, these improvements can make multi-modal travel a more convenient alternative to private car use.

This analysis showed that MaaS can influence the health impact areas and their health determinants by making multi-modal travel a more competitive alternative to private car use. MaaS can thus establish changes in travel behaviour, and in doing so, impact the further urban transport system, for example in terms of congestion and air pollution, but also in terms of equity and accessibility by increasing access to transport. The next chapter provides a more thorough analysis of the directions in which MaaS can change travel behaviour and what these changes can mean for the health impact areas.

6. Changing travel behaviour through MaaS

MaaS can improve travel experience and level of service of multi-modal transport, as described in the previous chapter. These improvements can change travel behaviour, which is one of the main ways to influence the health impact areas and impact health. However, in which direction travel behaviour will change is not clear. This chapter answers the sub-question: "*How can the introduction of MaaS change travel behaviour?".* The first results on behavioural changes from MaaS pilots are described and analysed (section 6.1), after which an analysis is presented based on the expert interviews and available literature on potential behavioural changes (section 6.2), followed by the conclusion (section 6.3).

6.1 Empirical results from first MaaS pilots

Worldwide many different MaaS projects and pilots are planned, implemented, ongoing or completed. Despite the large number of pilots, research and evaluation on how MaaS influences travel behaviour and modal split is very limited. The relevant pilots that do have results and that fulfil the high level MaaS definition of this research, are briefly described in the next section and the figures are presented at Appendix D.

6.1.1 UbiGo, Gothenburg

The UbiGo pilot in Gothenburg, Sweden has been thoroughly evaluated. Transport modes were offered to the participants (households) in flexible packages based on personal travel behaviour. A relatively small sample of 195 individuals in 83 urban households participated (Karlsson et al., 2016). It is important to note that the participants volunteered and were mainly early adopters, willing to use other modes of transport and interested in trying new technology: participants are therefore not directly representative of the general population. The participating households subscribed to the packages that suited their travel behaviour best (ibid.). Figures on changes in travel behaviour are depicted in Figure 6-1 and evaluation showed that (MuConsult, 2017):

- 50% of participants changed modes and / or
- 40% changes travel planning and / or
- 25% changed the movement chain and
- 30% of participants did not change travel behaviour

At the end of the trial, a large decrease of 48 percent in private car use was reported. An increase in alternative modes, particularly bus, tram and car sharing, was also seen (Karlsson et al., 2016). Furthermore, attitudes towards certain modes changed; perception to private car became more negative (23%), perception to car sharing (61%), bus/tram (52%) and bicycle sharing (42%) became more positive (ibid.).

6.1.2 Smile, Vienna

The Smile pilot in Vienna has been evaluated in a three-year research program. Over 1,000 users downloaded the application and the evaluation was performed through surveys among 200 users. Results show that Smile was mainly used for leisure trips and private errands (Smile mobility, 2015), which limits the usefulness to assess the use for the daily commute. In addition, Smile was tested among a group of users that already had relatively high levels of cycling and public transport use, low levels of private car use and high levels of shared car and bike system use, in comparison to the average Vienna resident (Bingen, 2017). Figures on mode use are presented in Figure 6-1 and some of the main results show that (MuConsult, 2017; Smile mobility, 2015):

- 48% used more public transport
- 21% reduced use of the private car
- 17% said to be using more environmentally friendly routes
- Multi-modality increased: 26% combined car and public transport, 20% combined public transport and bike

Smile mobility (2015) states that the pilot increased the usage of sharing systems and e-mobility whilst decreasing the use of private cars. Because the service encouraged people to take alternative routes (69%), Smart Mobility (ibid.) states that it can support breaking mobility routines and increase usage of alternatives to the private car.

6.1.3 Whim, Helsinki

Whim is the first operational MaaS service (corresponding to the definition of MaaS in this research) and offers MaaS packages to travellers in Helsinki, Finland and Birmingham, the United Kingdom. Some first survey results among the first users are presented in Figure 6-1 (Hietanen, 2017). These results show that local public transport use increased at the costs of private car use. An increase in taxis was also seen.

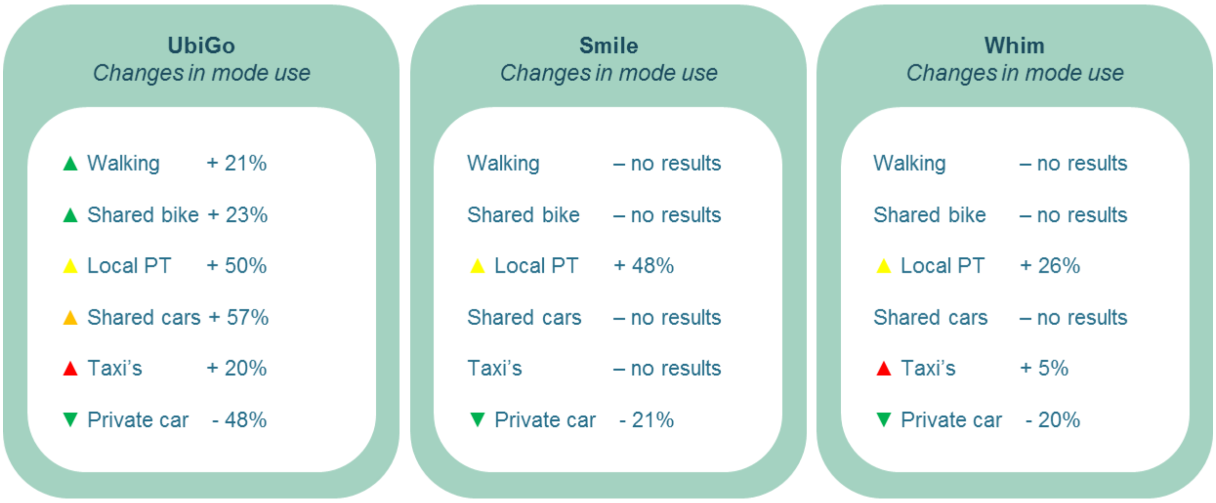


Figure 6-1: Changes in mode use seen among UbiGo, Smile and Whim users

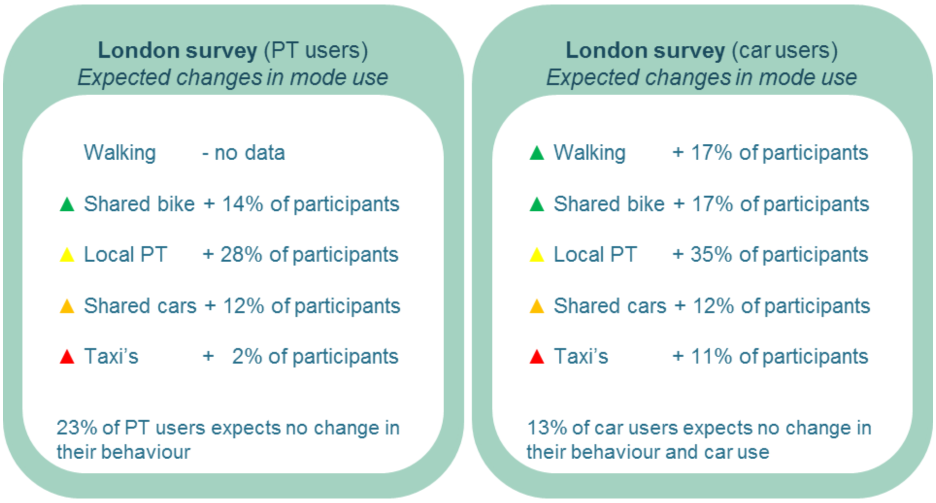


Figure 6-2: Expected changes in mode use among Londoners

6.1.4 MaaSLab research

Figure 6-2 shows results from the MaaSLab research (Kamargianni et al., 2018) on Londoners' attitudes towards MaaS, which also show similar changes in mode use and indicates overall positive change as use of active modes and public transport are expected to increase and car use to decrease. However, these results are expectations, and there is a difference between what people say they would do and what they really do.

6.2 Expected behavioural changes

First empirical results from the MaaS pilots show that MaaS offers good potential to change the way people travel. However, as advanced MaaS solutions have not yet been widely implemented, it is too early to be conclusive on the direction in which changes in travel behaviour, and especially mode use, will prevail.

Furthermore, the prevailing direction in which MaaS will change travel behaviour depends on how the service is designed, who is the operator of the service and what their interests are (Kamargianni interview, 13th of April 2018). For example, if the service aims to provide easy access to car travel for users that do not own a car, there is a risk that MaaS increases travel and car traffic (Lund, n.d.). Existing policies, incentives, and the way in which cities are built also has a huge effect on how MaaS will change travel behaviour (Kamargianni interview, 13th of April; Hietanen, 2014). The characteristics of cities and the populations they accommodate add further complexity to the effect of MaaS on travel behaviour (Arup, 2018).

Despite this uncertainty, the next sections describe the potential directions and scale for behavioural changes based on the empirical evidence from pilots, literature and experts' opinions from the interviews.

6.2.1 Reduced car ownership and car use

The main aim of MaaS is to replace private car usage by making multi-modal transport easier to use. Because the offered MaaS services can be customised and personalised to the preferences of the individual traveller, the service may become a convenient alternative to private car use. In the longer term, this can also stimulate the shift from car ownership to car usership (MuConsult, 2017).

Kamargianni (Kamargianni interview, 13th of April, 2018) believes that MaaS as a replacement for car ownership has potential: research by MaaSLab (Kamargianni et al. 2018) found that 35 percent of regular car users in London would substitute car usage for public transport if MaaS were available. However, Kamargianni does stress that the final impact is still uncertain, which is concurred by Durand (Durand interview, 20th of March 2018), by stating that it is unknown whether the benefits associated with MaaS are able to outweigh the prestige, sense of autonomy and flexibility that car owners feel. Commuting by car in general generates higher levels of happiness than, for example, commuting by public transport, which can be explained by factors such as prestige, convenience, reliability and self-control (Lancee et al., 2017). Kamargianni (Kamargianni interview, 13th of April, 2018) also states that MaaS needs critical mass for the service to become a convenient alternative, meaning that there needs to be a wide variety of transport modes available in order to be able to bundle or to combine the offered modes.

Kamargianni (ibid.) says that the potential to reduce car ownership is also due to the societal changes currently ongoing. The new generation, referred to as the millennials, does not prioritise buying a car (Kamargianni et al., 2017) and offering MaaS can decrease the probability of millennials buying a private car (Kamargianni interview, 13th of April 2018). The combination of MaaS and this ongoing societal change increases the potential to reduce car ownership in the future.

In contrast to that, Meurs (Meurs interview, 27th of March 2018) argues that people in general want a car and the concept of sharing does prevent people from owning one. Both Meurs and Falconer (Falconer interview, 24th of April 2018) mention that MaaS should aim to replace a household’s second car, since the second car is often less needed and used, which is confirmed in research by Smith et al. (2018).

Potential for MaaS as a replacement for car ownership will increase when automated vehicles are widely introduced, says Meurs (Meurs interview, 27th of March 2018). This is backed in MaaSLab research (Kamargianni et al., 2017), stating that MaaS schemes and automated vehicles will exist in symbiosis. MaaS can make a good combination with automated vehicles when there are sufficient vehicles available and when users can select a car specified for the qualities that belong to the journey they are about to make (Meurs interview, 27th of March 2018). Meurs believes that the long term benefits of MaaS on car ownership will only be seen far in the 21st century, as new opportunities for MaaS will arise when automated vehicles become part of the urban transport system.

6.2.2 Total number of trips

MaaS providing improved access to the transport system may result in an increased number of trips made (Karlsson et al., 2017) and can fill in some of the trips that are traditionally difficult to serve with public transport. The introduction of MaaS may result in additional trips and more people travelling longer distances, according to Meurs (Meurs interview, 27th of March 2018). Research by Karlsson et al. (2017) and Smith et al. (2018) confirm this, as MaaS can increase the perceived accessibility to the transport system and the access to the opportunity to travel. MaaS also has potential to serve currently unmet travel demand and trips that otherwise would have been foregone by people without reasonable or viable travel alternatives, according to Falconer (Falconer interview, 24th of April 2018).

6.2.3 Considered travel choices

Because travel behaviour is formed by habits, it is difficult for people to make changes in the way they travel (Durand interview, 20th of March 2018). Nevertheless, Alonso-González (Alonso-González interview, 4th of April 2018) believes that MaaS can help users rethink how they travel and, therefore, change the way people move, which is confirmed in research by Strömberg et al. (2018) and Karlsson et al. (2016). Ettema (Ettema interview, 21st of February 2018) makes a similar statement by saying that users become more conscious regarding their travel choices as a result of MaaS, which triggers the users to start trying new modes. Ettema (ibid.) argues that this is a result of more flexibility through the variety of trip options that the users get presented; a result of the mode integration. This is backed by the Smile evaluation, stating that the service can support breaking mobility patterns and increasing the use of alternative modes (Smart Mobility, 2015).

Durand (Durand interview, 20th of March 2018) agrees that the use of MaaS forces people to think about their trips and about trip chaining, to gain the most utility from their journey. Within UbiGo, users were forced to reconsider their trips because of their limited subscription packages. This resulted in 21 percent of UbiGo participants making more walking trips whereas they initially underestimated their expected use of active modes (Strömberg et al., 2018). Having a full range of modes at hand with a limited bundle required participants to reflect on what mode is more suitable for the upcoming trip (Strömberg et al., 2018). This shows that the service design and packages play an important role in how MaaS will change travel behaviour.

6.2.4 New attitudes towards modes

UbiGo showed that participants' attitudes towards modes changed as a result of costs, convenience, flexibility, (re)discovery of alternative transport modes and personal reflection (Karlsson et al., 2016). MaaS can provide a new and varied supply of modes through integrating traditional, existing modes with more innovative modes, encompassing sharing systems and ride-sharing services. Having this wider range of modes at hand helps users reflect on which mode is most suitable for the upcoming trip and influences the number of transport modes that people use during their travel (Alonso-González interview, 4th of April 2018). The variety and inclusion of new modes can stimulate participants to consider alternatives that they otherwise would have disregarded (Strömberg et al., 2018). The next three sections describe in what possible directions mode use may evolve and what potential scenarios for behavioural changes are currently relevant.

- *Impact of MaaS on ride-sharing and car sharing*

Ride-sharing services (e.g. Uber and Lyft) and car sharing services (e.g. Car2Go and GreenWheels) are seen as innovative transport modes and are often considered in MaaS schemes. Initially, the notion of car sharing is positive, according to Falconer (Falconer interview, 24th of April 2018), whom asserts that the benefit of car sharing is associated with people downsizing from two to one car per household. Through MaaS these services can become more popular, which has various effects on peoples' travel pattern. Two main scenarios were mentioned throughout the interviews, in which the roles of shared mobility and ride-sharing services play an important role (Meurs interview, 27th of March 2018; Hietanen interview, 3rd of April 2018; Kamargianni interview, 13th of April 2018).

Firstly, in the "preferred" scenario former car owners and users start making more multi-modal trips and increase their use of public transport and active modes. The role of ride-sharing services, taxis and shared vehicles in this scenario would be to feed the public transport system by providing better access and egress to the existing network, creating a more "*pluggable and connected city*", as stated by Hietanen (Hietanen interview, 3rd of April 2018). Smith (Smith email conversation, 12th of April 2018) writes that ride-sharing services are starting to experiment with operating on a fixed route, evolving to look more like public transport, which requires people to walk to pick-up and drop-off locations. This service design can potentially relegate ride-sharing services to the role of first and last-mile transport. The probability of this scenario occurring is, however, doubtful, according to Falconer, as the success of ride-haling services has been the point-to-point convenience (Falconer interview, 24th of April 2018). Fixed route ride-sharing services, e.g. UberHop and Go Connect in Canada, were discontinued after the services failed to attract many riders and subscribers (ibid.).

In the negative scenario, former public transport and active mobility users replace a large share of their trips with shared cars, taxis and ride-sharing services. Research by Kamargianni et al. (2018) showed that 22 percent of the regular public transport users would substitute public transport with car sharing. This is asserted by Smith, who writes that ride-sharing services are having big impacts in cities, overwhelmingly replacing former walking and transit trips (Smith email conversation, 12th of April 2018). As a result of MaaS making these services more accessible, people that used to walk might start using these services for short distance trips more often, even creating the risk of walking less than before (Meurs interview, 27th of March 2018). The risk for this less preferred scenario is backed by the negative effects associated with the popularity of ride-sharing services in cities such as San Francisco and New York In this scenario ride-sharing services can fulfil everyone's needs by bringing the travellers directly from A to B, which can lead to "chaos", congestion, double the amount of traffic and deterioration of public transport, according to Hietanen (Hietanen interview, 3rd of April 2018). Car sharing studies suggest that former car users that have switched to car sharing systems have decreased their car usage, whilst former public transport and active mode users increased their car use because they gained access to the car share service. However, the net effect of this shift turns out to be a decrease, according to Ettema (Ettema interview, 21st of February 2018).

- *Impact of MaaS on public transport use*

In the "preferred" scenario, MaaS functions as a first and last-mile solution providing access to the public transport network. Previous research has shown that this will especially be the case among non-public transport users while former public transport users increase the use of other alternatives, especially car sharing, ride-sharing and bike-sharing, because they are offered new modes of transport (Alonso-González interview, 4th of April 2018).

According to Meurs (Meurs interview, 27th of March 2018), the possibility of this scenario occurring depends on the area where MaaS is operating. Within large European cities, public transport will remain the back bone of the transport system, especially for busy corridors. In this case, MaaS provides an opportunity to improve access to public transport networks and corridors, especially in cities with evolved public transport. As a result, public transport use can increase, which is backed by results from UbiGo, showing that public transport usage has increased as a result of improved access (Meurs interview, 27th of March 2018; Karlsson et al., 2016). Falconer confirms this, by stating there is evidence suggesting that ride-sharing services complement public transport for particular trip types and for certain locations (Falconer interview, 24th of April 2018).

- *Impact of MaaS on active modes*

Research by MaaSLab (Kamargianni et al., 2018) expects an increase in walking trips as MaaS users have to walk to public transport stops and use other transport modes. This research also shows that some car users are willing to use bike sharing and make walking trips more often when MaaS is available and, thus, states that MaaS can contribute to the demand of active transport.

UbiGo results back this, as the evaluation showed that 21 percent of participants walked more whereas they initially underestimated their expected use of active modes. Strömberg et al. (2018) underline this:

> *"Paying for what they [users] used also initiated economic considerations in relation to the trip at hand. The participants reflected upon how they could best adapt to the system to avoid paying in vain. Again, this led to an increased use of active modes like cycling and walking: "With UbiGo I think … 'Now, the whole day has almost passed and I haven't used my daily ticket, should I activate now? No, I'll walk.'".*

Falconer points out that there can also be a role for route-based and semi-flexible ride-sharing services to enable walking trips (Falconer interview, 24th of April 2018), but as the great success of ride-sharing services has been point-to-point convenience, people need to be wary about assuming that quasi-route based MaaS services enable active mobility for access and egress. Falconer also mentions that the availability of mobility services can erode away people's propensity to walk and cycle, contributing to negative externalities, such as additional road network congestion and pollution.

The introduction of MaaS can create a risk that some people are attracted away from active modes for short distance trips because of the convenience factor. Within Dutch cities, the share of active mobility is already relatively high, which indicates people's willingness to use walking and cycling for transport (Falconer interview, 24th of April 2018). Falconer, therefore, thinks that in the Netherlands, the risk for a decreased use of active modes might be higher than the potential benefit. Alonso-González (Alonso-González interview, 4th of April 2018) adds to this that MaaS will probably not increase the number of unimodal bike trips in the Netherlands, but MaaS does have potential to increase multi-modal trips that include the bike, especially for egress trips. For the access part of the multi-modal trip, there is less potential as many Dutch people use their own bikes.

6.2.5 Summary on expected behavioural changes

The previous sections described behavioural changes expected when MaaS is introduced in the urban transport system. Table 6-1 below summarises the expected changes, which can induce a new modal split (Kruize interview, 28th of February 2018; Smith et al., 2018; Karlsson et al., 2017), a change in total kilometres travelled (Meurs interview, 27th of March 2018; Karlsson et al., 2017; Catapult, 2016) and changes in route choice, e.g. via rush hour avoidances or redirecting (Meurs interview, 27th of March 2018; Smile Mobility, 2015).

Table 6-1: Summary on changes in travel behaviour through MaaS and their references

Behavioural changes	**Referenced in research & literature**	**Referenced in interviews**	**Pilot**
Increase multi-modality	Arup (2018)	• Durand, 20th of February 2018 • Kamargianni, 13th of April 2018 • Alonso-González, 4th of April 2018	Smile UbiGo
More considered travel choices	Strömberg et al. (2018) Karlsson et al. (2016) Smart Mobility (2015)	• Ettema, 21st of February 2018 • Alonso-González, 4th of April 2018	Smile UbiGo
Reduced car ownership and car use	Kamargianni et al. (2018; 2017) MuConsult (2017)	• Durand, 20th of February 2018 • Kamargianni, 13th of April 2018 • Meurs, 27th of March 2018 • Falconer, 24th of April 2018	Smile UbiGo
New attitude towards modes	Karlsson et al. (2017; 2016)		Smile UbiGo
Influence number of trips	Karlsson et al. (2017) Catapult (2016) Smith et al. (2016)	• Meurs, 27th of March 2018 • Falconer, 24th of April 2018	
Changes in route choice		• Meurs, 27th of March 2018	Smile

6.3 Conclusion

MaaS can change the urban transport system by making multi-modal transport a more convenient way of travelling, which raises the question in which directions changes in travel behaviour will prevail. This chapter answers the sub-question ”*How can the introduction of MaaS change travel behaviour?”.* MaaS can change travel behaviour and travel patterns, most likely towards:

- Increased multi-modal travel
- Reduced private car ownership and use
- Increased number of trips
- More considered travel choices
- New attitudes towards modes
- Changes in route choice

These directions will most likely induce a new modal split and new number of trips made, preferably to a scenario in which public transport and active mode users continue their current behaviour and former car users start shifting towards more multi-modal travel patterns. However, there is potential for a negative scenario when the use of car-based services among former public transport and active mode users turns out higher than anticipated because of MaaS making these services easier to access. However, for now the positive direction has prevailed, when looking into the empirical evidence from MaaS pilots and expected change in behaviour in other research.

With the current state of knowledge it is still too early to be definite on the direction behavioural changes will prevail, as there is uncertainty and discussion on future scenarios and because final impacts are highly dependent on other factors, such as the design of the service and the objectives of the MaaS operator.

The next chapter goes into more depth on the possible pathways linking MaaS and health, based on the expected behavioural changes discussed in this chapter. When improving health is regarded one of the objectives, then MaaS offers several starting points for health improvements, for example through raising demand for active modes and reducing transport poverty through increasing access to the transport system. The next chapter identifies the main pathways via which MaaS can impact the health impact areas.

7. MaaS' impact on health: a conceptual framework

The previous chapters described how MaaS can change the way people travel, which affects individual health through behavioural changes and societal health via the environmental quality. This chapter answers the sub-question: *"Via which pathways can MaaS impact health?".* A conceptual framework is set up as part of this research to structure the complex, sometimes indirect relations between health, urban transport and MaaS. The framework provides an explicit structure on how MaaS can be linked to the health impact areas and health outcomes, by making a simplified representation of various relations between transport related factors and health determinants. First, the overall structure of the framework is described (section 7.1), then the impacts of MaaS on the health impact areas are analysed (section 7.2), after which a ranking of the pathways according to impact size on health is given (section 7.3), followed by a conclusion (section 7.4).

7.1 The conceptual framework

Based on the previous analyses, a conceptual framework is constructed. The aim of this framework is to visualise and provide for a better, and more well-founded understanding of potential pathways between MaaS, health determinants, health impact areas and health outcomes.

The provided framework has certain similarities to frameworks provided by van Wee and Ettema (2016) and Arup et al. (2015): the included health impact areas and health determinants largely correspond. However, the research differs from Arup et al. that also focusses on the influence of the built environment and transport infrastructure on health. Moreover, the research by van Wee and Ettema, for example, does not explicitly include equity, which is included in this framework.

Figure 7-1 presents the conceptual framework. Within the framework, the section '*Travel behaviour and health'* depicts the core of the model that is established based on the literature study on health and transport and the analysis of the urban transport system (chapter 4 and 5). The left side of the framework presents the section '*Mobility as a Service'*, which shows how the introduction of MaaS influences the relations presented in the core of the model, through changing travel experience and level of service of multi-modal transport. Moreover, some of the travel resistances (i.e. travel time, travel costs and access to transport – circled by a dotted line), do not only influence travel behaviour but also directly influence the health impact areas of equity and accessibility. For instance, lower travel costs will improve access to transport for low-income population groups, improving social equity (di Ciommo and Shiftan, 2017).

Furthermore, Table 7-1 holds the referencing for the main elements in the framework (*areas*) and Table 7-2 the referencing for the links between the elements (*arrows*), that describe the relations between the elements. These references will be further discussed below.

7.1.1 Explaining the framework: main elements and links

The conceptual model connects the introduction of MaaS via travel experience and level of service (*area I)* to travel behaviour (*area II*), which further influences the health determinants (*area III*), health impact areas (*area IV*) and the health outcome (*area V*). Between these areas arrows are depicted, that describe the relations between the areas.

During the analysis of MaaS in the urban transport system, it was concluded that the main impacts on health come from changing travel behaviour (*arrow A*), especially in terms of mode choice and choice to travel. Hence, the conceptual model departs from the notion that the health impacts of MaaS mainly arise from changes in travel behaviour. However, there is also potential for health impacts through accelerating the uptake of more sustainable and/or safe vehicles, such as electric vehicles and automated vehicles, but, it is believed, that this impact is not as influential as the changes that can be established via travel behaviour.

Subsequently, changes in mode choice, choice to travel and route choice affect the health determinants (*area III*) of active kilometres, crash risk, exposure to risk, noise level and emission level (*arrow B*). These health determinants are the main influencers of the health impact areas (*area IV*). Changes in the health determinants directly influence the health impact areas: for example, more active kilometres leads to higher physical activity and a reduction in environmental stressors.

Lastly, changes in these health impact areas (*arrow D*) influence the health outcomes (*area V*). Assessing the isolated contribution of transport on health outcomes in terms of diseases and illnesses is not possible with this framework on one hand due to simplicity of the model and on the other hand complexity of the real world system. The final health outcomes are therefore conceptualised by the three dimensions of health. In addition to the more obvious dimension of physical health, it is assumed that also mental health and social health are parts of health that can be influenced by MaaS. Strength of the evidence and causality of these links is, however, less well founded compared to the effects on physical health, and therefore their impacts are not as extensively included as physical health. Nevertheless, these dimensions were included to get an overall understanding of the relationships between MaaS and health rather than focussing on only one of the more obvious health benefits from, for example, active mobility and air quality. It also has to be mentioned that the dimensions in the health outcome (*area V*) are interrelated: there is evidence that suggests higher physical health relates to social health (e.g. te Brommelstoet, 2017), for example.

7.1.2 Explaining the framework: external factors

The conceptual model focusses on the behavioural changes that can be established through MaaS by improving travel experience and level of service and lowering travel resistances associated with multi-modal travel. Nevertheless, travel behaviour also depends on various other external factors that cannot be influenced by MaaS (*area F*). These factors include, for example, the transport infrastructure, location of activities as well as the needs, opportunities and abilities of individuals (van Wee et al. 2013). Furthermore, health is also dependent on other external factors that are out of the influential scope of MaaS (*area G*), for instance demographic factors and behavioural factors, such as smoking and diets (RIVM, 2014).

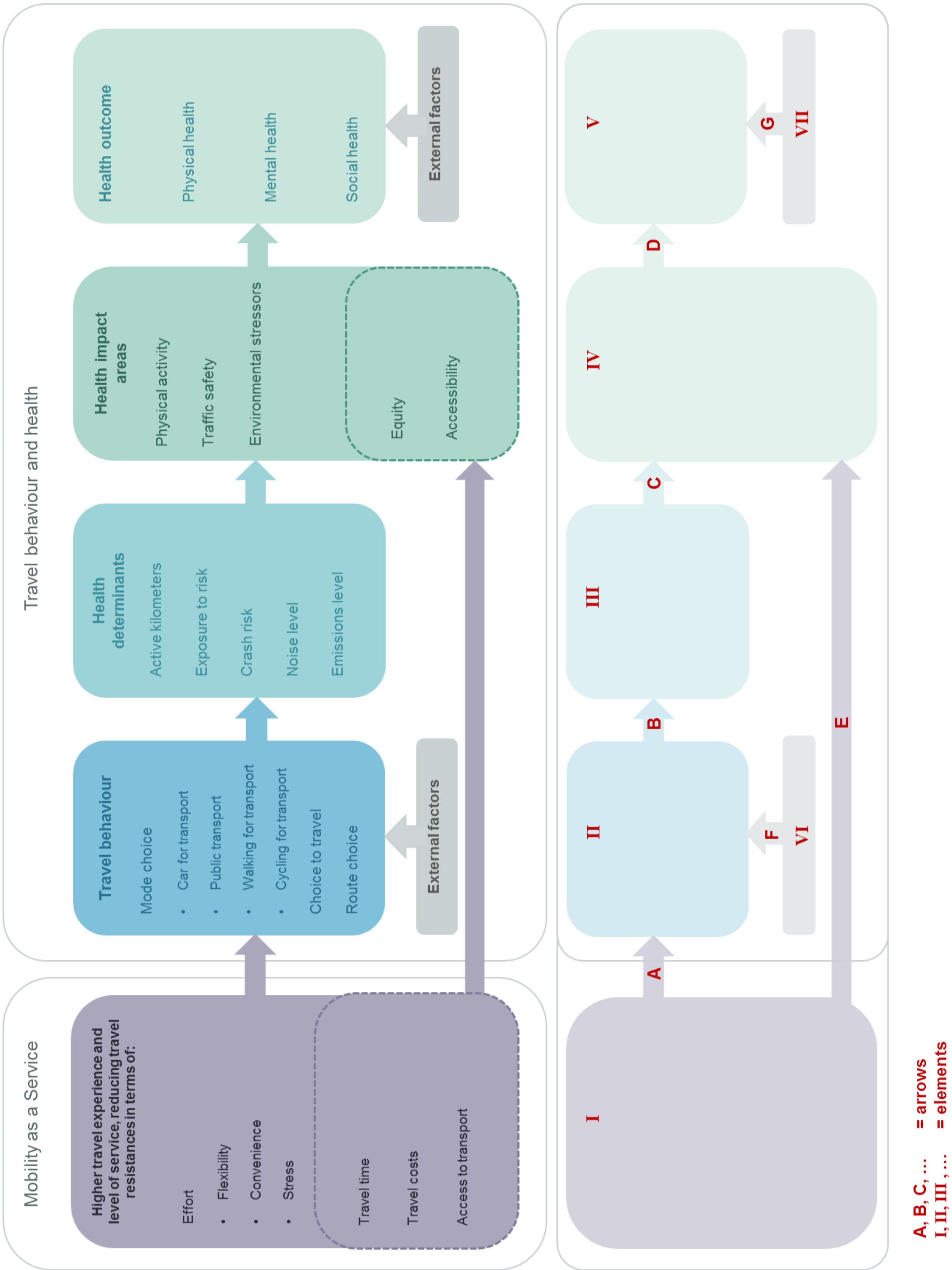


Figure 7-1: Conceptual framework

7.1.3 Explaining the framework: referencing

Table 7-1 describes the different areas in the framework and shows where the references can be found.

Table 7-1: Main areas within the framework

AREA	NAME	DESCRIPTION	REFERENCE
I	*Travel experience & level of service*	Travel experience is based on the travel resistances from the research by van Wee et al. (2013), which include: • Travel time • Travel costs • Effort (flexibility, convenience, stress) And added to this list is: • Access to transport	• Van Wee et al., 2013. • Chapter 5, section 5.1 describes how MaaS changes travel experience and level of service
II	*Travel behaviour*	Throughout literature, travel behaviour is often described as the sum of mode choice, number and frequency of trips, and route choice. Travel behaviour impacts the health determinants and therefore the health outcome.	• Van Wee et al., 2013. • Chapter 6: Analysis of how MaaS can change travel behaviour
III	*Health determinants*	The health determinants are the factors within the urban transport system with the greatest influence on the health impact areas. These are measurable factors which will be used as indicators during the health assessment, and include: • Active kilometres • Exposure to risk • Crash risk • Noise level • Emissions level	• Chapter 5, section 5.3: Identification of health determinants
IV	*Health impact areas*	The heath impact areas represent the main transport areas that influence health: • Physical activity • Traffic safety • Environmental stressors • Accessibility • Equity	• Chapter 4, section 4.2: Analysis of health effects of transport
V	*Health outcome*	The health outcome is divided in the physical, mental and social health dimension. Each dimensions has its own diseases, illnesses and conditions with which they are associated.	• Chapter 4, section 4.1 and section 4.2: Defining health and analysis of health effects of transport • Appendix B: Effects of transport on health
VI	*External factors affecting travel behaviour*	Travel behaviour is influenced by various other factors that are out of the scope of this research, such as transport infrastructure, locations of activities and needs, abilities and opportunities of individuals	• Van Wee et al., 2016 • Chapter 5, section 5.2: the urban transport system • Appendix B: Effects of transport on health
VII	*External factors affecting health outcome*	The final health outcome is influenced by, among others, personal characteristics and behavioural factors, such as smoking and diets,	• Van Wee and Ettema, 2016 • Chapter 4: Health effects of transport

Table 7-2 describes the arrows within the framework. The column *Example of relation* describes an example for a relationship. The other relations are explained in other sections of this report and mostly in the analysis of the urban transport system in chapter 5 chapter 6 and Appendix B and E.

Table 7-2: Arrows within the framework

	Arrow	Example of relation	References
A	*Impact of behavioural changes on MaaS*	MaaS can reduce car ownership, leading to a change in mode choice for upcoming trips.	• Chapter 6: Changing travel behaviour through MaaS • Table 6-1: Summary on expected behavioural changes
B	*Travel behaviour influences health determinants*	Changes in travel behaviour lead to a new modal split and a new total distance travelled.	• Chapter 5: Analysis of the urban transport system • Appendix E: Analysis of the urban transport system
C	*Health determinants impact the health impact areas*	The health determinants influence the health impact areas: e.g. an increase in crash risk reduces traffic safety.	• Chapter 5: Health determinants • Appendix E: Analysis of the urban transport system
D	*Health impact areas determine the health outcome*	Improved equity can lead to higher levels of social health.	• Chapter 4: Health effects of transport • Appendix B: Effects of transport on health
E	*Lower travel time, lower travel costs and access to transport influence equity and accessibility*	Lower travel times can lead to higher accessibility to certain destinations.	• Chapter 4: Health effects of transport • Appendix B: Effects of transport on heath
F	*External factors influencing travel behaviour*	Travel behaviour can be influenced by the personal characteristics such as income, affecting for example mode choice or choice to travel.	• Van Wee et al., 2016 • Chapter 5, section 5.2: the urban transport system • Appendix B: Effects of transport on health
G	*External factors influencing health outcome*	Health outcome depends on personal behaviour, for example on behaviour in terms of smoking or diet.	• Van Wee et al., 2016 • RIVM, 2014

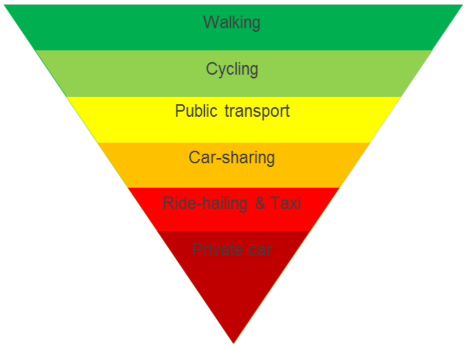
7.2 Ranking health impacts

As can be seen in the conceptual framework, one of the main ways in which MaaS can contribute to health is by inducing changes in travel behaviour, especially in terms of mode choice. This section describes the health risks and benefits of shifts in mode use to get an understanding of the strongest relations and the pathways providing the highest positive health outcomes. This information is also used during the health assessment.

7.2.1 Ranking mode choice

Figure 7-2 shows a ranking of the healthiest transport modes, adapted from Meuleman (2016). A shift from private-car based travel to active modes is considered as most beneficial to health, followed by a shift to public transport and lastly to car-sharing and ride-sharing & taxi services. The next sections describe the benefits and risks from these changes in mode use.

Figure 7-2: Transport pyramid



7.2.2 Ranking health impacts

Throughout Europe, several studies have estimated the health benefits and risks associated with a mode shift (e.g. Otero et al., 2018; Rojas-Rueda et al., 2016; Mueller et al., 2015; Rojas-Rueda et al., 2013; de Nazelle et al., 2011; de Hartog, 2010). The listed studies focussed primarily on health impacts resulting from physical activity, traffic safety and air pollution. Assessment of noise pollution, accessibility and equity were often not included or only briefly touched upon. Comparing the scale of net health benefits and risks from these studies resulted in the following ranking to establish the highest health benefits:

1. Physical activity
2. Traffic safety
3. Environmental stressors (mainly air pollution)
4. Accessibility
5. Equity

The next three sections go into more detail on the impacts on these areas from a mode shift.

- *Shift from vehicle based transport to active mobility*

Large-scale travel mode conversions from motorized cars to active travel reduce emissions, greenhouse gases and noise, among others (de Nazelle et al., 2011). Programs and policies that increase active travel are likely to generate large individual benefits through increases in physical activity, mental health and social interaction. Population wide effects are smaller, but could accrue through reductions in air and noise pollution (ibid.).

Study by Rojas-Rueda et al. (2013) quantified the health impacts of reduced car trips and increased public transport and cycling trips on morbidity in Barcelona. Results show that a 40 percent reduction in long-duration car trips resulted in an annual reduction of cases of diabetes, cardiovascular diseases, dementia, injuries, breast cancer and colon-cancer. The reduction in exposure to PM2.5 resulted in annual reductions of, e.g.

cardiovascular diseases and respiratory infections (ibid.). These health benefits result directly from an increase in physical activity and indirectly from reductions in traffic injuries and reductions in exposure to air pollution.

Study on bike sharing in Europe by Otero et al. (2018) investigated health impacts of car trip substitution by both regular and electric bike trips on number of deaths. The results demonstrate that health benefits associated with physical activity outweighed the health risk of traffic fatalities and air pollution, similar results to research on cycling in the Netherlands by de Hartog et al. (2010) and assessment by Mueller et al. (2015). Next to the health benefits provided by the major bike sharing systems in Europe, there was also an economic benefit for users. Promotion of shifting car drivers to use bike sharing systems can thus significantly increase health benefits and therefore be used as a tool for health promotion and prevention (Otero et al., 2018).

Positive health impacts in terms of both physical and mental health can be established through an increase in active travel as well as reductions in noise. Smaller, but negative impacts, can be observed through some increase in individual exposure to environmental stressors and traffic accidents for those switching to cycling. Positive impacts on a societal scale can be established through reductions of environmental stressors and lower crash risks.

- *Shift from vehicle based transport to public transport*

Overall, the contribution of public transport on societal health is overwhelmingly positive (van Oort et al., 2017). High quality public transport affects travel behaviour in a way that results in reduced traffic accidents, less emissions and noise pollution, increased physical activity, greater social inclusion, improved mental health and better access to destinations essential to health (Litman and Fitzroy, 2018; Badland et al., 2014). Considering these impacts, improving public transport can be used to achieve public health objectives and improvements (ibid.).

Research (Besser and Dannenberg, 2005; Mackett, 2011) suggests that if no other lifestyle changes are involved, people can greatly increase their levels of physical activity by using public transport instead of the car. Increased public transport use also leads to lower emissions and, hence, reduces the risk of premature deaths and certain diseases (van Oort et al., 2017). Policies that improve the quality of public transport may also enhance health benefits through more indirect outcomes, such as social capital, but these synergies are not sufficiently well understood to allow quantification at this time (de Nazelle et al., 2011).

- *Shift from private car use to ride-sharing and car-sharing*

A shift from private car use and ownership to car-based services may not result in health benefits similar to other mode shifts, but the providence of access to car-sharing and ride-sharing services can allow customers to give up their private vehicles in the future, increasing potential for several other health gains, for example reduced reliance on the car, less vehicle kilometres travelled, increased use of other transport modes and also more social interaction.

A study among Car2Go members showed that each Car2Go vehicle removed between 7 and 11 private vehicles from circulation, and reduced household vehicle kilometres travelled among the subscribers (Arup, 2018). Research in five U.S. cities by Martin and Shaheen (2016) on Car2Go also concluded that one-way car sharing is (almost) certainly reducing overall vehicle kilometres travelled, accompanying emissions and the number of vehicles on the road. However, other U.S. research on ride-sharing (e.g. Clewlow et al., 2017) shows that a significant percentage of ride-sharing trips would have been made by active modes or public transport, or they would not have occurred at all.

Furthermore, the inclusion of demand responsive transport can provide a service for those who otherwise have limited or no public transport service, positively reducing inequalities (Khreis et al., 2017). Accompanying health impacts can occur through increase in physical activity, reductions in traffic, and less air and noise pollution.

7.3 Conclusion

This chapter answers the sub-question: *"Via which pathways can MaaS impact health?".* A framework was provided to structure and visualise the impacts of MaaS on health. This framework shows that the main impacts of MaaS on health will come from changing travel behaviour in terms of mode choice, number of trips made and route choice, leading to a new modal split and total kilometres travelled.

The challenge for MaaS in relation to this shift in mode use is to reduce negative externalities from mobility by providing alternatives to those mobility options that create most negative externalities. Literature review on health impacts of transport policies showed that the largest positive health impacts can be established from supporting a shift in mode use from 1) car based transport to active mobility, 2) car based transport to public transport, and 3) private car based to car-sharing and ride-sharing systems. Highest health benefits are then expected in terms of 1) physical activity 2) higher traffic safety and 3) emissions. Noise, accessibility and equity are insufficiently covered within the available health impact assessments to include them in the ranking.

In relation to the new number of trips, it is important that these additional trips are not made with car-based services, but mostly with active modes or public transport. MaaS can worsen the accessibility of urban areas when the usage of car-based services increase more than initially anticipated compared to the use of public transport and active modes. When planning for further introduction of MaaS from a societal perspective, such conflicts must be addressed in order to best determine how to potentially integrate overall societal goals into the MaaS offer and business model.

The next section provides an assessment of the impact of MaaS on health by using the pathways established in the conceptual framework.

TESTING THE FRAMEWORK AND DISCUSSION

Testing the framework through a first assessment of the health impacts and explorative discussion on how to design for a positive health outcome.

8. Health assessment of MaaS

Within the previous phase, the main pathways between MaaS and health impacts were identified, visualised and analysed. A first health assessment of MaaS is performed in this chapter to test and apply the framework and to perform a first estimation of health impacts and their distribution in the Dutch urban environment. This chapter answers the sub-question: *"What is the potential impact of MaaS on health?"*. The limited available data regarding MaaS does not support the more traditional quantitative assessment, hence, a qualitative assessment is performed to assess the possible health impacts of MaaS. This chapter starts with a first health assessment (section 8.1), where after the scale and distribution of health effects among the Dutch urban citizens is discussed (section 8.2). An answer to the sub-question is given in the conclusion (section 8.4).

8.1 Assessing the health impacts of MaaS

Throughout the interviews, multiple experts acknowledged the link between MaaS and health. However, Kamargianni (Kamargianni interview, 13th of April 2018) emphasized that health is actually a second or third effect and that, similar to changes expected in travel behaviour, the health impacts of MaaS highly depend on the service design and the behaviour incentivised by the service (Hietanen interview, 3rd of April 2018; Sarasini et al., 2017). The next sections describe in more depth how MaaS can influence the health impact areas as depicted in the conceptual framework.

8.1.1 Physical activity

The impact of MaaS on active travel is an indirect effect established through promoting a shift to more multi-modal transport and discouraging car trips, thereby promoting more active alternatives. Overall, MaaS has good potential to contribute to the demand of active transportation (Kamargianni et al., 2018). As a result of the mode integration and personalised journey planning, people start rethinking their usual travel patterns, which increases the potential of travellers using more active modes as part of multi-modal trip. Since active modes are the cheapest modes, MaaS operators can be inclined to incentivise their use among their customers, according to O' Halloran (O'Halloran review, 21st of June 2018). This is acknowledged by Hietanen, who, as a MaaS operator, refers to active travel as cheap kilometres and as interesting from a business perspective (Hietanen interview, 3rd of April 2018).

Research by Kamargianni et al. (2018) on Londoners attitudes towards MaaS states that the overall increase in level of physical activity is expected to be minor positive and slightly higher than the current status, as some former car users are willing to walk and use bike sharing more often with MaaS. Also, the more frequent interchanges across modes will inevitably incur extra walking to travellers (ibid.). However, MaaS can also decrease physical activity in urban areas when the use of car-based services increase more than initially anticipated compared to the use of public transport (MuConsult, 2017).

The effect of MaaS on physical activity also depends on the geographical context, according to Falconer (Falconer interview, 24th of April 2018). Within a downtown environment access to car sharing motivates people to own fewer vehicles and drive less. Research by Car2Go in Vienna showed that among users of stationary car sharing services almost a quarter cycle more and 35 percent walks more since they joined the service.

Only 7 percent said they cycle less and 3 percent walks less often (Karlsson et al., 2016). But again, increased access to ride-sharing services can distort that picture, resulting in an over reliance on these services. Hence, MaaS also raises the risk of substantially reducing activity in a population, especially through the overwhelming effect of point-to-point ride-sharing services, and automated vehicles replacing walking and transit trips in the future (Smith email conversation, 12th of April 2018).

8.1.2 Traffic safety

The link between MaaS and traffic safety is less acknowledged throughout the interviews and in literature. Some thoughts regarding MaaS and traffic safety relate to the number of vehicles on the road, the increase in number of active modes and to the consumption of alcohol in combination with driving.

In case a person drinks alcohol, and/or is undertaking unusual travel for a special event, e.g. a concert or sports game, they may want to be compelled to avoid driving or riding a bicycle and be less willing or able to use public transport (Arup, 2018). Alonso-González says that some accidents can be reduced due to the use of taxi services in case of alcohol consumption (Alonso-González interview, 4th of April 2018). Study by Morrison et al. (2017) in the U.S. tested the hypotheses that increased Uber use is associated with fewer alcohol related traffic incidents. Their results have partially supported this hypotheses, however there was no associated change in total injury crashes.

Research by Moving Forward Consulting (2016) states that because MaaS strongly supports public transport, road accidents can reduce, leading to annually less accidents people injured or killed in road transport, which is also related to the *safety in numbers* effect. Kamargianni (Kamargianni interview, 13th of April 2018) mentions that traffic safety can increase since removing private vehicles from the network reduces the load on the network when passengers are directed to other modes, especially public transport (Kamargianni interview, 13th of April 2018). However, according to a research by MaaSLab, the probability of MaaS helping to reduce the number of private vehicles on the road, is minor (Kamargianni et al., 2018).

When automated vehicles become widespread, the potential effect of MaaS on traffic safety increases, according to Meurs (Meurs interview, 27th of March 2018): automated vehicles are overall saver than human controlled vehicles. By 2035 the automated vehicles are expected to lower accident rates, reduce carbon emissions and improve mobility access (Arup, 2017).

8.1.3 Environmental stressors

Changes in environmental stressors largely depend on number of trips made, total kilometres travelled, modifications of the vehicle fleet (e.g. electrification) and the scale of a mode shift from motorized vehicles to alternatives (Karlsson et al., 2017). MaaS can influence the total number of trips made, which is directly linked to noise pollution, air pollution and congestion. There is, however, potential for reductions in congestion when users are informed about rush hour avoidances and redirected in case of disruptions or over occupancy of vehicles. When MaaS induces more car-based travel, more transport related emissions occur, but increased travel with alternatives can lead to improvements in air quality (MuConsult, 2017).

The impacts of MaaS on environmental stressors depends mainly on what modes car users will shift to (Kamargianni et al, 2018) and at what pace (Alonso-González interview, 4th of April 2018). Alonso-González (ibid.) believes that in the early stages, the introduction of MaaS may worsen the level of emissions and noise because the early adopters of MaaS are initially former public transport users that are used to making more multi-modal trips. On the long haul, MaaS can improve the impact from environmental stressors when former unimodal car users shift to less polluting alternatives.

A reduction in air pollution can also be an outcome of the faster uptake of new technology and a shorter vehicle lifespan (Alonso-González interview, 4th of April 2018). This is acknowledged by Kamargianni (Kamargianni interview, 13th of April 2018), who says that the fleet of car sharing and ride-sharing services is renewed more frequently than privately owned vehicles due to the high usage. More frequent replacement of the fleet with electric vehicles and more technologically advanced vehicles can result in less local pollution (ibid.).

8.1.4 Accessibility and equity

The positive influence of MaaS on accessibility was acknowledged multiple times during the interviews and in literature, however, the outcome is highly dependent on the design of the service and on the aim of the operator. Since accessibility and equity are highly interrelated in this research, this section discusses both in parallel. With regard to equity some potential benefits were mentioned associated with personalised mobility and access to transport, but also risks for negative outcomes were addressed, especially with regard to economic factors.

MaaS has potential to help enhance accessibility of certain destinations through offering a wide range of alternative modes in combination with personalised journey plans. Services customised to the individual traveller are expected to have societal value: it can increase accessibility and the ability to utilise transport modes (MuConsult, 2017; Civitas, 2016). The mix of public and private modes may reduce some of the transport barriers associated with multi-modal travel, which improves accessibility to the transport network and thus to a wider range of reachable destinations and locations for the individual to perform activities (Alonso-González interview, 4th of April 2018).

One factor needed to overcome problems of accessibility to activities and opportunities, is the presentation and comprehensibility of information, according to KonSULT (2014). MaaS provides potential for good information on trip planning and multi-modal travel, which can contribute to mitigating social exclusion by increasing understanding of means to access destinations. At the same time, there is also a risk for exclusion of certain groups that do not know how to work with digital advanced services and interfaces (ibid.). This emphasises the importance for the design of the service and application. A MaaS system designed primarily for the urban elite (highly educated, high income and not mobility impaired) could widen the social gap within society. Durand (Durant interview, 20th of March 2018) describes it as:

> *"In general younger people want things to go fast, be seamless and efficient, but this does not work for everyone, which creates the risk of exclusion of certain groups."*

At the same time, MaaS can help vulnerable groups who normally are unable to travel independently, by providing access to more personalised journey plans and services (MuConsult, 2017), increasing feelings of self-control and reducing stress. MaaS has potential to increase mobility, and possibly activity for groups with limited mobility, especially when the service makes public transport easier to use (Smith email conversation, 12th of April 2018). Consequently, MaaS may enhance equity as various socio-demographic groups can have better access to travel and the city services they require (Arup, 2018).

When automated vehicles become part of MaaS, there is an increased opportunity to connect, for instance, people with limited mobility (ibid.). Seamless mobility will enhance the accessibility of disabled travellers as MaaS can assign special vehicles to these population groups (Kamargianni et al., 2018). When special needs transport evolves towards a bundling system, it becomes more appealing for some groups to use flexible transport (Meurs interview, 27th of March 2018).

Furthermore, alternatives for car ownership may address unmet travel demand, especially among lower income earners and disadvantaged groups residing in car-dependent locations but cannot afford to own and operate private vehicles (Arup, 2018). Exploring the current use of shared mobility, it is believed that these options offer solutions for residents of low density areas, as well as an affordable solution for low-income households (Civitas, 2016).

Others, however, do not see a direct benefit for social equity, specifically from the economic point of view, for example Alonso-González (Alonso-González interview, 4th of April 2018). According to Alonso-González (ibid), MaaS will not hinder people to use certain modes of transport, but the service will not allow certain segments of the population to get all the resources from MaaS either, because they cannot afford them. She mentions that the MaaS subscriptions do not imply a cheap service, as they include car sharing and ride-sharing services, which are in general not cheap services. This is also recognised within research by Karlsson et al. (2018), saying that those with low incomes may be less able to take advantage of MaaS based on pre-paid subscriptions as this group is not be able to pay large sums in advance. According to Alonso-González (ibid.) the pay-as-you-go option does not solve this imbalance because, for example, the taxi is still expensive.

8.2 Assessing the health impacts of MaaS

This section assesses the health impacts of MaaS based on the impacts described above, behavioural changes seen in the MaaS pilots and on the expected behavioural changes studied in a MaaSLab research (Figure 6-1 and Figure 6-2). The assessment is performed based on the following dimensions:

- **Nature of impact**: how the use of MaaS affects the health impact area in terms of increase, decrease, or equal, and will this impact be negative, moderate or positive.
  (▲ increase, ▼ decrease, or ≈ equal, and negative, moderate, or positive direction).
- **Likelihood of impact**: describes if the likelihood of the impact of the proposal is definite, probable or speculative.
- **Timing of impact**: is the impact on short-term or long-term noticeable.

Table 8-1: Health assessment

HEALTH IMPACT AREAS & HEALTH DETERMINANTS	DETERMINANTS OF HEALTH DETERMINANTS	NATURE	LIKELIHOOD	TIMING
Physical activity *- Active km*	Cycled kilometres ▲ Walked kilometres ▲	▲▲	Probable	Short-term
Traffic safety *- Exposure to risk* *- Crash risk*	VKT ▼ Active kilometres ▲ PT kilometres ▲ Number of trips ▲ Human factor – N.A. Vehicle technology ▲ Travel speed – N.A. Infrastructure – N.A.	▲	Probable	Long-term
Environmental stressors *- Emissions* *- Noise*	VKT ▼ Number of trips ▲ Vehicle technology ▲ Fuel type – N.A. Travel speed – N.A.	▼	Probable	Long-term
Accessibility *- Access to transport* *- Availability of modes* *- Travel resistances*	Access to transport ▲ Availability of modes – N.A. Travel time ▼ Effort - ▼	▲	Probable	Short-term
Equity *- Access to transport* *- Availability of modes* *- Travel resistances*	Access to transport ▲ Availability of modes – N.A. Travel time ▼ Travel costs ≈ Effort - ▼	≈	Speculative	Long-term

8.3 Case study: Dutch urban environment

Health implications from transport are highly dependent on the geographical context, as they are influenced by factors such as culture, transport infrastructure, attitudes towards modes and urban structures. So far, the health assessment was not context specific. However, this research chose to focus on the Dutch urban environment, and in doing so, this contains a quick scan on the scale and distribution of health effects in the context of the Dutch urban environment. This section discusses the following dimensions:

- **Scale of the impact:** the share of the Dutch population likely to be affected by MaaS.
- **Distribution of effects:** the groups most likely to be affected by the health impacts of MaaS.

To determine these two dimensions, insight is gathered regarding current travel behaviour, the potential for uptake of MaaS in Dutch cities and the health status among Dutch citizens living in urban environments.

8.3.1 Current travel behaviour

Looking at the modal split for two Dutch cities, Amsterdam and Utrecht, the bike is most popular for inner-city trips (Figure 8-2): bicycles are used in Amsterdam and Utrecht for 48 and 51 percent of trips, respectively (KiM, 2017). Public transport has a considerably low share in both cities (16% and 6%, respectively) in comparison to the number of car trips (21% and 29%). The modal split for travel between the city centres and the surrounding municipalities (Figure 8-1) shows that over half of travellers use private cars: for trips between Amsterdam and the surrounding municipalities, 55 percent of travellers use the car while in the Utrecht area, the count is 61 percent (Kim, 2017). The share of public transport remains low for these trips as well: 14 and 9 percent for Amsterdam and Utrecht, respectively.

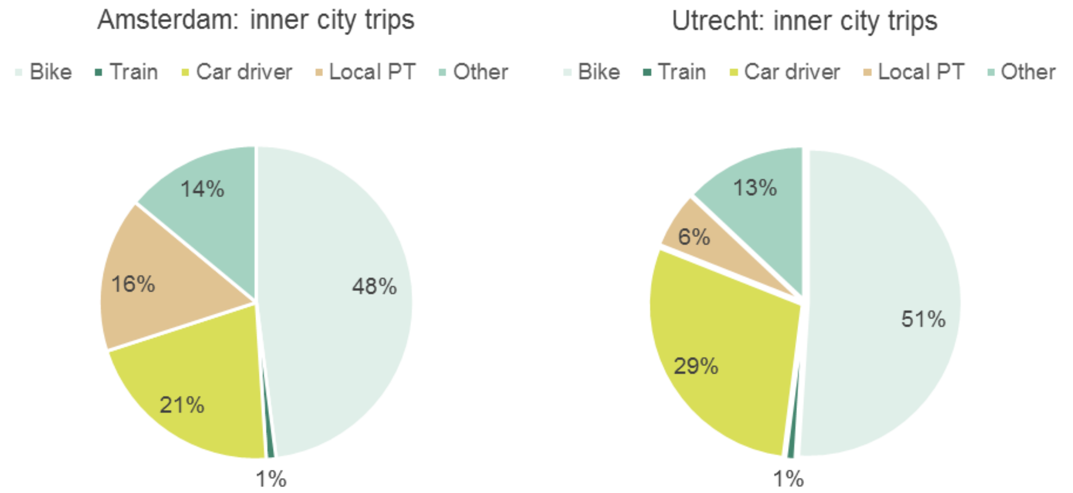


Figure 8-2: Modal split for inner city trips in Amsterdam & Utrecht (Kim, 2017)

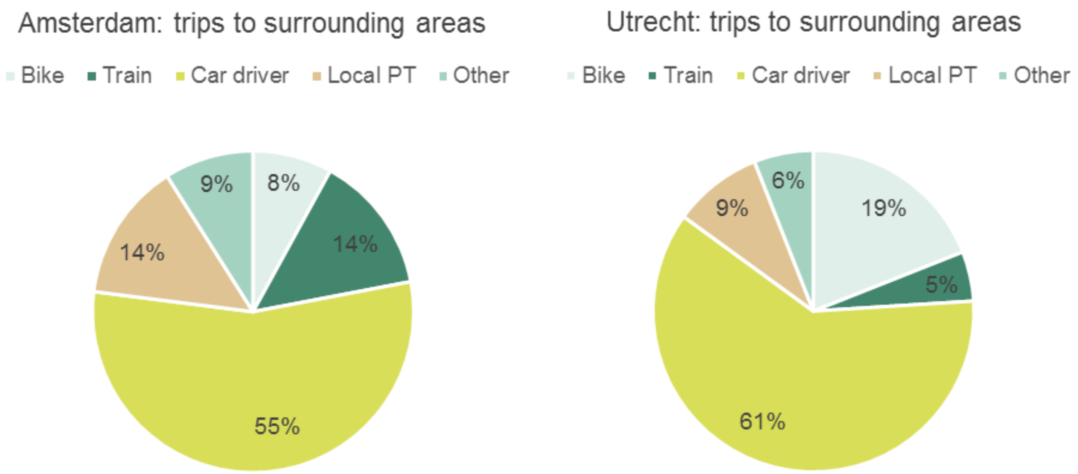


Figure 8-1: Modal split for trips between Amsterdam & Utrecht and surrounding areas (KiM, 2017)

How current travel behaviour in Dutch urban environments can evolve through MaaS is yet to be seen. However, the aforementioned data suggests that, especially between the city centres and surrounding municipalities, MaaS has potential to positively contribute to healthier travel patters as current shares of public transport and active mobility are low and private car use high. Within the city centre, potential for shifts towards more active modes is lower, as was also mentioned throughout the interviews.

8.3.2 Potential uptake of MaaS

The segmentation into potential user groups is useful to determine the impact scale of MaaS and the distribution of health effects among the Dutch population. Multiple studies (e.g. Sochor and Sarasini, 2017; Bingen, 2017) made assumptions on potential MaaS user characteristics based on available theory of MaaS users in combination with the evaluation of UbiGo and Smile pilots. User characteristics, summarised in Table 8-2, suggest that the most likely MaaS user lives in an urban environment, does not own a car, has a high use of public transport and bike, is relatively young, highly educated and environmentally aware. Research (Arup, 2018) confirms this: the greatest uptake so far has been among relatively young and affluent urban dwellers.

Table 8-2: Profile of potential MaaS users.

CHARACTERISTICS POTENTIAL MAAS USERS	SOURCES
Living in city centres, with: • High availability of public transport • Shared vehicles within 300 meters	• UbiGo and Smile pilot • Sochor and Sarasini (2017)
Personal characteristics: • Highly educated • High income • Environmentally aware • Between 20 – 40 years old	• UbiGo and Smile • Kamargianni et al. (2018)
Travel behaviour: • Multi-modal travellers • High levels of public transport and bike use • Little car use • Frequent use of share systems • Digitally mature	• UbiGo and Smile pilot • Alonso-González et al. (2017) • Durand interview, 20th of February (2018) • Sochor and Sarasini (2017) • Li and Voege (2017)

Bingen (2017) identified and segmented the potential MaaS user group in the Netherlands according to this user profile. Within the Dutch population, 11 percent fits the category of *environment-conscious urban traveller,* the group most likely to adopt MaaS based on their living environment, personal characteristics and travel behaviour (in line with the profile presented in Table 8-2).

However, more significant health impacts are expected when users that do not fulfil the characteristics of the *environment-conscious urban traveller* start adopting MaaS. In the Dutch context, this refers to the uptake of MaaS by the category of *environment-unconscious urban travellers*, comprising approximately 18 percent of the Dutch population (Bingen, 2017). This group lives in urban environments, but is car-minded and does not use public transport or bike often. When MaaS succeeds in offering a user-friendly service that is able to compete with the private vehicle, this group might change their travel behaviour with more significant health effects as result. This is supported by Meurs (Meurs interview, 27th of March 2018), who asserted that the impact of MaaS on health increases when the role of MaaS within society grows beyond the niche. However, it will likely be more difficult to persuade former car owners or frequent car users to change their travel behaviour (Pankratz et al., 2017).

The health impacts described in the health assessment will be slightly lower when mainly travellers from the smaller group of *environment-conscious urban traveller* shift towards MaaS than in a situation where the group of *environment-unconscious urban traveller* starts using MaaS. Chances are high that the first uptake of MaaS will be among early adopters and among the *environment-conscious urban traveller*.

8.3.3 Health status in the Dutch context

The next sections briefly touch upon the health status of the Dutch population, to place the health assessment in a wider context and discuss the potential impact scale of MaaS.

- *Physical activity*

When looking into physical activity, one in three Dutch citizens got little exercise in 2017 and hardly half of the Dutch population older than four years fulfilled the physical activity norm. This negative trend is expected to continue until 2030 (RIVM, 2017). Around half of the Dutch population is overweight and almost 15 percent has severe weight problems, and the number of people coping with weight problems is increasing (CBS, 2018). Being overweight (5.2%) and little physical exercise (3.5%) are the second and third largest contributors of various determinants of the Dutch disease burden (RIVM, 2014). Since MaaS can increase demand for active mobility, some of the issues described above can improve since even relatively small increases in physical activity through active mobility are already associated with some protection against chronic diseases and improved quality of life.

- *Traffic safety*

For traffic safety, especially in relation to active modes, potential for impacts through MaaS is lower. Considering crash risk factors, the Netherlands is one of the safest countries when it comes to fatal traffic accidents. However, the number of serious injuries has increased, especially among cyclists and pedestrians (CBS, 2016). A shift from car based travel towards more public transport and active modes can thus have some impacts, but probably minor, since levels of cyclist and pedestrians in Dutch cities are already high.

- *Environmental stressors*

When looking into environmental stressors, improvements can be made. Air quality in the Netherlands has improved during the last decades (VTV, 2018), but negative health impacts are still present and current air quality decreases life expectancy with an average of 13 months. Overall, air pollution in Dutch cities is accountable for 5 to 12 percent of diseases (Peeters interview, 1st of March 2018), mainly causing lung diseases, respiratory diseases, and cardiovascular diseases (ibid.). Concentrations of PM and NO_2 are highest cities such as Amsterdam and Rotterdam, where air pollution levels are roughly equal to other European cities (RIVM, n.d.). Traffic related factors within the Dutch environment that cause the highest burden of disease are exposure to particulate matter and traffic noise (VTV, 2018; RIVM, n.d.). Because traffic is expected to grow, pollution will increase during the coming years. A modal shift induced by MaaS from motorised vehicles towards public transport and more active modes of transport, but also to low or zero-emission vehicles, can improve noise pollution and concentrations of PM and NO_2 in the Netherlands, however, only in the long haul.

- *Accessibility*

The large share of bicycle usage in combination with relative compact cities and high spatial density makes the Netherlands less vulnerable to transport poverty, according to research by Decisio (2017) and Martens (2013). The well-developed bicycle infrastructure and the high level of bicycle ownership may have helped to avoid some of the transport problems related to accessibility and equity among disadvantaged groups. The bicycle is namely very low cost and therefore suitable for low income groups (Martens, 2013). However, there remain regions within the Netherlands where transport poverty and accessibility of destinations impacts the possibilities to participate in society, especially among vulnerable groups (Decisio, 2017). The contribution of MaaS to transport poverty is present, but depends highly on the design of the service in terms of variety of modes included and accessibility to these modes for various population groups.

- *Equity*

Also in the Netherlands, health impacts are not distributed equally. When considering, for example, the distribution of diseases among Amsterdam inhabitants, several inequities can be noticed: lower health is seen among the elderly, residents with a low level of education and/or income and residents from a non-western origin (GGD Amsterdam, 2016). Results from the health monitor 2016 by the city of Amsterdam show that risk groups for low perceived health in terms of high chances of chronic diseases, physical impairments, mental illnesses, loneliness, social exclusion, sedentary lifestyles, obesity and noise hindrance are the population groups often characterised as low educated, low income and low employment, among others (GGD Amsterdam, 2016). These characteristics are in contrast to the group of potential MaaS users described above, which suggests that positive health outcomes of MaaS are less likely to benefit vulnerable population groups.

8.4 Conclusion

This chapter answers the sub-question: "*What is the potential impact of MaaS on health?"*. The framework was used to perform the health impact assessment in terms of nature, likelihood and timing of impacts on the health impact areas. The health assessment showed that MaaS can establish positive health impacts; on the short-term especially in terms of physical activity via an increased demand for active modes and public transport, and also in terms of improved access to various destinations. In the long haul, change can be expected in terms of traffic safety, environmental stressors and equity, when MaaS becomes more widespread and exists in symbiosis with concepts such as automation, electrification and sharification. Impacts on equity are speculative as it is uncertain if travel costs will decrease and if the service considers a wide variety of populations instead of only the urban-elite. Improvements in equity are therefore highly dependent on the design of the service and the aim of the MaaS operator.

The assessment of scale and distribution of health effects in the Dutch urban environment showed similar results and indicated that there is space for improvement: for example in terms of physical activity, environmental stressors and equity. Data on modal split suggests that between city centres and surrounding municipalities MaaS has potential to contribute to healthier travel behaviour, as current shares of public transport and active modes are low and car use is high. Furthermore, Dutch inhabitants most likely to adopt MaaS are highly educated, low-income and already have high use of active modes and low use of private cars. Uptake of MaaS by this group can result in some, but lower health improvements, even creating a risk for negative impacts via increased use of ride-sharing services and a wider socio-demographic gap.

Overall, MaaS has good potential to have positive impact on many elements of transport in cities, which can bring a positive outcome to issues related to health. The final direction and impact size regarding these areas is uncertain because it depends on the design of the service, what the service incentivises, the operational context and the stakeholders involved. The next chapter discusses ideas to enhance the chance of positive health impacts in terms of service design and stakeholder involvement.

9. Designing for a positive health outcome

The previous chapter contained a first health assessment of the MaaS, with a small case study on the health impacts in the Dutch urban environment. However, as mentioned in literature and throughout the interviews, the direction in which MaaS will change health is influenced by the design of the service and the aims and roles taken by the involved stakeholders. The sub-question this chapter answers is "*How to design MaaS to generate positive health impacts?".* Package design and stakeholder positioning are discussed to generate positive impacts on health, whilst mitigating the negative effects. First, an analysis of MaaS package design is given (section 9.1), after which a pro health scenario is discussed and design ideas for a pro health package are explored (section 9.2). Then, different development scenarios regarding stakeholder positioning are discussed (section 9.3) and an answer to the sub-question is presented in the conclusion (section 9.4).

9.1 MaaS package design

Packages are an important element within the MaaS definition used in this research. Study by Kamargianni et al. (2018) describes the packages as a demand management tool that can help motivate consumers to use more innovative and sustainable modes of transport. The same study shows that 40 percent of survey respondents agreed on trying new modes they previously did not use if their MaaS package includes them. Furthermore, a share of 31 percent of respondents (ibid.) agreed that they would cycle more if they were given discounts on MaaS products for every mile. Types of modes, amount of modes and special features included in packages thus influences mode use. From a health perspective these packages are interesting as they can be used to steer behaviour, which is more difficult in case of pay-as-you-go subscriptions. However, travellers highly appreciate the flexibility MaaS can offer (Kamargianni et al., 2018; Sochor et al., 2016), something that might be limited by the packages: this emphasises the need to find a balance between what is preferred by the consumer versus what is preferred by stakeholders involved in the MaaS development.

Attributes in MaaS package design have to be carefully considered as they are directly linked to the usage of the service (Ratilainen, 2017). Research by Matyas et al. (2017) presented a selection of core attributes, which can be varied in package subscription. The following attributes are considered:

- Type of transport modes included
- Amount of each transport mode offered
- Mode specific features (e.g. 10 minute taxi guarantee)
- Innovative attributes (e.g. special prices)
- Price of the package (monthly payment or pay-as-you-go)

Research on MaaS package design so far is limited (e.g. Ratilainen, 2017), but one example of packages is provided in the Whim service. Whim offers three types of packages segregated according to the size of the plan. Figure 9-1 shows the Whim packages and illustrates how the attributes may vary between subscription plans in terms of price, types of modes included, amount of modes and mode specific features.

	Whim To Go	Whim Urban	Whim Unlimited
Monthly payment	Free	49€	499€
Local public transport	Pay per ride	Unlimited Single Tickets	Unlimited Single Tickets
Taxi (5km radius)	Pay per ride	10€ per ride	Unlimited
Car	Pay per ride	49€ per day	Unlimited
City Bike	Not included	Unlimited (30min)	Unlimited
Cancel anytime	✓	✓	✓
Add-ons incl regional HSL ›			
	Read more	Read more	Read more

Figure 9-1: Whim packages

9.2 Pro health scenario and package

This section discusses the potential for a healthy MaaS service in terms of service design and stakeholder involvement. The aim of this discussion is to offer design ideas and entry points for MaaS development to increase the chance for health benefits and mitigate the risk for a negative health outcome.

9.2.1 Pro health MaaS scenario

As discussed previously, there are two potential MaaS user groups in Dutch urban environments; the *environment-conscious urban traveller* and the *environment-unconscious urban traveller.* Taking into consideration these user groups and their characteristics, two outlying scenarios are possible based on the directions in which travel behaviour can when travellers use MaaS. Figure 9-2 shows the potential user groups on the left and summarises the travel behaviour changes in a pro health scenario and negative health scenario.

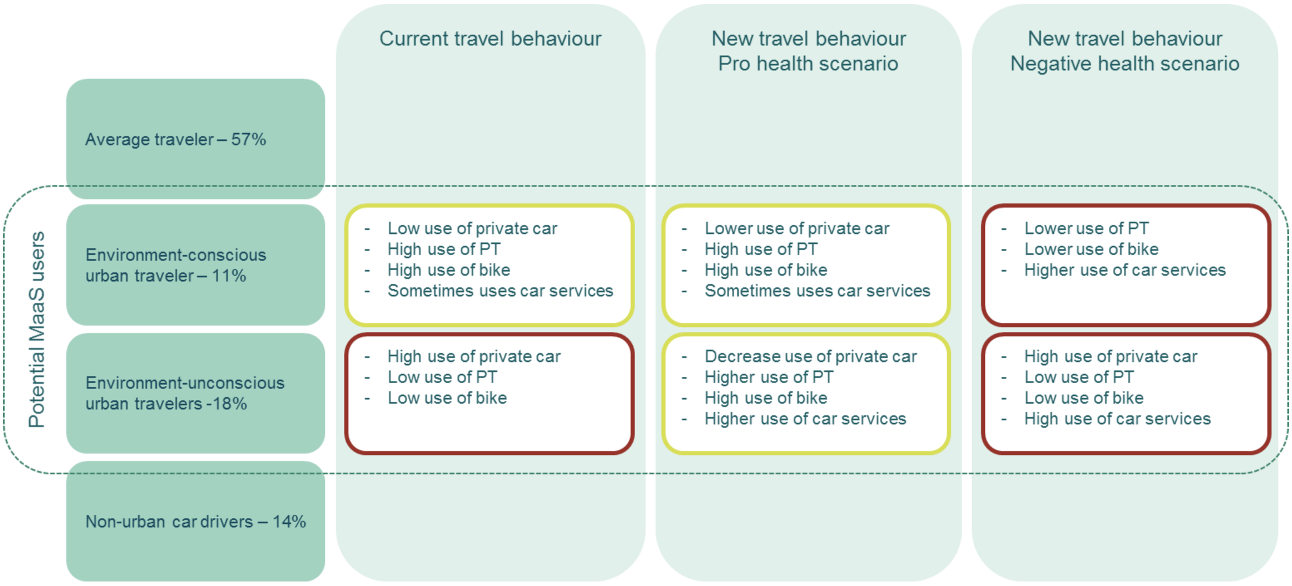


Figure 9-2: Scenarios based on changes in travel behaviour from pilots

Table 9-1 provides a more thorough description of the pro health scenario in terms of health impact areas. The left column shows the direction for health impacts and the right column describes the function of MaaS in establishing this pro health scenario.

Table 9-1: MaaS in a pro health scenario

PRO HEALTH SCENARIO	ROLE OF MAAS IN PRO HEALTH SCENARIO
Physical activity ▲ Active kilometres	Public transport forms the backbone of MaaS through increased travel experience in terms of improved transfers, a personalised journey planner, real-time travel information and higher feelings of control, which reduce the alliance on the car and private vehicle use. MaaS promotes active mobility among users by incentivising use of public transport and active modes for short trips and as part of multi-modal trips by focussing on access and egress to publicly available services.
Traffic safety ▼Crash risk ▼Exposure to risk	MaaS improves traffic safety by reducing overall car use and number of vehicles on the road. Support the use of active modes to increase the number of cyclists and pedestrians, and therefore lower the risk of getting involved in an accident (*safety in numbers*). On the longer term, the rise of automated vehicles is accelerated by integrating these vehicles in MaaS services and sharing concepts, to reduce the number of vehicles and crash risk. Furthermore, there is flexibility to choose a mode dependent on the trip the user wants to make and their state of being: in case of drunkenness, people can use ride-hailing instead of bike or car.
Environmental stressors ▼Emissions ▼Noise pollution	Lower the impact of environmental stressors via a reduction in vehicle kilometres travelled through incentivising a shift to alternative modes, focussing on a shift from car based trips to active modes and public transport. For car-based trips, a wider transition is supported towards more sustainable, technology-advanced vehicles, e.g. low or zero-emission vehicles (electric vehicles) and vehicles with more state-of-the-art technologies that emit less emissions and noise. The pace of this uptake is supported through MaaS by replacing the fleet of car-sharing and ride-sharing services more frequently.
Accessibility ▲Access to transport ▼Travel time ▼Effort	Increase overall accessibility and at moments (e.g. night time) and to areas that are not well served with the current (public) transport system to improve access to important destinations and opportunities, such as social contacts, employment or health-care. Widen the variety and number of modes accessible by integrating private and public modes of transport to increase travel options and reduce travel times by making transfers more convenient, pluggable, stress free and faster.
Equity ▲Access to transport ▼Travel time ▼Travel costs ▼Effort	Contribute to equity in transport by considering a wide diversity of population. E.g. increase the number of modes accessible for people without a car and to support vulnerable groups (in terms of spatial access, travel costs, travel time, travel information, convenience, flexibility), which enables them to take part in society, have social connections and reach important destinations. Relatively affordable ride-sharing, taxis and car sharing services provide access to destinations that would otherwise have been difficult to reach for some population groups or might have led to trips foregone. Another focus is on bundling transport for special need population groups that cannot afford or have difficulties with accessing traditional transport. Offer connections to important destinations for more vulnerable groups, for example to health care through a partnership with special needs transport.

9.2.2 Pro health package

The objectives for a positive health scenario described in the previous section are used for the design of a pro health package. According to Holmberg et al. (2016), a healthy and sustainable package aims to maximise the use of the existing public transport system, rather than maximising the service satisfaction for the consumer. Research by Ratilainen (2017) shows that also among consumers a service with public transport as backbone is preferred. With this in mind, the main aim of the pro health package is to find a balance between what is desired from a health perspective and what is convenient from a consumer perspective. Table 9-2 presents the package design ideas: on the left the attributes, in the middle the design ideas and in the right column what these ideas try to establish.

Table 9-2: Pro health package design

ATTRIBUTES	DESIGN IDEAS FOR ATTRIBUTES	AIM OF THE DESIGN IDEAS
Type of modes *&* *Amount of each mode*	**Modes included:** • Local public transport • Shared bike • Taxi & ride-sharing • Car rental • Car sharing • Regional train **Unlimited number of trips:** • Local public transport • Shared bike (up to +/- 30 min) • Regional train **Limited (by price and/or distance):** • Taxi & ride-sharing • Car rental; pay per day • Car sharing; pay per km/min	A healthy MaaS package aims to offer a wide variety of both public and private modes to increase multi-modal travel options and flexibility to choose during travel. The public transport modes and active modes are unlimitedly available, or against very reasonable pricing, to ensure that these modes form the back bone of the service. Taxi and ride-sharing services require additional payment on top of the monthly payment for trips that could have been made with other modes. Exceptions are to made for vulnerable population groups, e.g. by offering additional options for special needs transport.
Mode specific features	**Taxi / ride-sharing:** • Within a radius of 5 km for a fixed price • Pick up time guarantee **Shared bike systems:** • Free up to +/-30 min to make sure that occupancy is high	Mode specific features are included to limit the use of modes with high negative externalities (motorised, private, single occupant vehicles) that negatively affect health and for trips that could have been made with alternative modes on short distances. Taxi and ride-sharing are limited by setting the possible pick up and drop off locations in terms of a maximum radius. Whim (Whim, n.d.) calculated that 5km connects most people in Helsinki to public transport, and for trips over this limit standard taxi prices apply to limit their use. Include a guaranteed pick up time to reduce stress during travel and control over a trip.
Innovative attributes	**Individual health benefits:** • Step count • Calorie burn count **Personalisation of trips:** • Max. walking distance • Max. cycling distance **Impact air quality:** • Max. CO_2 quota • Compare trips on CO_2 quota **Special pricing:** • Discount on active trips **Trialability:**	Moreover, innovative attributes (e.g. special pricing, special discounts, individual benefits) are used to promote and nudge healthy travel behaviour among users. Another important innovative attribute is the inclusion of trialability, which is a tool to introduce consumers to new modes and new travel patterns. Trialability is seen as a change moderator for sustainable travel behaviour and enables people to trial certain behaviour before engaging (Durand interview, 20th of April, 2018; Strömberg et al., 2016).

	• Offer new modes and discount on first trips with these modes	
Price of the package	**Tariffs:** • Offer different sized plans to consumers for them to find a package suited to their behaviour.	To be competitive with private cars and be accessible for different socio-economic groups, different subscription options are available and the price of the packages is competitive with private car use and ownership.

9.3 Stakeholder involvement

The possibilities for a healthy service depend largely on who is the stakeholder operating the service, what their main aim is regarding the service and what behaviour this operator aims to incentivise. Since the MaaS ecosystem is not yet fully established and roles are still to be decided on, an exploration of the roles in the MaaS ecosystem and the involved stakeholders is needed to increase the change for positive health outcomes and mitigate negative outcomes, especially since health is not a value common between all stakeholders in the ecosystem. This section explores how the stakeholders engaged in the MaaS development can be positioned within the ecosystem to increase the positive impacts on health.

9.3.1 Stakeholders' positions within the MaaS ecosystem

As public and private parties are investigating their role within the development of MaaS and within the MaaS ecosystem, numerous strategies and roadmaps for MaaS have been presented, e.g. by Arup (2018), MuConsult (2017), Kamargianni and Matyas (2017), Catapult (2016) and Holmberg et al. (2016). These roadmaps are used to identify the stakeholders involved and interested in the development of MaaS. Appendix C includes a list of these parties and their main interests and objectives within the MaaS development.

Several studies (e.g. Smith et al., 2018; Holmberg et al., 2016) explored development scenarios for stakeholder involvement and the consequences of these predictive scenarios on the design of the service. Three scenarios are discussed; market-driven development, public-controlled development and public-private development, with a focus on the fulfilment of the role of the MaaS operator. MaaS operators can have different objectives regarding the service and their interest will influence the direction in which travel behaviour changes prevail. The next sections elaborate briefly on these development scenarios and their implications for health and MaaS.

- *Market-driven development*

The market-driven development implies that the role of MaaS operator is absorbed by private actors or new emerged MaaS start-ups (Smith et al., 2018). The public sector in this scenario is more of an enabler rather than a driving force as private actors are expected to push the development (ibid.).

In this development, the role of MaaS operator is driven by commercial interest with the main goal to maximise the number of subscribers (Holmberg et al., 2016). A MaaS service that is left to the market focusses on designing an optimal service for the individual and this creates a risk that business models will emerge that congest the city (Haverkamp, 2018; Huizenga, 2018). This development may induce a greater use of vehicles in the form of ride-sharing services and a demand reduction for public transport (Catapult, 2016). Research by Holmberg et al. (2016) states that public transport would be one service among many others, suggesting that a private controlled service would likely not have the same public transport coverage as a publicly owned scheme, as the service is commercially most interesting in dense urban areas and city centres.

On the more positive side, research by Smith et al. (2018) points out that this development provides more incentives and better capabilities to develop innovative services that meet the traveller's needs, leading to a service that is better at competing with private cars. A market driven system may also promote the use of active modes, as these are seen by the MaaS operator as cheap kilometres (O'Halloran review, 18th of June 2018), which is confirmed in the interview with Hietanen (Hietanen interview, 3rd of April 2018)

Form a health perspective, this scenario is overall believed to be less beneficial for several reasons; firstly, the role of public transport is smaller and public transport coverage is expected to be lower than in a public-controlled development and therefore negative health impacts may occur, especially regarding accessibility and equity. Secondly, the risk for more car-based trips is also believed to be higher, resulting in negative impacts for physical activity, traffic safety and environmental stressors.

- *Public-controlled development*

In this scenario, public authorities drive MaaS developments by enabling and funding development, implementation and operation (Smith et al., 2018; Li and Voege, 2017). Research by Smith et al. (2018) provides three arguments for this development; first, the main purpose is to contribute to societal good through facilitating a modal shift from private cars to service based transport; second, public transport is the backbone of MaaS; and third, the public sector strives towards reducing the amount of travel and increasing the modal share of public transport. They argue that public control is needed in order to steer MaaS towards societal good, which is preferred from a health point of view.

This scenario is believed to be more beneficial from a health perspective, firstly because coverage of public transport is greater than in case of a market-driven development, second because public transport forms the backbone, third as the number of trips and car-based transport is expected to be lower than in the private controlled scenario, where the operator might aim to maximise its revenue by selling as many and as expensive trips as possible (Smith et al., 2018). Lastly, there is more potential to focus on the equity aspect of the service.

- *Public-private development*

This development should be interpreted as a middle way between the two development scenarios described above, implying that both sectors fulfil a role in the development of MaaS. In this scenario the public sector supports and facilitates the alignment between the MaaS operator and transport operators and private operators play a larger role in the creation of public value (Smith et al., 2018). Public transport authorities strategy for MaaS explicates that they will enable third parties to develop MaaS offerings that give access to public transport and other transport services.

It has been suggested (de Cani, 2018) that MaaS operators and transport operators should be managed by the public sector to prevent fragmentation and ensure that mobility solutions do not worsen urban mobility and thereby negatively impacting health. These public parties play an important role within the development of MaaS since they have the interest, power and means to alter legislation, allocate subsidies, design new policies and create a regulatory framework for the development of MaaS within their environments.

9.4 Conclusion

This chapter answers the sub-question: "*How to design MaaS to generate positive health impacts?".* MaaS package design provides an opportunity to manage demand and to help motivate consumers towards more healthy travel behaviour and travel patterns, especially in terms of mode choice.

The main challenge and trade-off for the design of a healthy package, is to create a package that is both appealing to the consumer, incentivises healthy travel behaviour and is interesting from a MaaS operators' perspective. Research by Ratilainen (2017) shows that among consumers a package with public transport as backbone is preferred, which is in line with the preferred package from a health point of view. The pro health package therefore aims to incentive the use of public transport, complemented with active modes and occasionally car-based services. The presented design ideas are focussed on motivating this type of behaviour, for example by limiting the pick-up and/or drop-off location for taxi services and offering innovative features such as a step count or calorie burn measure to nudge users towards more healthy behaviour. In considering equity principles, the package design aims to consider a wide diversity of population groups, including more vulnerable groups, by, for example, offering bundling options for special needs transport but also in terms of subscription options.

The design of a healthy service depends largely on who is the stakeholder operating the service and the behaviour this operators aims to incentivise. From a health perspective, the MaaS development is preferably driven by a public entity or in collaboration with public entities, rather than a commercial third party. Commercial third parties in general aim to maximise the number of subscribers to the service, rather than maximising the use of healthy and sustainable modes, and societal benefits are therefore less secured. Another possibility is that a public entity establishes conditions and guidelines to ensure that the opportunities provided by MaaS are in line with their broader objectives regarding urban mobility, sustainability and health. Without clear regulations some of the negative impacts of MaaS can become a threat to the liveability in cities and thus to societal health.

CONCLUSIONS AND RECOMMENDATIONS

Concluding on the potential impacts of MaaS on health presenting limitations of this study and recommendations for further research.

10. Conclusion and recommendations

This chapter constitutes the main conclusions, some limitations of this study and recommendations for further research. Section 10.1 provides the main conclusion derived based on the findings of this research and gives an answer to the main research question. Next, recommendations for the development of MaaS from a health perspective are given in section 10.2 and section 10.3 provides recommendations for further research.

10.1 Conclusion

The aim of this study was to explore the pathways and impacts on urban health of the novel mobility concept Mobility as a Service. MaaS can improve or worsen urban mobility issues: creating an opportunity or risk to liveability in cities. In addition to this, MaaS holds potential to impact a variety of sectors beyond transport, of which health is one. In this study, the potential health implications of MaaS were analysed by means of an exploratory research to answer the following question:

"What could be the impacts of MaaS on health within urban environments?"

This thesis used a conceptual framework and health assessment to show MaaS has the potential to contribute to positive health outcomes in urban environments. MaaS services can be used as an entry point for different stakeholders to deliver health improvements at the individual and societal scales. It will require, however, further attention and investment in the design of the service from the diversity of stakeholders influencing mobility and health processes. Government will likely need to play an active role in service design to achieve positive health impacts. There is a clear risk that poorly conceived MaaS designs will produce negative outcomes in important parts of the urban system, for example in terms of congestion, emissions, stress, social equity and accessibility. Any negative impacts on the urban system have health implications.

- *Linking health, transport and MaaS*

Literature study on the relations between health and transport led to a set of five impact areas that can establish health impacts through transport: *physical activity, traffic safety, environmental stressors, accessibility* and *equity*. Together these areas formed the main focus to generate health impacts and were used as guidelines throughout the research to construct the conceptual framework and perform the health assessment.

Review of MaaS literature and explorative interviews with experts revealed that MaaS can change the urban transport system: MaaS services can improve travel experience and service level of multi-modal transport through integrating private and public modes; creating more personalised journey plans; offering real-time travel information; using one digital platform and intermodal journey planner; and integrating ticketing and payment systems. Together, these components have good potential to increase access to the (public) transport system and lower travel resistances associated with multi-modal travel: *travel costs*, *travel time* and *effort*. Use of MaaS can lead to reductions in travel time and, believed by some but contradicted by others, lower travel costs. The third resistance factor affected is effort, which is determined by feelings of flexibility, convenience and stress during travel. By making interchanges more seamless, connected and comfortable, and by increasing flexibility and feelings of control over disruptions, MaaS can reduce effort. The discussed improvement can enhance the opportunity for health benefits associated with the travel itself, e.g. by lowering stress, but also through positioning MaaS as a more competitive alternative to private car use and ownership in cities, which enhances the opportunity for health benefits associated with a mode shift from car based transport to alternatives.

Analysing how MaaS can change the urban transport system and affect the health impact areas highlighted that the main way for the service to influence health is by changing travel behaviour in terms of mode choice, choice to travel and route choice. Directions for behavioural changes were identified and analysed during the expert interviews and in combination with behavioural changes seen among participants in MaaS pilots (UbiGo, Smile and Whim), it was shown that MaaS can change former travel towards more multi-modal patterns, potentially towards:

- Increased multi-modal travel
- Reductions in private car ownership and use
- Increased number of trips
- More considered travel behaviour
- New attitudes towards modes
- Changes in route choice

However, as advanced MaaS solutions have not been widely implemented and pilot participants volunteered and were mainly early adopters willing to use new modes and keen on trying new technology, it is too early to be conclusive on the direction in which changes in travel behaviour, and especially mode use, will prevail.

- *The conceptual framework and health impact assessment*

Through conceptualising the relations between the introduction of MaaS, the urban transport system and the health impact areas, a framework was created to visualise the main pathways for health impacts of transport that could assist in assessing the health impacts of MaaS. This framework is believed to provide for a better understanding of potential health impacts of mobility concepts in general and was used to perform a health impact assessment on the MaaS concept.

In testing the framework, it was asserted that MaaS provides good potential for health benefits, for example: less stress associated with multi-modal travel, more physical activity through increased demand for active modes, some traffic safety improvement by reducing private cars, less pollution through a reduction in congestion and private car use and more social interactions through increased accessibility. The impact on equity is, however, speculative, as this area is especially dependent on the service design, the price of the service and the inclusion of bundling systems, such as special needs transport. For now, uptake of MaaS has been among the so-called urban elite, increasing the risk of widening the gap between socio-economic groups.

Some of these health impacts can be established on the short term, such as increased physical activity and improved accessibility, but changes in traffic safety, environmental stressors and equity will only be noticeable on the longer term when concepts such as automation, electrification and sharification have made their way into society and into MaaS.

Furthermore, some of these health impacts are conflicting: increased access to the transport system may result in an increase in the number of trips made – a desired impact on an individual scale - but somewhat undesired on a societal scale with increased negative health impacts from congestion, accessibility and emissions. These are focus points to take into consideration during the design of the service.

To provide for a more complete assessment on these health impact areas, this research looked into the scale and distribution of health effects in the Dutch urban environment. In this context, the group most likely to adopt MaaS is the group that already has shown a low use of private vehicles and a high use of active modes and public transport. Uptake of MaaS by this group will result in some, but lower health gains, even creating potential for negative health implications. In the long haul, car reliant travellers may shift towards MaaS when the concept becomes more widespread and competitive with the convenience associated with private car use. Uptake of MaaS in this group can lead to wider health gains and reductions in urban mobility issues. This could be achieved when shared, automated vehicles become more widespread.

With the current state of knowledge it is still too early to be definite on health implications, as there is uncertainty and discussion on what the service will look like, what kind of behaviour is incentivised and who will operate the service.

- *Increasing the change for a positive health outcome*

MaaS offers various entry points: through increasing the demand for active modes and public transport, increasing accessibility to transport, reducing environmental stressors by lowering the number of car based trips and accelerate the uptake of more technology advanced vehicles, and trends of automation, electrification and sharification. The main challenge and trade-off for the design of a healthy package is to create a package that is both appealing to the user, incentivises healthy travel behaviour and is interesting from a business perspective. Preferred from both a consumers perspective and health perspective is a MaaS design that positions public transport as the backbone.

In case the MaaS operator is engaged with the wider impacts of MaaS, health considerations can become part of the service. MaaS packages, in contrast to the pay-as-you-go subscriptions, provide an opportunity to manage demand and to help motivate and nudge users towards healthy travel behaviour. Therefore, MaaS developments are preferably driven by a public entity or in collaboration with public entities, rather than a commercial third party. A public-driven MaaS development can ensure for more social security, better coverage of (public) transport, less car-based trips, better equity considerations and higher accessibility of urban environments. Without clear regulations set by national and city governments, some of the negative impacts of MaaS can become a threat to liveability in cities and to various aspects of health.

- *Discussion on conclusions*

In line with the conclusions, it can be stated that MaaS has good potential for positive health impacts. However, the author advises that the framework and health assessment should not be misused as a way to make a stronger case for the introduction of MaaS, when no consideration is paid to the wider (health) implications of the service design and involvement of stakeholders. In addition, MaaS should not be positioned as a measure to solve health problems because health it a side-effect of the service. Moreover, there are many other reasons to focus on improving health and liveability in urban environments. Falconer (Falconer interview, 24th of April 2018) stated during the interviews:

> *"I think there is well enough evidence/studies out there on population health, transport and the built environment that demonstrates that we should be focussing on making our cities liveable, walkable, cycle able and healthy and we should not be using some form of evolving mobility paradigm as the excuse to develop more healthy cities. In other words, healthy cities do not depend on mobility services. MaaS shouldn't be the enabler to make cities more walkable."*

Nevertheless, it is believed by the author that MaaS offers strong opportunities for positive change regarding urban mobility and healthy travel behaviour in urban environments. When the starting points for health improvements made in this research are considered during development and design of the service, benefits can emerge for both individuals and society.

10.2 Limitations

The research goal was stated as follows: "*to better understand the link between MaaS and health through explorative researching the concept and its main elements and inter-relationships with health".* The assumption was made that it would not be possible to gain complete understanding of the health impacts of MaaS. Nevertheless, it is believed by the author that this research has provided more and better support that lead to increased understanding of potential health impacts of MaaS. In doing so, this study explored opportunities to include health objectives during the MaaS development. However, there are limitations regarding research methodology, the study and conceptual framework, and they are discussed in this section.

- *Exploratory research*

While this study provides some valuable insights and pathways to consider health during the development of MaaS, it is based on an exploratory analysis which comes with certain limitations. The main limitation of this approach comes from the qualitative information that was collected and interpreted, which could have been subject to bias. In contrast to the extensive, even though complex, body of knowledge regarding transport and health, literature and empirical data on MaaS is limited. This is one of the primary reasons experts were consulted and their opinions and views became a vital part of this study. During the interviews, the novelty of the topic was acknowledged several times and, it is believed, that therefore many of the interviewees were careful in giving their opinion, making statements and expressing their views. It was often being emphasised that given answers were mainly thoughts and first opinions, sometimes not that well founded. There is a possibility that some more biased and unfounded statements have made their way into this report.

- *Complexity of research area*

As highlighted in this research, the body of knowledge on transport and health is extensive but complex due to the many inter-relationships, occasionally lack of causality and dependency on external factors. The impacts of transport on health are part of a more complex system than was possible to capture within the time, knowledge and methods used in this research. Health impacts from transport are linked to wider demographic, social and economic factors, which makes it difficult to estimate the impacts of a single mobility concept, such as MaaS, on specific health outcomes. Also, estimating the final impacts of MaaS terms of illnesses and diseases would not have been well founded with the current state-of-knowledge and data.

Furthermore, as it was often mentioned during this study, MaaS can accelerate currently ongoing trends in the transport sector, such as electrification, sharification and automation. This research and the framework did not account for the potential of synergy effects between these innovations.

- *Simplicity of the conceptual framework*

The conceptual framework, just as any other research with the current state-of-knowledge, is unable to capture the real world complexity of the research area. The framework did not account for health implications from, e.g. travel for fun, impacts from travel experience on well-being and self-selection effects (see research van Wee, 2009). Also, the role of the factor stress involved in travel and its impact on health is relatively simplistic in the framework. This is also the case for the influence of transport on social interactions and social health.

It was noted during this research that there is a lack of health impact assessments that include the effects of mobility policies and programs on the health impact areas of mental and social health. This study tried to include these dimensions but due to complexity and limited research the possibility to assess these aspects with the provided framework is restricted. However, it is believed that MaaS can have a large contribution to these areas in terms of stress, feelings of self-control and improved social interactions.

- *Limited empirical evidence and early adopters*

Empirical evidence on how MaaS changes travel behaviour is not widely available as pilots are currently ongoing, they are small scale or not publicly accessible. Also, the first participants in these pilots were mainly early adopters keen on trying new technologies and, therefore, changes in travel behaviour seen among these participants are not directly representative of the general population. Despite the first participants being early adopters and the fact that the empirical evidence came from a modest number of pilots and research, the empirical evidence was used to support the identification of pathways and health assessment.

- *Assumptions during health assessment*

In testing the framework, a health assessment of qualitative nature was performed instead of the more traditional quantitative method that is used to perform health impact assessments. This was a consequence of, among others, limited causality between some pathways in the framework and limited empirical data on behavioural changes, both world-wide and within the specific context of the Dutch urban environment. In order to execute the qualitative assessment with the framework, many assumptions were made on the most likely MaaS users in the Netherlands, their current travel behaviour and their associated health status. These assumptions were based on some studies by, for example, the Municipality of Amsterdam and data from organisations such as RIVM and CBS, but could have been more strongly supported with more research.

10.3 Recommendations

Based on this study and the main conclusions, recommendations are proposed on the use of the framework, for incorporating the potential for health benefits during MaaS development and for further research.

10.3.1 Recommendations related to use of the framework

The pathways and determinants presented in the framework can be used during further development of MaaS services and ecosystems when designing for health impacts. The core of the framework and presented pathways, focussed on travel behaviour and health determinants, can be used to define the nature of impacts for planned or new transport policies or programs on health. It is believed that the framework can be used for different transport related projects of varying scales and in different research areas, for example as a checklist to ensure that decision makers consider the opportunities and potential impacts of a project in a more holistic way. However, attention must be paid to the limitations of the framework discussed above.

10.3.2 Recommendations for public entities to establish positive health impacts

To enhance the chance that final outcomes prevail in the positive direction, the following recommendations are proposed to the public sector, as the involvement of the government in MaaS can help to shape the service and to align the interests of MaaS operators and the public sector, so that it benefits the broader objectives, including improved health and environmental quality.

- *Start MaaS pilots with a health focus*

The first recommendation is to start more MaaS pilots with a focus on health. Testing MaaS products through pilot case studies would help to provide the evidence needed to demonstrate the wider impacts of the service on individual health (e.g. via physical activity), but also, for example, on environmental impacts (e.g. via environmental stressors and traffic safety). The Ministry of Infrastructure and Water Management is about to launch several MaaS pilots throughout the Netherlands and one in the more rural area of Twente that is specifically focussed on the social aspects of MaaS, showing the interest of the national government for the wider impacts of the service. Furthermore, more empirical evidence on the health benefits of MaaS increases the synergy between the sectors of transport and health, a positive development. MaaS can be used as a way to establish more synergy between the sectors of health and transportation and this synergy can be supported when MaaS operators and, for example, health insurance companies are encourages to work together in stimulating healthy travel behaviour.

- *Set regulations and regulatory frameworks*

As MaaS developments are quick, it is recommended to involved authorities to react and define their position within the system before changes prevail in the negative direction. Policy makers and city authorities have to engage with the MaaS ecosystem to be able to contribute to benefits in terms of social equity, accessibility and air quality. Public entities have the interest, power and means to alter legislation, allocate subsidies, design new policies and create a regulatory framework for the development of MaaS within their environments and they have to set the regulations to facilitate the development in the positive direction. Think of limitations regarding ride-sharing services and facilitation of sharing concepts.

- *Facilitate partnerships between health care companies and MaaS*

As the MaaS ecosystem is still evolving, space is created for parties active in sectors affected by MaaS to get involved, such as the health sector. When the MaaS ecosystem aims to incorporate health benefits, the public sector has to become more involved and encourage these collaborations. To establish these partnerships, it is recommended to MaaS facilitators, such as municipalities or city governments, to organise different rounds with workshops or brainstorm sessions with potential partners and parties affected by the wider effects of MaaS. Potential interesting partnerships to incorporate in the MaaS development are health care companies, special needs transport services and services like UberHealth and UberAssist.

Exploring these collaborations with the health sector is also recommended to MaaS operators. MaaS in relation to health is namely interesting business wise because active kilometres are “cheap kilometres” and at the same time lead to better physical and mental health, an interesting development for health insurance companies.

- *Accelerate innovative mobility services with MaaS*

Cities must make a commitment to promote the use of low- or zero emission vehicles, sharing systems (especially bike share) and autonomous vehicles, and incorporate related policies into their planning cycles in order to reduce urban mobility issues and negative effects on health. MaaS can be a way to accelerate these developments and introduce these new services among their users, if implemented and designed well. To facilitate these transitions, city governments are required to build infrastructure in a way that it can be retrofitted with new ownership models and shifting travel behaviours.

- *Design infrastructure that facilitates healthy behaviour*

The role of the built and spatial environment was not included in this study, whilst the impact of surroundings plays an important role in changing travel behaviour towards more active and healthy travel patterns. For example, the desirability of the environment in which people travel impacts distance travelled by foot or by bike. It is recommended to city governments to pay more attention to comfort and convenience of using active modes in terms of quality and desirability of infrastructure and routes, the safety of the transport infrastructure and the distance and time it takes to travel to common destinations by bike or foot, as they play an important role in the daily travel choices. An example of such an interesting opportunity for investment is the *bicycle highway*.

10.3.3 Further research

First, a more general recommendation has to be made regarding the research area, which is also emphasized by van Wee and Ettema (2016): future studies focussing on the area of transport and health have to be aware of the complexity and pay attention to interdependencies and lack of causality between relations to prevent coming to false conclusions, e.g. overestimations. Some recommendations for further research are presented.

- *Evaluate the share of consumers choosing for packages or pay as you go subscriptions*

Research on MaaS packages so far has been limited (e.g. Ratilainen, 2017). It would be interesting to perform a study on consumer preferences for packages or pay-as-you-go subscriptions. Package subscriptions are considered to be demand management tools that can be used to steer behaviour into certain directions, whilst pay-as-you-go subscriptions do not offer this opportunity. It is likely that these options have different effects on travel behaviour among their users and, thus, different impacts on health. A research on this topic could be performed through studying stated preferences among potential MaaS users or by analysing user data from large operational MaaS service, like Whim. However, this data is not publicly available at the moment.

- *Estimate potential for health impacts in rural areas*

Worldwide many different MaaS projects and pilots are planned, implemented, ongoing or completed, but mainly located in urban environments. This focus on urban areas limits the potential for evaluation on how MaaS influences health in more rural areas, especially in terms of accessibility and equity. It is recommended to conduct more pilots and evaluations on how MaaS changes behaviour in these areas.

- *Test the effects on travel behaviour from a healthy MaaS design*

The discussion on healthy package design in this research was limited, but more research on this topic is essential for the development of MaaS as a health enhancing concept. There are many other opportunities to steer behaviour, for example mentioned by KonSULT (2014): through offering new modes other than those for which the traveller has sought information, a mode shift can be prompted. Also the factor of *trialability*, researched by Sochor et al. (2016), is an interesting method to introduce people to new behaviour. Alonso-González (Alonso-González interview, 4th of April 2018) emphasized that trialability is a business tool to encourage people to become engaged with a service. As a starting point it would be interesting to analyse the effects on travel behaviour of the proposed attributes and features (e.g. step count, CO2 quota, special discounts) that aim to nudge users towards healthier behaviour. More knowledge in how the design for health can applied during further development of MaaS.

- *Quantify results from the health assessment*

The study so far has provided qualitative results, whilst the case for health would be stronger when health impacts are be quantified. It is recommended to quantify the health impacts of a mode shift induced by MaaS, especially for physical activity (active minutes), traffic safety (number of traffic related accidents per mode) and environmental stressors (levels of air pollution and noise pollution in dB, PM and NO_2). Accessibility and equity are health impact areas which are more difficult to measure because they are more complex and subject to some subjectivity, but there are indicators that can be used to strengthen the evidence for these areas as well.

Bibliography

Aapaoja, A., Eckhardt, J., Nykanen, L. (2017). Business models for MaaS. Presented at the 1st international Conference on Mobility as a Service (ICOMaaS), Tampere, Finland

Alonso-Gonzalez, M., Nair, J., van Oort, N., Cats, O., & Hoogendoorn, S. (2017). Krijgt MaaS de auto uit de stad? *NM Magazine*. Retrieved from http://www.nm-magazine.nl/artikelen/krijgt-maas-de-auto-uit-de-stad/

Arup. (2016). Cities Alive: Towards a walking world.

Arup. (2018). Mobility-as-a-Service: the value proposition for the public and our urban systems.

Arup, BRE, University College London, & Area Research. (2015). Health + Mobility: a design protocol for rmobilizing healthy living.

Bassett, D., Pucher, J., Buehler, R., & Thompson, D. (2008). Walking, Cycling, and Obesity Rates in Europe, North America, and Australia. *Journal of Physical Activity and Health*, (5), 795–814.

BC Centre for Disease Control. (2017). FACT SHEET: Supporting Health Equity Through the Built Environment. Retrieved from http://www.bccdc.ca/resource-gallery/Documents/Educational%20Materials/EH/BCCDC_equity-fact-sheet_web.pdf

Besser, L. M., & Dannenberg, A. L. (2015). Walking to public transit: steps to help meet physical activity recommendations. *American Journal of Preventive Medicine*, *29*(4), 273–280. https://doi.org/10.1016/j.amepre.2005.06.010

Bingen, L. (2017) Op naar een integraal aanbod van mobiliteitsdiensten: een segmentatie van reizigers ten behoeve van MaaS. https://dspace.library.uu.nl/handle/1874/355792

Boniface, S., Scantlebury, R., Watkins, S., & Mindell, J. (2015). Health implications of transport: Evidence of effects of transport on social interactions. *Journal of Transport & Health*, *2*, 441–446. https://doi.org/10.1016/j.jth.2015.05.005

Borrell, C. (2015). Social inequalities in transport: Going beyond the evidence. *Journal of Transport & Health*, *2*(2), 101–102. https://doi.org/10.1016/j.jth.2014.10.007

Catapult. (2016). Mobility as a Service: exploring the opportunity for mobility as a service in the UK. Retrieved from https://ts.catapult.org.uk/wp-content/uploads/2016/07/Mobility-as-a-Service_Exploring-the-Opportunity-for-MaaS-in-the-UK-Web.pdf

Cavoli, C., Christie, N., Mindell, J., & Titheridge, H. (2014). Linking transport, health and sustainability: Betters data sets for better policy-making. *Journal of Transport & Health*, (2), 111–119.

CBS. (2018). 1000 duizend volwassenen hebben morbide obesitas. Retrieved 22 February 2018 from https://www.cbs.nl/nl-nl/nieuws/2018/27/100-duizend-volwassenen-hebben-morbide-obesitas

CDC. (2014). Facts about Physical Activity. Retrieved 20 March 2018, from https://www.cdc.gov/physicalactivity/data/facts.htm

Charlier, P., Coppens, Y., Malaurie, J., & et al. (2017). A new definition of health? An open letter of autochthonous peoples and medical anthropologists to the WHO. *European Journal of Internal Medicine*, *37*, 33–37. https://doi.org/10.1016/j.ejim.2016.06.027

Clewlow, R., & Mishra, G. (2017). Disruptive Transportation: The Adoption, Utilization, and Impacts of Ride-Hailing in the United States. Retrieved from http://usa.streetsblog.org/wp-content/uploads/sites/5/2017/10/2017_UCD-ITS-RR-17-07.pdf

Cohen, J., Boniface, S., & Watkins, S. (2014). Health implications of transport planning, development and operations. *Journal of Transport & Health*, *1*, 63–72. https://doi.org/10.1016/j.jth.2013.12.004

Dannenberg, A., & Sener, I. (2015). Why Public Health and Transportation.

de Cani, R. (2018, May). *The Future of Mobility [PowerPoint slides]*. Retrieved from https://europe.uli.org/wp-content/uploads/sites/127/ULI-Documents/Richard-de-Cani.pdf

de Hartog, J., Boogaard, H., Nijland, H., & Hoek, G. (2010). Do The Health Benefits Of Cycling Outweigh The Risks? *Environmental Health Perspectives*, *118*(8), 1109–1116. https://doi.org/10.1289/ehp.0901747

de Nazelle, A., Nieuwenhuijsen, M., Anto, J., & et al. (2011). Improving Health Through Policies That Promote Active Travel: A review of evidence to support integrated health impact assessment. *Environment International*, *37*(4), 766–777. https://doi.org/10.1016/j.envint.2011.02.003

Decisio. (2017). Schetsmatige Business Case en Value Case MaaS. Retrieved from http://decisio.nl/wp-content/uploads/Eindrapport-MaaS.pdf

Deloitte. (2017). Deloitte Review: The rise of mobility as a service. *Deloitte Review*, *20*, 111–130.

Di Ciommo, F., & Shiftan, Y. (2017). Transport Equity Analysis. *Transport Reviews*, *37*(2), 139–151. https://doi.org/10.1080/01441647.2017.1278647

Eisenmann, C. (2018, April). *Is active travel a stable physical activity behavior? Evidence from the German Mobility Panel [Presentation slides]*. Presented at the Nederlands Mobiliteit Panel, Den Haag.

Elkington, J. (1994). Towards the Sustainable Corporation: Win-Win-Win Business Strategies for Sustainable Development. *California Management Review*, *36*(2), 90–100. https://doi.org/10.2307/41165746

EPA. (n.d.). Health and Environmental Effects of Particulate Matter (PM): Health Effects. Retrieved 19 February 2018, from https://www.epa.gov/pm-pollution/health-and-environmental-effects-particulate-matter-pm

EPA. (2017). Sources of Greenhouse Gas Emissions, Transportation Sector Emissions. Retrieved 18 January 2018, from https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

Ettema, D., & Smajic, I. (2014). Walking, places and wellbeing. *The Geographical Journal*, *181*(2), 102–109. https://doi.org/10.1111/geoj.12065

European Commission. (2017). Horizon 2020 - Work Programme 2016 - 2017 Smart, green and integrated transport [Work Programme 2016 - 2017]. Retrieved from http://ec.europa.eu/research/participants/data/ref/h2020/wp/2016_2017/main/h2020-wp1617-transport_en.pdf

Gemeente Amsterdam. (2016a). Amsterdamse Thermometer van de Bereikbaarheid 2016. Retrieved from https://www.amsterdam.nl/parkeren-verkeer/bereikbaar/thermometer/

Gemeente Amsterdam. (2016b). Smart Mobility Actieprogramma 2016 - 2018. Retrieved from https://drive.google.com/file/d/0Bz0U6OArm0dIeFMwSVRBUTdtOEE/view

Gerike, R., de Nazelle, A., Nieuwenhuijsen, M., & et al. (2016). Physical Activity through Sustainable Transport Approaches (PASTA): a study protocol for a multicentre project. *British Medical Journal*, *6*. https://doi.org/doi:10.1136/ bmjopen-2015-009924

GGD Amsterdam. (2017). Veel gestelde vragen over verontreiniging van de buitenlucht.

Goodacre, S., Collins, C., & Slattery, C. (2013). *Cambridge VCE Health and Human Development Units 3 and 4 Pack* (Second edition). Melbourne: Cambridge University Press.

Gould, E., Wehrmeyer, M., & Leach, M. (2015). Transition pathways of e-mobility services. *WIT Transactions on Ecology and the Environment*, (194), 349–359. https://doi.org/doi:10.2495/SC150311

Halonen, J., Hansell, A., Gulliver, J., & et al. (2015). Road traffic noise is associated with increased cardiovascular morbidity and mortality and all-cause mortality in London. *European Heart Journal*, *36*(39), 2653–2661. https://doi.org/10.1093/eurheartj/ehv216

Hamari, J., Sjoklint, M., & Ukkonen, A. (2015). The Sharing Economy: Why People Participate in Collaborative Consumption. *Journal of the Association for Information Science and Technology*, *67*(9), 2047–2059. https://doi.org/10.1002/asi.23552

Haverkamp, S., & Bakker, N. (2018). Bij MaaS gaat het om de markt en om de spelregels. *Verkeerskunde*, *2*(69), 30.

Hietanen, S. (2017). *Mobility as a Service - The End of Car Ownership? [PowerPoint presentation]*. Retrieved from https://bit.ly/2KVOgdp

High Speed Two (HS2) Limited. (2013). High Speed Rail (London - West Midlands): Health Impact Assessment. Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/378711/Health_impact_assessment.pdf

Holmberg, P., Collado, M., Sarasini, S., & Williander, M. (2016). *Mobility as a service - MaaS: Describing the framework*. Gothenburg: Viktoria Swedish ICT. Retrieved from https://www.viktoria.se/sites/default/files/pub/www.viktoria.se/upload/publications/final_report_maas_framework_v_1_0.pdf

Huber, M., Knottnerus, A., Green, L., & et al. (2011). How should we define health? *British Medical Journal*, *343*(4163), 235–237. https://doi.org/10.1136/bmj.d4163

Jittrapirom, P., Caiati, V., Feneri, A.-M., Ebrahimigharehbaghi, S., Alonso-Gonzalez, M., & Narayan, J. (2017). Mobility as a Service: A Critical Review of Definitions, Assessments of Schemes, and Key Challenges. *Urban Planning*, *2*(2), 13–25. http://dx.doi.org/10.17645/up.v2i2.931

Joffe, M., & Mindell, J. (2002). A framework for the evidence base to support Health Impact Assessment. *Journal of Epidemiology Community Health*, *56*, 132–138.

Jongeneel, W., Staatsen, B., van Kempen, E., & Fischer, P. (2008). RIVM: Gezondheidseffecten van wegverkeer: een quickscan. Retrieved from https://www.rivm.nl/bibliotheek/rapporten/630800001.pdf

Kamargianni, M., Li, W., Matyas, M., & Schafer, M. (2016). A crititcal review of new mobility services for urban transport. *Transportation Research Procedia*, *14*, 3294–3303. https://doi.org/10.1016/j.trpro.2016.05.277

Kamargianni, M., & Matyas, M. (2017). The Business Ecosystem of Mobility-as-a-Service. In *96th Transportation Research Board (TRB) Annual Meeting*. Washington DC. Retrieved from https://docs.wixstatic.com/ugd/631dd3_ed47f87853cc44639ea99b7f7631598c.pdf

Kamargianni, M., Matyas, M., Li, W., & Muscat, J. (2018). Londoners’ attitudes towards car-ownership and Mobility-as-a-Service: Impact assessment and opportunities that lie ahead. University College London. Retrieved from https://www.ucl.ac.uk/consultants/images/casestudies/maas

Karlsson, M., Sochor, J., Aapaoja, A., Eckhardt, J., & Konig, D. (2017). MAASiFiE: Deliverable 4: Impact Assessment. MAASiFiE project funded by CEDR. Retrieved from http://publications.lib.chalmers.se/records/fulltext/248829/local_248829.pdf

Karlsson, M., Sochor, J., & Stromberg, H. (2016). Developing the ‘Service’ in Mobility as a Service: experiences from a field trial of an innovative travel brokerage. *Transportation Research Procedia*, *14*, 3265–3273. https://doi.org/10.1016/j.trpro.2016.05.273

Kavanagh, P., Doyle, C., & Metcalfe, O. (2005). Health Impacts of Transport: a review. Institute of Public Health in Ireland. Retrieved from https://www.publichealth.ie/files/file/IPH_Transport_text_44pp.pdf

Khreis, H., May, A. D., & Nieuwenhuijsen, M. J. (2017). Health impacts of urban transport policy measures: A guidance note for practice. *Journal of Transport & Health*, *6*, 209–227. https://doi.org/10.1016/j.jth.2017.06.003

Konig, D., Eckhardt, J., Aapaoja, A., Sochor, J., & Karlsson, M. (2016). MaaSiFiE: Deliverable 3 Business and operator models for MaaS. MAASiFiE project funded by CEDR. Retrieved from https://www.vtt.fi/sites/maasifie/PublishingImages/results/cedr_mobility_MAASiFiE_deliverable_3_revised_final.pdf

KonSULT. (2014). The Knowledgebase on Sustainable Urban Land use and Transport. Retrieved 15 June 2018, from http://www.konsult.leeds.ac.uk/

Lancee, S., Verhoeven, R., & Burger, M. (2017). Mood during commute in the Netherlands. *Transport Research Part A: Policy and Practice*, *104*, 195–2018. https://doi.org/10.1016/j.tra.2017.04.025

Lee, H., & Turney, K. (2012). Investigating the Relationship between Perceived Discrimination, Social Status and Mental Health. *Society and Mental Health*, *2*(1), 1–20. https://doi.org/10.1177/2156869311433067

Li, Y., & Voege, T. (2017). Mobility as a Service (MaaS): Challenges of implementation and Policy Required. *Journal of Transportation Technologies*, *7*, 95–106. http://file.scirp.org/Html/1-3500349_74675.htm

Litman, T., & Fitzroy, S. (2018). Evaluating Transportation Demand Management Traffic Safety Impacts. Retrieved from http://www.vtpi.org/safetrav.pdf

LSE Cities. (2013). Going Green: How cities are leading the next economy. LSE Cities. Retrieved from https://lsecities.net/files/2012/09/goinggreen.pdf

Lucas, K., Mattioli, G., Verlinghieri, E., & Guzman, A. (2016). Transport poverty and its adverse social consequences. *Proceedings of the Institution of Civil Engineers - Transport*, *169*(6), 353–365. https://doi.org/10.1680/jtran.15.00073

Lucas, K., van Wee, B., & Maat, K. (2016). A method to evaluate equitable accessibility: combining ethical theories and accessibility-based approaches. *Transportation*, *43*(473), 473–490. https://doi.org/10.1007/s11116-015-9585-2

Lund, E. (n.d.). Mobility-as-a-Service - What is it, and which problems could it solve? Retrieved from https://en.trivector.se/fileadmin/user_upload/Traffic/Whitepapers/Mobility_as_a_Service.pdf

MaaS Scotland. (2018). Mobility as a Service; Positioning Scotland for an Emerging Global Market. Retrieved from https://maas-alliance.eu/wp-content/uploads/sites/7/2018/02/MaaS-Positioning-Scotland-for-an-Emerging-Global-Market_PUBLIC.pdf

Mackett, R. (2014). The health implications of inequalities in travel. *Journal of Transport & Health*, *1*(3), 202–209. https://doi.org/10.1016/j.jth.2014.07.002

Mackett, R., & Brown, B. (2011). Transport, Physical Activity and Health: Present knowledge and the way ahead. University College London. Retrieved from http://discovery.ucl.ac.uk/1333502/

Mackett, R., & Thoreau, R. (2015). Transport, social exclusion and health. *Journal of Transport & Health*, *2*(4), 610–617. https://doi.org/10.1016/j.jth.2015.07.006

Martens, K. (2013). The role of the bicycle in limiting transport poverty in the Netherlands. In *Transportation Research Record Journal of Transportation Research Board*. https://doi.org/DOI: 10.3141/2387-03

Martin, E., & Shaheen, S. (2016). Impacts of Car2Go on vehicle ownership, modal shift, vehicle miles travelled, and greenhouse gas emissions: an analysis of five North American cities [Working paper]. Retrieved from http://innovativemobility.org/wp-content/uploads/2016/07/Impactsofcar2go_FiveCities_2016.pdf

Matyas, M., & Kamargianni, M. (2016). Stated Preference Design for Exploring Demand for 'Mobility as a Service' Plans. Cape Town, South Africa.

Meuleman, A. (2016). Shared Mobility Should be a Part of Every SUMP. Retrieved 21 June 2018, from https://share-north.eu/2016/05/shared-mobility-should-be-a-part-of-every-sump/

Mindell, J. (2015). Setting up the Journal of Transport and Health, a New Cross-Disciplinary Journal. *Publications*, *3*, 120–130.

Mindell, J. (2017). Road Travel Casualties. *Journal of Transport & Health*, *6*, 7–9. https://doi.org/10.1016/j.jth.2017.08.004

Ministerie van Infrastructuur en Milieu. (2017). Marktconsultatie Mobility as a Service (MaaS) in Nederland. Retrieved from http://www.verkeerskunde.nl/Uploads/2017/11/Marktconsultatie-MaaS.pdf

Ministry of Infrastructure and Water Management. (2018, November). *MaaS pilot Amsterdam*. Retrieved from https://dutchmobilityinnovations.com/spaces/1105/maas-regional-pilots/MaaSlanding

Mink, E. (2018). IenW wil een vinger aan de pols houden. *Verkeerskunde*, *2*(69), 30.

Morrison, C. N., Jacoby, S. F., Dong, B., & et al. (2018). Ridesharing and Motor Vehicle Crashed in 4 U.S. Cities: An Interrupted Time-Series Analysis. *American Journal of Epidemiology*, *187*(2), 224–232. https://doi.org/10.1093/aje/kwx233

Moving Forward Consulting. (2016). Healthy, Safe and Ecological Road Transport, Mobility and Energy use for better Sustainability in Finland with ITS-Intelligent Transportation Systems. Retrieved from http://www.moving-forward-consulting.com/wp-content/uploads/2016/06/20160411-HERMES-Study-for-MINTC-final.pdf

MuConsult. (2017). Mobility as a Service: Bouwstenen voor keuzen I&M [White paper].

NRC. (2018). Hoe Uber San Francisco nog drukker maakt. Retrieved 5 March 2018, from https://www.nrc.nl/nieuws/2018/02/10/hoe-uber-san-francisco-nog-drukker-maakt-a1591745

Otero, I., Nieuwenhuijsen, M. J., & Rojas-Rueda, D. (2018). Health impacts of bike sharing systems in Europe. *Environment International*, *115*, 387–394. https://doi.org/10.1016/j.envint.2018.04.014

Pankratz, D. M., Willigmann, P., Kovar, S., & Sanders, J. (2017). Framing the Future of MObility: Using Behavioural Economics to Accelerate Consumer Adoption. *Deloitte Review*, *20*, 93–111.

Park, J. (2017). What will autonomous vehicles mean for sustainability? Retrieved 28 July 2018, from https://thefuturescentre.org/articles/11010/what-will-autonomous-vehicles-mean-sustainability

PHSA Population and Public Health team, & Healthy Built Environment Alliance. (2018). Healthy built environment linkages toolkit: making the links between design, planning & health. Retrieved from http://www.bccdc.ca/pop-public-health/Documents/HBE_linkages_toolkit_2018.pdf

Public Health Ontario. (2017). Living near major traffic linked to higher risk of dementia. Retrieved 18 January 2018, from https://www.sciencedaily.com/releases/2017/01/170104192302.htm

Ratilainen, H. (2017). *Mobility-as-a-Service: Exploring Consumer Preferences for MaaS Subscription Packages Using a Stated Choice Experiment*.

Richardson, B. C. (2005). Sustainable transport: analysis frameworks. *Journal of Transport Geography*, *13*(1), 29–39. https://doi.org/10.1016/j.jtrangeo.2004.11.005

RIVM. (n.d.). Hoe schoon is onze lucht? Retrieved 6 March 2018, from https://www.rivm.nl/media/milieu-en-leefomgeving/hoeschoonisonzelucht/

RIVM. (2014). A healthier Netherlands. Retrieved 18 January 2018, from https://www.rivm.nl/en/Documents_and_publications/Common_and_Present/Newsmessages/2014/RIVM_forecasting_study_a_healthier_Netherlands_with_more_people_living_with_a_chronic_disease

RIVM. (2017a). Hoeveel mensen voldoen aan de door de Gezondheidsraad geadviseerde Beweegrichtlijnen 2017? Retrieved from https://www.volksgezondheidenzorg.info/sites/default/files/hoeveel_mensen_voldoen_aan_gr_beweegrichtlijnen_2017.pdf

RIVM. (2017b). Ruim de helft van Nederlanders voldoet aan Beweegrichtlijn. Retrieved 22 June 2018, from https://www.volksgezondheidenzorg.info/onderwerp/sport-en-bewegen

Rojas-Rueda, D., de Nazelle, A., Andersen, A., & et al. (2016). Health impacts of active transportation in Europe. *PLoS ONE*, *11*(3). https://doi.org/10.1371/journal.pone.0149990

Rojas-Rueda, D., de Nazelle, A., Teixido, O., & Nieuwenhuijsen, M. (2013). Health impact assessment of increasing public transport and cycling use in Barcelona: A morbidity and burden of disease approach. *Preventive Medicine*, *57*(5), 573–579. https://doi.org/10.1016/j.ypmed.2013.07.021

Saidla, K. (2017). Health promotion by stealth: active transportation success in Helsinki, Finland. *Health Promotion International*. https://doi.org/doi: 10.1093/heapro/daw110

Sarasini, S., Sochor, J., & Arby, H. (2017). What characterises a sustainable MaaS business model? Presented at the 1st international Conference on Mobility as a Service (ICOMaaS), Tampere, Finland.

Schepers, P., Hagenzieker, M., Methorst, R., & et al. (2014). A conceptual framework for road safety and mobility applied to cycling safety. *Accident Analysis & Prevention*, *62*, 331–340. https://doi.org/10.1016/j.aap.2013.03.032

Smile mobility. (2015). Pilot operation. Retrieved 22 February 2018, from http://smile-einfachmobil.at/pilotbetrieb_en.html

Smith, G., Sochor, J., Karlsson, M., & (in press). (2018). Mobility as a Service: Development scenarios and implications for public transport. *Research in Transportation Economics*, *xxx*(xxx), xxx. https://doi.org/10.1016/j.retrec.2018.04.001

Sochor, J., & Sarasini, S. (2017, November). *Users' motives to adopt Mobility as a Service [PowerPoint presentation]*. Presented at the ICoMaaS. Retrieved from http://www.tut.fi/verne/aineisto/S4_Sochor.pdf

Sochor, J., Stromberg, H., & Karlsson, M. (2014). Travellers' Motives for Adopting a New, Innovative Travel Service: Insights from the UbiGo Fiedl Operational Test in Gothenburg, Sweden. Presented at the 21st World Congress on Intelligent Transportation Systems, Detroit, USA.

Sochor, J., Stromberg, H., & Karlsson, M. (2015). Challenges in integrating user, commercial, and societal perspectives in an innovative mobility service. Presented at the 94th Annual Meeting of the Transportation Research Board, Washington DC, USA.

Transport Systems Catapult. (2015). *Traveller Needs & UK Capability Study*. London. Retrieved from https://www.bvrla.co.uk/sites/default/files/documents/jamie_chan-pensley_traveller_needs_uk_capability_study.pdf

U.S. Department of Transportation. (2015). Transportation and Health Tool. Retrieved 23 January 2018, from https://www.transportation.gov/mission/health/literature-and-resources

van Acker, V., Van Wee, B., & Witlox, F. (2010). When Transport Geography Meets Social Psychology: Toward a Conceptual Model of Travel Behaviour. *Transport Reviews*, *30*(2), 219–240. https://doi.org/10.1080/01441640902943453

van de Ven, H. (2018). ANWB-leden over MaaS. *Verkeerskunde*, *2*(69), 31.

van Oort, N., van der Bijl, R., & Verhoof, F. (2017). The wider benefits of high quality public transport for cities. Presented at the European Transport Conference in Barcelona. Retrieved from https://nielsvanoort.weblog.tudelft.nl/files/2017/09/Van-Oort-et-al-Wider-benefits-of-PT-5E-framework-ETC-proceedings2017.pdf van Oort, N., & Veeneman, W. (2017). Thredbo: Bevordert MaaS autogebruik? *OV Magazine*. Retrieved from https://nielsvanoort.weblog.tudelft.nl/files/2017/10/OV-Magazine-15-sept-2017-Threadbo-congres-Stockholm.pdf

van Wee, B. (2009). Self-selection: a key to better understanding of location choices, travel behavior, and transport externalities? *Transport Reviews*, *29*(3), 279–292. https://doi.org/10.1080/01441640902752961

van Wee, B., Annema, J. A., & Banister, D. (2013). *The Transport System and Transport Policy: an introduction*. Cheltenham, UK: Edward Elgar Publishing Limited.

Vella-Broderick, D., & Stanley, J. (2013). The significance of transport mobility in predicting well-being. *Transport Policy*, *29*, 236–242. https://doi.org/10.1016/j.tranpol.2013.06.005

Weiss, M., Dekker, P., Moro, A., Scholz, H., & Patel, M. (2015). On the electrification of road transportation - A review of the environmental, economic, and social performance of electric two-wheelers. *Transportation Research Part D*, *41*, 349–366. https://doi.org/10.1016/j.trd.2015.09.007

WHIASU. (2011). Health Impact Assessment: A practical guide.

WHO. (n.d.a). Chronic respiratory diseases. Retrieved 15 March 2018, from http://www.who.int/respiratory/en/

WHO. (n.d.b). Equity. Retrieved 22 June 2018, from http://www.who.int/healthsystems/topics/equity/en/

WHO. (n.d.c). Obesity: data and statics. Retrieved 22 June 2018 from http://www.euro.who.int/en/health-topics/noncommunicable-diseases/obesity/data-and-statistics

WHO. (2014a). Basic Documents: Forty-eight edition. Retrieved from http://apps.who.int/gb/bd/PDF/bd48/basic-documents-48th-edition-en.pdf#page=1

WHO. (2014b). Mental health: a state of well-being. Retrieved 10 July 2018, from http://www.who.int/features/factfiles/mental_health/en/

WHO. (2017a). Physical activity. Retrieved 25 January 2018, from http://www.who.int/mediacentre/factsheets/fs385/en/

WHO. (2017b, April). Mental disorders. Retrieved 15 March 2018, from http://www.who.int/mediacentre/factsheets/fs396/en/

WHO. (2017c, May). Cardiovascular Diseases (CVDs). Retrieved 15 March 2018, from http://www.who.int/mediacentre/factsheets/fs317/en/

WHO. (2018). Priority risks and future trends. Retrieved 24 January 2018, from http://www.who.int/heli/risks/ehindevcoun/en/

Appendices

A. Interview questions

Experts from the both the fields of health and transportation/mobility are interviewed for this research. A first literature study resulted in a list of relevant topics for the interviews. For each topic a list with example questions is made. From this list certain questions are selected for the interviews, dependent on the expert and his/her expertise.

INTERVIEWEE	DATE	EXPERTISE
Leendert van Bree	20th of February, 2018	Dr. Leendert van Bree has worked for the RIVM (National Institute of Public Health and the Environment), PBL (Netherlands Environmental Assessment Agency) and the University of Utrecht in the department of Human Geography and Planning and Social Urban Transitions. Currently Leendert is the owner of the consultancy firm LvB Business Development, focussing on healthy, social, inclusive, and careful cities of the future.
Dick Ettema	21st of February, 2018	Dick Ettema is an associate professor in the department of Human Geography and Spatial Planning at the University of Utrecht. Together with Bert van Wee he worked on an article *Travel behaviour and health: A conceptual model and research agenda* (2016). This article proposes a conceptual model of the complex relationships between travel behaviour and health, which makes it very interesting for this study. Below is the summary of the interview with Dick Ettema in Dutch.
Ellen Peeters	28th of February, 2018	Ellen Peeters werkt als senior adviseur voor de gezonde leefomgeving. Haar achtergrond is milieu gezondheidskunde. Ze werkt voor de gemeente Utrecht als gezondheidsadviseur bij het maken van ruimtelijke plannen en stadsontwerpen en geeft advies aan zowel stedenbouwers als mobiliteit adviseurs.
Hanneke Kruize	28th of February, 2018	Hanneke Kruize is werkzaam voor het RIVM binnen het thema ‘de gezonde leefomgeving’, en is bezig met onderzoeken naar de gezonde leefomgeving en gedrag, actief transport en gezonde mobiliteit. Ze is gepromoveerd op verschillen tussen sociale groepen.
Susana Saiz	1st of March, 2018	Susana Saiz is a consultant within the energy and sustainability team of Arup, working in Madrid. She is also working on the health related projects in the built environment, like WELL and for example on research about how the built environment impacts human health
Maria Montero	16th of March, 2018	Maria Montero is a strategic sustainability planner in Arup. She has a special expertise in strategy sustainability analyses and planning, stakeholder management and environmental and social risk management.
Anne Durand	20th of March, 2018	Anne Durand is working at KIM since 2017. She is working on a project about MaaS and the impact on the preferences and the travel behaviour of travellers in the Netherlands. The goal of this study is to understand MaaS in relation to travellers.
Henk Meurs	27th of March 2018	Henk Meurs is CEO and founder of MuConsult and professor in mobility and spatial development at the Radboud Universty in Nijmegen.
Sampo Hietanen	3rd of April 2018	Sampo Hietanen is the founder of MaaS and CEO of MaaS Global.
Maria Alonso Gonzalez	4th of April 2018	Maria Alonso Gonzalez is a PhD researcher in the Smart Public Transport Lab of the TU Delft. Her PhD project involves the forecast and evaluation of new mobility services and in particular (sub)urban Demand Responsive

		Transport (DRT). Her research interest also include Mobility-as-a-Service as full integration of the existing mobility services.
Maria Kamargianni	13th of April 2018	Maria Kamargianni is the head of MaaSLab and an expert in the MaaS concept. Her work has focussed on MaaS product design and pricing, demand and supply analysis, and business models. She is also a lecturer in Transport & Energy at UCL Energy Institute in London.
Ryan Falconer	24th of April 2018	Ryan Falconer is the cities leader in Western Australia and he leads the Transportation Consulting business in Canada. His work deals with transport strategy for governments and private clients and transport in urban environments. He is one of the authors of the 'Mobility-as-a-Service; The value proposition for the public and our urban systems for Arup in March 2018.

A1 – Health in general

- What is your definition of health?
- There are two definitions which are commonly used (WHO and Huber), how do these definitions influence the way we consider health within research?
- How do you consider the difference between individual and societal health?
- What do you consider the main challenges for health in future cities?

A2 - Health and transport

- Is there an influence between health and transportation/mobility?
- How large is the role of transport/mobility within health of a population?
- Via which relationships does urban mobility influence health?
- Can transport be used to influence social health?
- Which new transportation innovations can change travel behaviour and influence urban health? *(for example initiatives like car/bike sharing, automated vehicles, ride-hailing applications, etc.)*
- Can people be motivated to make more healthy, socially responsible choices? In what ways?
- What changes in travel behaviour can have the highest impact on health?
- How would you measure the health impact of new mobility concepts?

A3 – MaaS: the concept

- What is your definition of MaaS?
- Which modes are included in a MaaS scheme?
- What do you consider the core characteristics of MaaS?

A4 - MaaS and travel behaviour

- What are the main ways in which MaaS will change travel behaviour?
- Will MaaS stimulate people to make more multimodal trips?
- Will MaaS become an alternative or a complement to public transport?
- Will MaaS stimulate people to make more considerate travel choices, for example because of environmental or health reasons?

- Are “last-mile” connectivity options (taxi, ride-hailing, car sharing) adding to vehicle use and / or reducing active travel, therefore creating additional challenges?
- What will be the influence of ride hailing/ride sourcing on travel behaviour?
- Are some private-sector provided services (car sharing, ride-hailing, etc.) replacing trips that would otherwise have been made by conventional public transport?
- MaaS is often positioned as a system to solve some of the existing and future mobility challenges within cities, what do you consider the main mobility related challenges for cities? (e.g. congestion, noise pollution, etc.) and how can MaaS address these?
- Within Dutch cities the share of active modes is already relatively high, can MaaS still increase these percentages?
- What are potential negative effects of MaaS on travel behaviour?
- Are the first results from the pilots Smile and UbiGo representative for Dutch cities?
- How will the introduction of electric/autonomous vehicles influence MaaS and travel behaviour?

A5 - MaaS in relation to health

- Can MaaS influence health in urban environments? How?
- What MaaS features can influence health?
- How can MaaS be used to strengthen social inclusion and cohesion in cities?
- Do you think MaaS can contribute to creating healthier cities in terms of:
    - Accessibility
    - Air quality
    - Noise pollution
    - Traffic safety
    - Physical activity
    - Social equity
    - Or any other relations to health you can think of?
    - How?
- How can MaaS be used to help users make more considerate decisions?
- Do you think it would be possible so stimulate travellers to become more healthy with MaaS? For example through providing packages with ‘healthy/active’ modes?
- How can MaaS be used to influence health?

B. Effects of transport areas on health

The table below shows how transport areas relate to the health dimensions and health outcomes presented in the research.

Table -1: Transport areas and their influence on health

Link	Dimension	Relationship	Reference
Physical activity	Physical health	Active mobility increases physical activity and therefore improves physical health of individuals. People who are physically active tend to live longer and have a lower risk for cardiovascular diseases, diabetes and some types of cancer. Physical inactivity is also one of the leading causes of obesity.	CDC, 2014., Mackett, 2011., Kwasniewska et al., 2010, Basset at al., 2008, Chida, 2008, Saelens et al., 2003, Hou et al. 2004.,
	Mental health	Physical activity, which can be provided in the form of active mobility, has a positive effect on mental health. It can reduce the risk of stress, anxiety, depression and possibly delays Alzheimer's disease and other forms of dementia.	Arup, 2016., CDC, 2014., Nort et al., 1990., WHO, n.d.,
	Social health	Active mobility is thought to stimulate social cohesion and social interaction between people interacting on the streets during their active commute. Walking for example increases social cohesion.	Te Brommelstroet et al., 2017., Boniface et al., 2015. PASTA, 2016.,
Traffic safety	Physical health	Traffic crashes, and the injuries and deaths caused by them, occur frequently and therefore road traffic is a leading cause of morbidity and mortality around the world, affecting physical health.	WHO, 2015., Dannenberg and Sener., 2015
	Mental health	The amount of walking and cycling is related to safety perceptions. Traffic unsafety related to certain modes of transport can create negative traffic perceptions which can deter people from using certain modes, especially cycling and walking.	Mindell, 2017., Cohen, 2014., Jacobsen et al., 2009., Jacobsen, 2003.
Environmental stressors	Physical health	Exposure to air pollution can lead to premature death, lung diseases, cardiovascular diseases, eye and throat irritation, and even to cancer, amongst others. Noise pollution caused by traffic can lead to hearing loss and decreased performance.	Arup, 2016., Van Wee., Ettema., 2016., Halonen et al., 2015., Mackett, 2015., Cohen, 2014., Jongeneel et al., 2008., EPA., n.d.,
	Mental health	Noise pollution can lead to sleep deprivation and disturbance, annoyance, lower sleep quality, which in turn might lead to other mental health issues. New research has also	GGD Amsterdam, 2017., Arup, 2016., Dannenberg and Sener, 2015., Cohen,

		shown that air pollution can cause neurological diseases, like autism.	2014., Jongeneel et al., 2008.
Accessibility	Physical health	Transport provides access to places that support physical health, for example healthy food, medical care, family, friends, and green spaces to allow for physical activity.	Mackett, 2014
	Mental health	Access to green spaces, health care and social services can improve mental health and quality of life.	WHO, 2017., de Nazelle et al., 2011.
	Social health	Access to destination is very important from a social health perspective because it allows individuals to participate in society. If transport options are not sufficient, this might lead to social exclusion, social inequity and limited social capital.	Van Oort, 2017., Boniface et al., 2015., Mackett, 2015., Sen, 2000
Equity	Mental health	Transport can enhance the health and quality of life of vulnerable populations, including the young, elderly, disabled and low income, by providing affordable, accessible transport to opportunities, essential goods and services. Perceptions of inequality, for example in access to goods and services, can cause stress-related illnesses.	Lee and Turney, 2012.,
	Social health	Availability of transport can contribute to socially inclusive cities by attributing to a safe and healthy society with equal opportunities for all inhabitants. Transport should provide a variety of affordable and accessible modes to benefit all socio-economic groups within a city.	Van Oort, 2017., Borrell, 2015., Cohen et al., 2014

C. Stakeholder identification and stakeholders

As public and private parties are still investigating their role within the development of MaaS and within the MaaS ecosystem, numerous strategies and roadmaps for MaaS are presented throughout literature and research (Smith, 2018), including research by Arup (2018), MuConsult (2017), Kamargianni and Matyas (2017), Catapult (2016) and Holmberg et al. (2016). These roadmaps are used to identify the main stakeholders that are interested in the development of the MaaS ecosystem. Table -2 below contains the list of stakeholders important in the core of the MaaS ecosystem and some parties potentially interested in MaaS from the health-care sector.

Table -2: List of relevant stakeholders

CATEGORY	STAKEHOLDER

Governments	• National government
	  ○ Ministries:
	    • Ministry of Infrastructure and Water Management
	    • Ministry of Health, Welfare and Sport
	• Local authorities
	    • Regional authorities
	    • City authorities
	    • Municipalities

MaaS operators	• Private firm or public party
Transport operators	• Public transport services • Private transport services
Data providers	• e.g. NDOV
Transport knowledge institutions	• e.g. MaaS Lab & Smart lab (TU Delft) • KiM
Health knowledge institutions	• RIVM - National Institute for Public Health and the Environment • International: World Health Organization (WHO)
Health insurance companies	• e.g. Achmea, VGZ, Menzis
Customers	• Individuals and/or companies
Local communities	• Urban communities externally affected by transport

For these stakeholders the objectives, problem perceptions, ability and instruments are researched within the MaaS ecosystem with regard to health.

Table -3: Description of the category governments

GOVERNMENTS	NATIONAL GOVERNMENTS, MINISTRIES
Description	Cooperation between legislative bodies in the Netherlands.
Objectives	Aim is to strengthen the relationship with the MaaS industry to establish itself as a global home for MaaS, benefiting from the positive economic, social and environmental impacts this can potentially create (MaaS Scotland, 2018). • *Ministry of Infrastructure and Water Management:* aims to achieve a liveable, connected and safe environment in the Netherlands and support the transport network through exploring new infrastructure and mobility concepts.

	• *Ministry of Health, Welfare and Sport:* main aim is to keep everyone healthy as long as possible and to restore the sick to health as quickly as possible. Encourages people to adopt healthy lifestyles. There is potential for MaaS to contribute in the areas of (MaaS Scotland, 2018): - Sustainability and transport efficiency - Inclusivity and community building - Environment and health
Problem perception	MaaS can be an opportunity to achieve policy goals regarding mobility (Mink, 2018), but also regarding economic, social and environmental impacts (Holmberg et al., 2016). To achieve these goals, it is important that the public sector objectives are aligned with the business models of the MaaS operators and transport providers, and with the services from the health sector.
Ability	Legislative and policy-defining Ability which is important as they can define the shape of MaaS within the Netherlands and how the service meets the needs of the society.
Instruments	Legislation, regulation, policy creation, state budget allocation, subsidy, facilitation of MaaS in pilots.

Table -4: Description of category small governments

LOCAL AUTHORITIES	**REGIONAL AUTHORITIES, CITY AUTHORITIES AND MUNICIPALITIES**
Description	Regional authorities, city authorities and municipalities within the Netherlands.
Objectives	Ensuring that MaaS can exist over time and becomes sustainable from an economical, a social and an environmental perspective (Holmberg et al., 2016). More specifically, cities, municipalities, etc., aim to improve liveability in urban environments. Focus is on improving transport efficiency, delivering environmental benefits and impacting factors like connectivity, safety, accessibility, social equity, amongst others.
Problem perception	MaaS provides an opportunity to contribute to some of these objectives regarding urban mobility, liveability and the quality of urban environments, for example by lessening congestion and reducing other negative externalities (Holmberg et al., 2016). There is also potential to worsen them, dependent on the design and aim of the service. City authorities should try to innovate around the MaaS concept to deliver local policy benefits and shape MaaS within the needs of their cities (de Cani, 2018).
Ability	Local governments are empowered to create regional/local policies, strategies and measures regarding the shape of MaaS. They can create the regulatory environment and constraints under which service operators are required to operate (Arup, 2018).
Instruments	Policy creation, regulation, regional budget allocation, subsidies, facilitation of MaaS.

Table -5: Description of the category MaaS operator

MAAS OPERATOR	
Description	The MaaS operators designs and offers a mobility service that creates added value to its users without owning a car. It provides a flexible and seamless door-to-door mobility experience via one single application, that gives access to a wide variety of transport services via one single payment channel, instead of multiple ticketing and payment operations (MaaS Alliance). The core innovation is to aggregate transport operators and mobility services in one digital platform (Catapult, 2016).
Objectives	Aim is to aggregate transport operator services (Catapult, 2016) and maximise the number of subscribers to the service (Holmberg et al., 2016) to create a service that is profitable in generating revenue and market share through innovation & differentiation (Arup, 2018).
Problem perception	The design of the service can incentivise healthy travel behaviour, or not. When the business of the MaaS operator and healthy behaviour can be combined in such a way that it creates interest business wise, there is potential for a collaboration. If MaaS incentivises healthy behaviour and at the same time benefit the MaaS operator in terms of profitability and revenue, there is a potential for the MaaS operator to support and steer users towards healthy travel behaviour.

Ability	The MaaS operator has the ability to partner up with the transport operators and design the service, packages and interface to stimulate healthy travel behaviour and use of healthy modes.
Instruments	Service design and partnerships with transport operators.

Table -6: Description of the category public transport operators

TRANSPORT OPERATORS	**PUBLIC TRANSPORT OPERATORS**
Description	The (public and private) organisations that provide capacity and access to the mobility assets within MaaS. They sell their capacity to MaaS operators and provide access to their collected data via API's to the data providers and MaaS operators. They may include traditional public transport operators and also private mobility providers like taxi services, ride-hailing services and other sharing systems.
Objectives	To continue or expand their businesses with MaaS by improving efficiency and increasing coverage (Arup, 2018). MaaS is a new revenue source to their existing business and provides access to new customers and travellers (Holmberg et al., 2016).
Problem perception	The operators want to deliver their services within the MaaS packages and expand their business. Therefore interest in healthy behaviour is low. Operators that provide car trips want to deliver as many trips as possible and do not have a large interest in stimulating healthy travel behaviour, as car trips are not seen as the healthiest choice within this research. Transport operators that deliver the services that are in general seen as healthy might be interested in the promotion of healthy travel behaviour, as their service forms a backbone in this.
Ability	They have the "choice" to be included within the MaaS service.
Instruments	Lobbying, investments / funding.

Table -7: Description of the category data provider

DATA PROVIDER	**E.G. NDOV, PARKING DATA, ETC.**
Description	Intermediary agent (public or private) that facilitates the exchange of data and information between the MaaS provider and transport operators. They collect and modify large amounts of data and make this data useful for MaaS providers and others (Ministry of I&W, 2017). They perform analysis on the data to improve planning, monitoring and modification. (MuConsult, 2017). Offers analytics capabilities and a fast, reliable and secure manner to store, retrieve and share data (Catapult, 2016).
Objectives	Aim to increase their revenues next to the existing service platforms they operate (Holmberg et al., 2016). MaaS provides a new service platform to do so.
Problem perception	The data provider can provide the MaaS operator with data which is relevant for incentivising healthy behaviour, for example the number of steps, the total amount of CO_2, etc.
Ability	The role of the data providers is important because this stakeholder operates and modifies the travel data, which is essential to the functioning of the MaaS chain.
Instruments	Facilitate the exchange of data and information.

Table-9: Description of the health knowledge institutions

HEALTH KNOWLEDGE INSTITUTIONS	**RIVM, WHO**
Description	Knowledge institutes that do research on health and well-being and provide knowledge and guidelines. • *RIVM*: knowledge institute in the Netherlands that collects and collates knowledge and information on health from various sources. They apply this knowledge themselves and place it at the disposal of policy-makers, researchers, regulatory authorities and the general public (RIVM website). • *WHO:* directing and coordinating international authority on health within the United Nations' system (WHO website).

Objectives	• *RIVM:* promote public health & consumer safety and protect the quality of the environment. • *WHO:* build a better, healthier future for people all over the world and ensure the highest attainable level of health for all people by gathering independent knowledge, expertise and research on health (WHO, website)
Problem perception	Healthy mobility is one or a range of topics of interest for these institutions. Focus is on low carbon transport and active mobility as main healthy transport methods. If MaaS can stimulate a shift from car-based transport towards these modes, it is seen as a positive development and a means to improve citizens health and the environmental quality. However, there is also the potential for MaaS to worsen the situation, dependent on the design.
Ability	The institutes apply knowledge themselves and place it at the disposal of policy-makers, researchers, regulatory authorities and the general public. They have relatively low Ability as they can only provide information and expertise to support government and society in improving health and environmental quality. What happens with this information is uncertain.
Instruments	Research, knowledge and advice on health.

Table -8: Description of the health knowledge institutions

HEALTH INSURANCE COMPANIES	E.G ACHMEA, VGZ, MENZIS
Description	Societal responsible businesses that serve the healthcare needs of their policyholders. The companies provide their clients with a basis health care package including curative care and they take care of the finances for them.
Objectives	Goal is to realise good, affordable and accessible health care for their clients, aiming to improve health and quality of life. A healthy population reduces the load on the services these institutes provide.
Problem perception	Health insurance companies are benefiting from policyholders pursuing a healthy life style, of which travel behaviour is an important element. The healthier their clients are, the lower the risk of high healthcare costs for the company. This creates potential for the health insurance companies to partner up with the MaaS operators in the promotion of healthy travel behaviour. MaaS global is an example of this as they are already looking into the possibilities for this collaboration.
Ability	The health insurance companies are an important, potential partner in the MaaS and health concept, which makes them an interesting stakeholder in the guidance of MaaS towards healthy behaviour.
Instruments	Partnerships with MaaS operators

Table -9: Description of the category customer

CUSTOMERS	INDIVIDUALS AND/OR COMPANIES
Description	MaaS users (travellers and companies) consume the MaaS offer from the MaaS provider.
Objectives	Need for transportation between origin and destination against reasonable travel costs, low travel time and convenient travel experience with good connections (van de Ven, 2018).
Problem perception	The customer wants to have a convenience travel experience and probably does not have health as important criteria to choose and use MaaS. However, if MaaS incentivises healthy travel behaviour in, for example, an economical way, the customer can be motivated to make healthy travel choices
Ability	The customer makes the decision on the service that he or she intends to purchase. The customer defines the use and the demand of the service, and is therefore crucial to the success of MaaS.
Instruments	Decision to use the service and create the demand.

D. MaaS pilots & characteristics

D1 - MaaS components

Throughout literature and interviews, various different characteristics and components of a MaaS scheme are mentioned as important for the service. These characteristics are presented in Table 10 below. From these components the main components are selected that were mentioned most often.

JITTRAPIROM	KAMARGIANNI	MUCONSULT	DURAND & HARMS
• Integration of transport modes • Tariff options • One platform • Multiple actors • Use of technologies • Demand orientation • Registration requirement • Personalisation • Customisation	• Intermodal journey planner • Payment methods • Booking systems • Real time information • Mobility packages	• Integration of various transport modes • Tariff options • Digital platform with smart ticketing, booking and planning • Personalisation • Real time information • User centric	• Simplicity • Trialability • Convenience • Choice freedom • Flexibility • Autonomy • Reliability of autonomous modes • Costs of the service, willingness to pay • Travelers characteristics

Table 10: MaaS core characteristics

D2 - MaaS pilots

There are several MaaS pilots and projects being tested or in operation worldwide. Table -13 holds an overview of some of the pilots with the highest levels of integration, based on the classification by Kamargianni et al. (2016). Within this research the chosen definition for MaaS uses the highest level of integration and all the pilots and projects that fulfil this level are shown.

Table 11: MaaS pilot characteristics

PROJECT	CHARACTERISTICS	RESULTS
UbiGo, Gothenburg, Sweden.	Pilot from 2013 – 2014 in the urban environment of Gothenburg. This pilot uses the highest level of integration; ticket integration, payment integration, ICT integration and mobility package integration (Kamargianni et al., 2016). 195 individuals in 83 urban households participated voluntary (Karlsson et al., 2016. The modes that were included are public transport, bike sharing, car sharing, car rental and taxi.	Yes
Smile, Vienna, Austria.	Pilot from 2014 – 2015 in the urban environment of Vienna. This pilot uses the second highest level of integration; ticket integration, payment integration and ICT integration (Kamargianni et al., 2016). Over 1000 individual made use of the service. The modes that were included are public transport, (e-)bike sharing, (e-)car sharing, taxi, and also parking garages, charging stations, regional trains and ferries (Jittrapirom et al., 2017).	Yes
Whim, Finland.	Operational pilot, started in 2016 – in Helsinki. This pilot uses the second highest level of integration; ticket integration, payment integration and ICT integration (Kamargianni et al., 2016). The modes that are included are public transport, rental car, taxi, regional rail, bike sharing and car sharing.	Limited

UbiGo, Gothenburg

The UbiGo pilot in Gothenburg has been thoroughly evaluated. Changes in mode use are shown in Table-12.

MODALITY	LESS OFTEN	SAME USAGE	MORE OFTEN
Private car	48%	48%	4%
Shared bike	16%	61%	23%
Bus / Tram	4%	46%	50%
Local train	7%	75%	18%
Shared car	6%	37%	57%
Taxi	12%	68%	20%
Walking	6%	73%	21%

Table-12: Changes in modal choice from participants of UbiGo pilot (Karlsson et al., 2016)

Smile, Vienna

The Smile project in Vienna has been evaluated in a three-year research program. Over 1000 pilot users downloaded the application and after evaluation 75% said to be satisfied. The evaluation, performed through surveys amongst 200 users, showed that Smile was mainly used for leisure trips and private errands (Smile mobility, 2015).

Whim, Helsinki

Whim is introduced in Helsinki and some first surveys among users show the results in Table 13 and Table 14.

Table 13: Projected modal split for Whim users in Helsinki 2020 (Hietanen, 2017)

MODALITY	CURRENT MODAL SPLIT	PROJECTED MODAL SPLIT
Public transport	34%	46%
Private car	29%	-
Rental car	-	2%
Taxi	-	13%
Car share	-	2%
Bike	6%	11%
Walking	29%	-
Other	2%	-

Table -14: Trips made in Helsinki before and after whim (Hietanen, 2017)

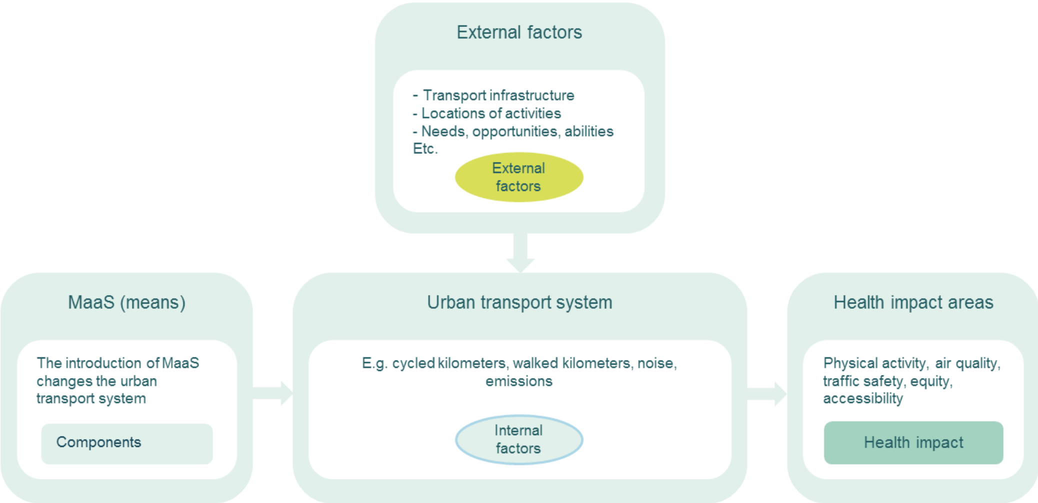
MODALITY	BEFORE WHIM	AFTER WHIM	CHANGE
Public transport	48%	74%	+ 26%
Private car	40%	20%	- 20%
Rental car	-	1%	+ 1%
Taxi	-	5%	+ 5%
Bike	9%	*Excluded from result data*	-
Other	3%	-	
Walking	*Excluded from result data*	*Excluded from result data*	-

E. The Urban Transport System

Appendix E describes the methodology behind the construction of the system diagram in section E1 and the reasoning and references behind the found relations in the diagram in E2.

E1 – The system diagram: relations between elements

Figure 1: Links between the elements in the urban transport system



E2 – The system diagram: description of elements

Elements	**Description**
Internal factor (blue factor)	Elements that can be influenced by the other (external and internal) factors within the urban transport system.
External factor (green factor)	Elements that cannot be influenced by the introduction of MaaS or the internal factors within the urban transport system, but do impact the health outcome as they can contribute to the health impact areas via several direct and indirect relationships. E.g. transport infrastructure can create hazardous traffic situations and decrease traffic safety, however this factor cannot be changed through the introduction of MaaS or any other factor with the urban transport system. They include, for example: • Transport infrastructure • Locations of activities (van Wee et al., 2013) • Needs, opportunities and abilities (van Wee et al., 2013)
MaaS (means)	MaaS is considered in this research as a means to change travel behaviour and urban mobility and, therefore, potentially influence health of individuals and society.
Health impact areas	The five health impact areas are linked to the main health outcomes of the system and they determine whether the desired situation (improved health) has been attained. These five areas have a direct impact on the health outcomes (diseases, illnesses and conditions) and are influenced through changes the urban transport system and travel behaviour induced by MaaS. The impact areas are: • Physical activity • Traffic safety • Environmental stressors • Accessibility • Equity

E3 – Definitions of factors

The definitions of the factors most important for linking health and the urban transport system are described in the table below.

Table -15: Urban transport system: definitions, links and references:

TYPE	FACTOR	DEFINITION	LINKS	REFERENCE
Health impact areas	*Physical activity*	Active mobility can provide physical activity throughout the journey, like walking and cycling (and to some extent public transport).	Physical activity as a result of active kilometres travelled, provided through cycled and walked kilometres.	Eisenmann, 2018; Doorly, 2017; Mackett, 2011; Bassett, 2008.
	Traffic safety	Accidents and collisions during transport that cause unintentional deaths and harm, impacting actual safety in form of accidents and perceived safety of travel.	Depends mainly on exposure to risk and crash risk.	Schepers et al., 2014; Van Wee et al., 2013; Jacobsen et al., 2009; 2003
	Environ-mental stressors	Referring to both air pollution (NOx and PM) and noise pollution that affect the air quality in cities.	Result of vehicle emissions and noise pollution as a negative side effect of vehicle kilometres travelled.	Karlsson et al. 2017; Jongeneel et al., 2008
	Access-ibility	Ability and ease of reaching a number of key activities and opportunities by means of transport.	Result of accessibility of transport, availability of modes and the travel resistances travel time and effort.	Ciommo and Shiftan., 2017; Van Wee et al., 2013
	Equity	Differences in access to transport caused by affordability, accessibility and availability of transport modes, which can worsen inequity.	Result of availability of modes, the access to these modes (physical) and the travel time, travel costs and effort involved in a journey.	Ciommo and Shiftan, 2017; van Wee et al., 2016
Travel resistance	*Travel time*	The total time required to make a trip from A to B.	Influences and is influenced by the number and frequency of trips, the mode choice and the route choice.	Van Wee et al., 2013
	Travel costs	The amount of money individuals or households spend in order to access and use the transport system.	Travel costs for a trip depend, amongst others, on the chosen mode. If monetary travel costs increase, travel decreases (=number of trips), all other things being equal. It depends on the mode choice what the influence of a cost change is on travel behaviour.	Ciommo and Shiftan, 2017; Van Wee et al., 2013
	Effort	Effort is a term used for a broad class of factors influencing the decision to make a trip, mode choice, or route choice, so: • Perceived safety • Accident risk • Travel info • Stress • Discomfort • Reliability • Physical effort	All effort aspects can influence the decision to travel and the decision to choose a certain mode. The lower the effort, the higher the amount of transport (=number of trips).	Van Wee et al., 2013
Travel behaviour	*Choice to travel*	About the number of trips made and the number of foregone trips. Also determines the total km travelled.	The distance travelled a result of the total travel time, travel costs and effort, so the travel resistances.	Van Wee et al., 2013

	Mode choice	The choice for a certain mode for a trip.	Mode choice is a result of the travel costs of a journey, the total travel time and the effort (travel resistances). The chosen modes determines together with the total km travelled the km travelled per mode.	Van Wee et al., 2013
	Route choice	Traffic distribution over space and time.	The location of activities is an important determinant of traffic distribution	Schepers et al., 2014; van Wee et al., 2013
	Transport infra-structure	The available transport infrastructure.	Can create community severance in case of road infrastructure. It can also promote or discourage use of certain modes. The amount of active kilometres depends on the transport infrastructure and if it encourages people to walk or cycle.	Mackett, 2011
	Human factor	Driving style of the vehicle driver. Important aspect is the travel speed.	Influences the traffic safety through influencing the risk of a crash. A high traffic speed can increase the risk of getting involved in an accident.	Mackett, 2011.
	Vehicle technology	The characteristics of a vehicle in terms of technology and design, used resources, technical characteristics, design etc.	Can impact traffic safety in terms of vehicle design and type. The used resource (EV, fuel-based) influences the level of emissions and level of noise. Influences comfort and costs.	Van Wee et al., 2009.
	Vehicle speed	Travel speed of a vehicle	Higher travel speed increases crash risk.	Mackett, 2011
	Fuel type	Type of fuel used in a vehicle	Fuel type is an determinant of the amount of emissions a vehicle emits.	
	Locations of activities	Where activities are located	Influences travel behaviour.	Van Wee et al., 2013
	Needs, opportuniti es, abilities	Explains motivation for travel behaviour in terms of needs, presence of opportunities and individual abilities (time, money, skills etc.)	Influences travel behaviour.	Van Wee et al., 2013
Internal factors	*Access to transport*	Access to and from to modes and the network. Also includes the distance to travel modes and ease of accessing a mode in terms of physical access, ticketing	Access to transport relates to travel resistances (travel time and effort) and availability of modes.	e.g. Di Ciammo and Shiftan, 2017
	Availability of modes	The variety and number of modes available and accessible to reach a destination	Availability of modes influences accessibility of destinations, access to transport and travel behaviour.	
	Active kilometres	The amount of kilometres travelled with active modes (walking and cycling).	Sum of cycled and walked kilometres.	
	Vehicle kilometres	The amount of kilometres travelled with vehicles.	Result of the total kilometres travelled with motorized vehicles. Affects emissions and noise pollution.	Jacobsen, 2003
	Walked kilometres	The amount of kilometres travelled by foot.	Sum of total km travelled by foot. Public transport trips also influence the total km travelled by foot as walking is also part of trips made with public transport. Affects active kilometres.	
	Cycled kilometres	The amount of kilometres travelled by bike.	Sum of all kilometres made by bike. Increases active kilometres.	

	Public transport kilometres	Total distance travelled by public transport.	Sum of all kilometres made by public transport modes. Can increase active kilometres.	
	Community severance	Segregation that happens when transport infrastructure limits people's mobility, creating a barrier effect.	Transport infrastructure can provoke physical and social segregation in the form of community severance, which reduces accessibility.	Arup, 2016
	Noise	The level of noise pollution as a result of traffic in decibels.	Result of the vehicle technology & characteristics and the amount of vehicle kilometres travelled. More VKT leads to more noise pollution.	Jongeneel et al., 2008
	Emissions	The level of emissions from motorized vehicles in PM and NOx.	Result of the vehicle technology & characteristics and the amount of vehicle kilometres travelled. More VKT leads to more emissions.	Jongeneel et al., 2008
	Crash risk	Refers to crash and injury risk of transport.	Determines the traffic safety and is a result from interaction between the safety pillars; transport infrastructure, driving behaviour (road users) and vehicle technology (design and technology in used vehicle). Also the amount of vehicle kilometres relates to crash risk.	Schepers et al., 2014; Jacobsen, 2003
	Exposure to risk	Exposure to risk as a result form travel behaviour (mode choice, number of trips and distribution over time and space)	Result from travel behavioural choices and influences traffic safety by increasing the risk of getting in an accident when exposure is high.	Schepers et al., 2014

F. Sustainable development

This chapter elaborates on the ways in which MaaS can contribute to sustainable development in the transport sector. It is namely believed by transport professionals that the MaaS service can enable a paradigm shift towards more sustainable urban mobility (Li and Voege, 2017). This chapter discusses the possibilities for MaaS to make transport more sustainable.

F1 - Sustainable development

To analyse the contribution of a concept in terms of sustainability, the Triple Bottom Line framework, also named the three P's (PPP), is often used (Elkington, 1994). This framework includes three dimensions, which are defined as People, Planet and Profit, to connect sustainable development and businesses. The framework offers an approach to analyse the impact of a business or concept in terms of sustainability. Planet stands for the environmental aspects and the future environment, People for social aspects and Profit for financial aspects. Sustainability is defined as the part where environmental, social and economic aspects overlap (Vogtlander, 2009). The effects of MaaS on sustainable development are researched through analysing the contribution MaaS can bring to sustainable transportation.

F2 - Sustainable transport

A definition for sustainable transport is derived from research by Richardson (2005): "*the ability to meet today's transportation needs without comprising the ability of future generations to meet their transportation needs"*. A sustainable transport system has low environmental impact, encourages public transport development, green vehicles, sharing systems, fuel-efficient transport and non-motorised modes of transport such as walking and cycling (UNESCAP, 2012). The MaaS concept can make the transport sector more sustainable by promoting sustainable mode use, increasing network efficiency and playing a role in automation, electrification and sharification, among others. The following sections highlight how MaaS can contribute to a more sustainable transport system.

F3 - Sustainable transport and MaaS

The main ways in which the MaaS business can contribute to sustainability is by inducing a modal shift towards multi-modal travel with sustainable modes, increasing (resource) efficiency of the current transport system and by overcoming psychological barriers associated with innovative, sustainable mobility concepts, like car-sharing and car-pooling. The next sections briefly discuss these directions.

1) Greater use of sustainable modes

A shift towards greener modes is the most important strategy to achieve a sustainable transport system, according to a study conducted by LSE cities (2013). MaaS can change travel behaviour and promote a mode shift towards sustainable modes, since the main aim of the service is to replace private car ownership and use with more multi-modal travel, possibly leading to a greater use of public transport and active mobility. MaaS is considered as environmentally sustainable when public transport forms the backbone of the service (Holmberg et al., 2016). Research (e.g. Kamargianni et al., 2018) and first results from MaaS pilots (UbiGo, Smile and

Whim) have demonstrated that the use of public transport and active modes increased while car use decreased.

2) *Efficiency of existing network*

MaaS can create a more balanced and integrated transport system due to the fact that MaaS can increase efficiency of the current transport system by maximising efficiency of existing transport assets, better managing supply and demand, especially for busy routes, and reducing traffic congestion (MaaS Scotland, 2018). The increase in efficiency of the existing network is further elaborated on in the section on sharification later on.

3) *Support other ongoing sustainable transitions in transport*

MaaS can be used as an accelerator for current ongoing sustainable transitions in the transport sector, leading to positive synergy effects. Briefly discussed are the concepts of automation, electrification and sharification in relation to MaaS and sustainable development.

• *Automation*

Mentioned several times throughout literature and during the interviews (e.g. Meurs interview, 2th of March 2018; Kamargianni et al., 2017) is how MaaS and the introduction of automated vehicles can benefit from each other in many ways, as they can exist in symbiosis. Sustainability benefits associated with automated vehicles are related to improved fuel efficiency, less emissions, reductions in the number of vehicles on the road and a lower demand for parking spaces (Park, 2017). On the more negative side, automation of the transport sector can increase the number of trips and kilometres travelled.

• *Electrification*

The uptake of e-mobility services is reliant upon the interest and acceptance of society (Gould et al., 2015). The current state of research suggests that MaaS is becoming integral to society and, therefore, can make to the introduction of alternatively fuelled vehicles into the city more easily. MaaS offers a considerable opportunity to decarbonise urban transport through reducing the need for private car ownership and start utilisation of electric vehicles within the current mobility model (ibid.). Electrification of the transport system can reduce local emissions and noise pollution, among others.

• *Sharification*

MaaS can stimulate a shift away from ownership-based transport to access-based transport via sharing systems (Saidla, 2017), which is especially interesting from the People dimension. The sharing economy can be seen as an example of the value of the internet to its consumers, and is defined as "*the peer-to-peer based activity of obtaining, giving, or sharing the access to goods and services, coordinated through community-based only services."* (Hamari et al., 2015). It is an economic-technological phenomenon shaped by information and communication technology, growing consumer awareness and social sharing (Hamari, et al., 2015). Its core business is about the sharing of products and services through online platforms. MaaS has good potential to contribute to the sharing economy as the service can introduce more people to sharing systems for bikes and cars (Kamargianni et al., 2018). MaaS can accelerate the move from a ownership based business model to a service based one, by spreading concepts like car sharing, car renting, carpooling and ride-hailing (Gould et al., 2015).

Guiding users from the concept of ownership towards the concept of user-ship is one of the main ways towards higher efficiency of the transport network and higher resource efficiency. From a social perspective, the sharing economy also stimulates social interactions and user contributions from its participants. Another positive outcome related to sharing, is the increased efficiency of modes. When transport is shared and used by more than one person, the efficiency of the system increases and transport related emissions per person are reduced. Also, sharing can cause the total number of needed vehicles to decrease and therefore eventually the total need and use of raw materials and resources.

4) Reorganisation of urban space

MaaS can add to the sustainable transport system by making place to reorganise urban space. The combination of a reduction in idleness and less cars being needed for travel, means less space needed for parking. These unused and redundant parking spaces can be used for other purposes, such as greenery, public space, cycle lanes and pedestrian areas.

F4 - Conclusion

In conclusion, MaaS has good potential to contribute to sustainable development in terms of People, Planet and Profit. MaaS can add to sustainability of transport systems, primarily as a result of synergy effects with the continuing rise of more sustainable mobility concepts of sharing, automation and electrification. The upscale of ride-hailing, taxis and car-sharing is an opportunity to decarbonise the transport sector and promote the use of low-emissions or zero-emission vehicles. The introduction of electric and automated vehicles promotes an opportunity to support the shift towards more sustainable transport with lower negative externalities and thus less negative health impacts in terms of air quality. On a more negative note, MaaS can increase travel demand, particularly by motorized modes if no attention is paid to the design of the service, and by increasing the number of trips and trip lengths, resulting in more congestion and emissions.