beyond
the obvious

Impacts of Automated Driving on Health and Quality of Life

Reetta Mäkinen

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VTT
PL 1000
02044 VTT
Puh. 020 722 111
https://www.vtt.fi

VTT
P.O. Box 1000
FI-02044 VTT, Finland
Tel. +358 20 722 111
https://www.vttresearch.com

Preface

This report was made as a Master's Thesis for Tampere University under Degree Programme in Industrial Engineering and Management.

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VTT Technical Research Centre of Finland Ltd. provided the intriguing topic for this Master's thesis. I would like to thank everyone at VTT and especially the great Transport and Mobility team; I have learned so much and enjoyed these fascinating months in your company.

Espoo, 27 June 2019
Reetta Mäkinen

ABSTRACT

Reetta Mäkinen: Impacts of Automated Driving on Health and Quality of Life
Master's Thesis
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Automated driving is one of the current hype phenomena generating widespread interest. Automated vehicles are a growing topic of discussion in both the academic and gray literature. Although fully automated vehicles are still far in the future, various levels of automation-featured vehicles are gradually gaining groud in road traffic. Impact assessment of automated driving promotes the development of automated systems and support decision-making in the field of transport. VTT Technical Research Centre of Finland Ltd. has studied the impacts of transport and mobility for decades, and has produced impact analyses with a broad scope in this field. The impact assessment of automated driving has recently seen further developments; this thesis continues the work and expands it to the themes of health and quality of life.

This thesis aimed to explore the impacts of transport and mobility on individuals' health and perceived quality of life and, further, to exploit the findigs under the domain of automated driving. One of the main objectives was to identify potential pathways of action from the introduction of automated driving to its health implications. The study was conducted in three phases: First, a review was done of the extant literature. Second, a conceptual framework for transport and its implications for health and quality of life was constructed with the help of a literature study and insights from specialists in diverse fields of health and transport. Third, the framework and supporting literature were used to formulate the potential pathways of action mentioned above. Finally, the results were discussed in a work group to ensure the validity and reliability of the results. The thesis process was iterative; i.e. the results from the literature and specialist interviews were utilized throughout the work right from the start.

This thesis has three key results. First, it provides a comprehensive and worthwhile overview of the concepts of health and quality of life in the context of transport and mobility, which can be used to support future discussion and research. The second key result is the illustrative conceptual framework, which provides insights into transport and its health implications. Finally, potential pathways from the introduction of automated driving to its impacts on health and quality of life are presented. Understanding these pathways to impact will not only support further development and decision-making; it will also help pinpoint future topics of research. One of these will be assessing the direction and magnitude of the potential impacts of automated driving.

Keywords: Automated driving, mobility, health, quality of life, impact assessment

The originality of this thesis has been checked using the Turnitin OriginalityCheck service.

TIIVISTELMÄ

Reetta Mäkinen: Automaattiajamisen terveysvaikutukset
Diplomityö
Tampereen yliopisto
Tuotantotalous
Kesäkuu 2019

Automaattiajaminen on yksi tämän ajan niin kutsutuista hype-ilmiöistä, joka herättää laajalti keskustelua ja saa palstatilaa niin tieteellisissä kuin harmaissa julkaisuissa. Täysautomaattisia ajoneuvoja tuskin nähdään liikenteen seassa vielä hetkeen, mutta eri automaatiotason kulkuneuvot yleistyvät liikenteessä vähitellen. Automaattiajamisen vaikutusten arviointi ja ymmärtäminen edistää automaattisten järjestelmien kehitystä ja tukee kehitystyöhön liittyvää päätöksentekoa. Teknologian tutkimuskeskus VTT Oy:ssä on tutkittu liikenteen ja liikkumisen vaikutuksia laaja-alaisesti jo vuosikymmenien ajan ja viime vuosina on kehitetty myös automaattiajamisen vaikutusarviointia. Tämä diplomityö jatkaa vaikutusarviotyötä ja laajentaa sitä terveyden, hyvinvoinnin ja elämänlaadun teemoihin.

Tämän diplomityön tutkimuksen tavoitteena oli perehtyä liikenteen ja liikkumisen vaikutuksiin yksilöiden terveyteen sekä koettuun elämänlaatuun, minkä jälkeen hyödyntää tuloksia automaattiajamisen terveysvaikutusten tunnistamiseen ja luokitteluun. Tavoitteiden saavuttamiseksi työssä tutustuttiin laajasti alan kirjallisuuteen sekä haastateltiin asiantuntijoita terveys- ja liikennealoilta. Tutkimus voidaan jakaa kolmeen vaiheeseen, joista ensimmäisessä tehtiin yhteenveto olemassa olevasta kirjallisuudesta. Toisessa vaiheessa tämän kirjallisuuskatsauksen ja asiantuntijahaastatteluiden avulla muodostettiin työn käsitteellinen viitekehys liikenteen ja liikkumisen vaikutuksista terveyteen ja elämänlaatuun. Kolmannessa vaiheessa viitekehystä ja aiempaa kirjallisuutta hyödynnettiin automaattiajamisen terveysvaikutusten potentiaalisten vaikutuspolkujen muodostamiseksi. Tulosten luotettavuuden varmistamiseksi tulokset keskusteltiin läpi kokeneiden liikennealan tutkijoiden kanssa.

Tutkimuksessa on kolme päätulosta. Tämä diplomityö tarjoaa kattavan katsauksen terveyden ja elämänlaadun konsepteihin sekä niiden ymmärtämiseen liikenteen ja liikkumisen kontekstissa. Toisena päätuloksena on havainnollistava liikenteen ja liikkumisen terveysvaikutusten viitekehys, johon on kattavasti koottu eri tekijöitä, jotka vaikuttavat yksilön terveyteen ja elämänlaatuun liikenteen kontekstissa. Kolmantena päätuloksena on automaattiajamisen liikennejärjestelmään kohdentuvien suorien vaikutusten yhdistäminen potentiaalisiin terveysvaikutuksiin vaikutuspoluin. Vaikutuspolkujen ymmärtäminen tukee automaattiajamisen teknologian kehittämiseen liittyvää työtä ja päätöksentekoa sekä mahdollistaa jatkotutkimuksen, jossa automaattiajamisen potentiaalisten vaikutusten suuntaa ja suuruutta voidaan arvioida yksityiskohtaisemmin.

Avainsanat: Automaattiajaminen, liikkuminen, terveysvaikutus, elämänlaatu, vaikutusarviointi

Tämän julkaisun alkuperäisyys on tarkastettu Turnitin OriginalityCheck -ohjelmalla.

Contents

List of symbols

ADS	Automated driving system
AD	Automated driving
AV	Automated Vehicle
DALY	Disability Adjusted Life Years
DDT	Dynamic driving tasks
HALE	Healthy Life Expectancy
HALY	Health Adjusted Life Years
HEAT	Health Economic Assessment Tool for walking and cycling model
HIA	Health Impact Assessment
HRQL	Health-Related Quality of Life
IAIA	International Association for Impact Assessment
ITHIM	Integrated Transport and Health Impact Modelling Tool
KPI	Key Performance Indicator
MET	Metabolic Equivalent of Task
ODD	Operational Design Domain
OEDR	Object and Event Detection and Response
PYLL	Potential Years of Life Lost
QALY	Quality Adjusted Life Years
QoL	Quality of Life
TA	Technology Assessment
SEM	Socio-Economical Model
SAE	Society of Automotive Engineers
TAPAS	Transportation, Air pollution and Physical Activities model
TQoL	Transport Quality of Life
UTOPHIA	Urban and Transport Planning Health Impact Assessment model
VKT	Vehicle Kilometers travelled
YLD	Years Lived with Disability
YLL	Years of Life Lost

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Introduction

The domain of impacts on health of the population and public health is not new in the field of transport and mobility – quite the opposite. Already in ancient Rome, Julius Caesar banned horse-drawn carts from dawn to dusk to fight gridlock, noise, accidents, and pollution (Morris 2007). Today the transport system is different but the challenges are much the same, although to a wholly different extent. The transport system is in continuous flux, with several trends being recognized as driving forces of change. For example, new mobility services (Nikitas et al. 2017; Sarasini & Linder 2018), electrification of the transport system (Bilgin et al. 2015; Dyke et al. 2010), connected vehicles (Lu et al. 2014), and sharing economy (Cohen & Kietzmann 2014) are considered to shape the future of the transport system. Among other things, automated driving is envisioned to be one of the revolutionizing trends of future mobility which will lead to a paradigm shift in transportation systems in terms of user experience, mode choices and business models (Chan 2017). This change will inevitably influence the health of the population, which provides an important research topic for this study.

1.1 Background

Health is a wide-ranging concept, classically described as a *"state of complete physical, mental and social well-being – not merely the absence of disease"* (WHO 2005; WHO 1948); its typical indicators are morbidity and mortality (e.g. Larsson & Mercer 2004). Quality of life (QoL), on the other hand, can be seen as a broader concept which includes individuals' perception of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards and concerns. It is affected in a complex way by the person's physical health, psychological state, level of independence, social relationships and personal beliefs. (WHO 1997). In health discussions, quality of life is usually approached by its four dimensions of well-being: physical, psychological, social and economic (Kirch 2008). The concepts of health and quality of life overlap, with dimensions of well-being included in both, but their approach is different. This can be seen, for example, from their typical measures of disability-adjusted life years (DALY) and quality-adjusted life years (QALY). The former measures health loss and the latter health gain; thus they express inverse values. (NCCID 2015).Transport and mobility are related to health throughout numerous pathways of action (e.g. Nieuwenhuijsen 2016). Traditionally, the impacts are considered as implications of levels of physical activity, as a cause of injuries and mortal accidents, and through air pollution and emissions (e.g. WHO 2006). Nowadays, the impacts on our perceived quality of life and well-being are taken into account more broadly, together with a post-traditional concept of health (Lee & Sener 2016; Steg & Gifford 2005). There is an expanding body of research on this topic, and the health outcomes of transport and mobility are a growing topic of discussion (Widener &

Hatzopoulou 2016) as much around the dinner table as in global decision-making fora.

It is also clear that transport is undergoing a sea change. New technologies and other drivers of change are revolutionizing transport as we know it and adding to the diversity. Rapid advances in vehicular structure, materials and technology (both incremental and radical) and shifts in the mobility preferences of people are challenging the transport system. For example, Hoppe et al. (2014) have identified a broad range of potential technology changes in transport. These are summarized in Figure 1.

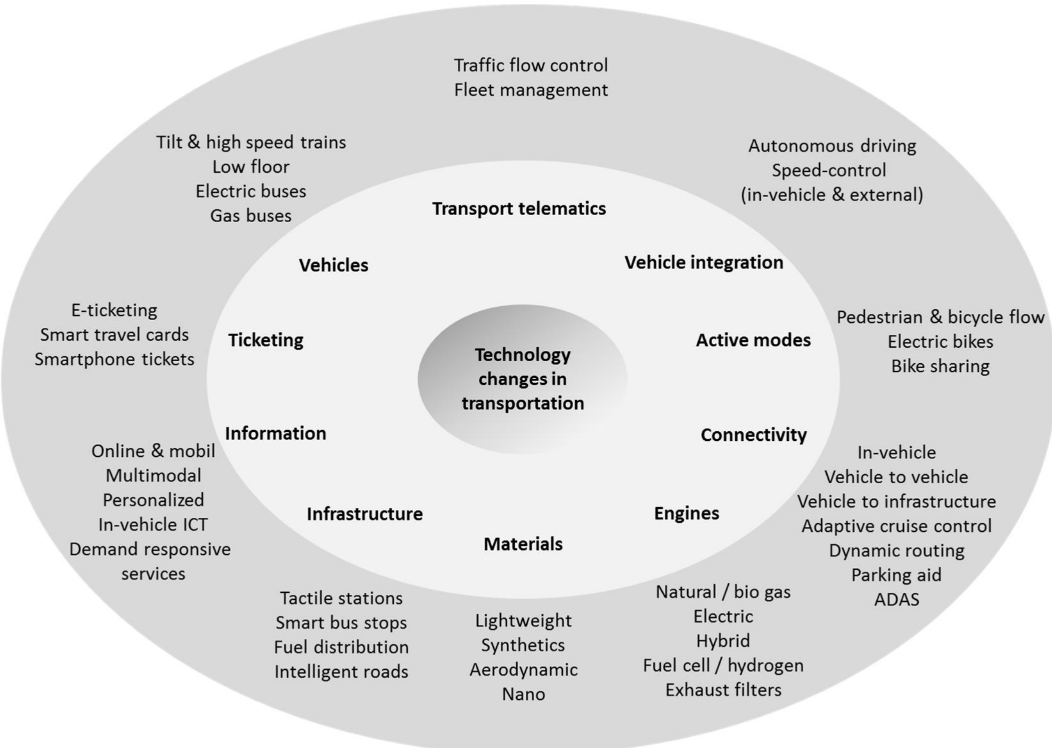

Figure 1. Technology changes related to public and private transportation (Hoppe et al. 2014)

Changes in the transport system will undeniably be reflected in the health and quality of life of populations (Steg & Gifford 2005), providing a fruitful topic for research. According to Hoppe et al. (2014), knowledge about the future is lacking in the field of transport and its transformation. Even though uncertainty is unavoidable, defining the range of uncertainty can help deal with the challenges and risks and even identify opportunities. Authors consider it important to shed light on the field of uncertainty, because understanding changes with respective impacts can provide insights on where to focus attention, decisions and actions to shape the future development of transportation and mobility. Partidário et al. (2012) conclude that impact assessment is a useful future-orientated tool which can proactively advise decision-makers on what might happen. Thus, impact assessment may help to develop proposals for action, enhancing opportunities, avoiding risks and mitigating harmful effects.

The emergence of autonomous vehicles is one topic that has evoked interest widely and will provide both challenges and opportunities in the future. Deloitte's report (Corwin et al. 2015), among many others, states the following: *"Autonomous-drive technology is no longer a case of science fiction; the question now is when and how will it become more mainstream and widely adopted?"* Reading only the headlines, it would seem that truly automated vehicles (AV) are just around the corner, revolutionizing our daily mobility. However, that is not the case; e.g. the Gartner Group (Ramsey & Isert 2018) places the deployment of truly autonomous vehicles at least 10 years or more into the future.

Hoadley (2018) raises an important concern of optimism bias conveyed by the media and literature about the introduction of automated vehicles in a discussion paper from the Polis network. She notes that expectations — which include predictions like self-driving cars will be there tomorrow, will always operate perfectly and will solve congestion and eliminate accidents — are envisioned to the public both in academic and gray literatures. Hoadley states that it is important to understand that while automated cars may bring some benefits, there is also the possibility that their widespread introduction can also lead to detriments, e.g. increased congestion, negative environmental impacts and health hazards. This is also recognized in the European Commission's white paper (Zmud & Reed 2018), which states that the potential benefits of widespread adoption of connected and automated vehicles, and the technologies enabling them, will solve some problems but can also create new ones. Thus, there is a need for assessing impacts to support competent decision-making, which provides options for early and smart integration of e.g. health, environmental, social and economic issues.

Cavoli et al. (2017) reviewed the literature on automated driving and vehicles using different social and behavioral topics such as underlying trends, market and technology development, usage and impacts, and different roles of stakeholders. Their method of review included a comprehensive search of five different literature databases. The final set of selected literature consisted of 432 papers from both academic and gray literature. The authors categorized and coded the papers according to the different topics and listed the frequency of the topics. The results are presented in Figure 2 and show that topics like health/well-being, accessibility and physical activity seem to be less studied and reported on, and all of them are discussed more in the gray than academic literature. Engholm et al. (2018) provide a noteworthy insight into the Cavolis et al. (2017) review — the system level impacts of automated driving are broad in scope but on a relatively shallow level of analysis. These notations provide a major incentive to explore the topics of health and quality of life further under the domain of automated vehicles and driving.

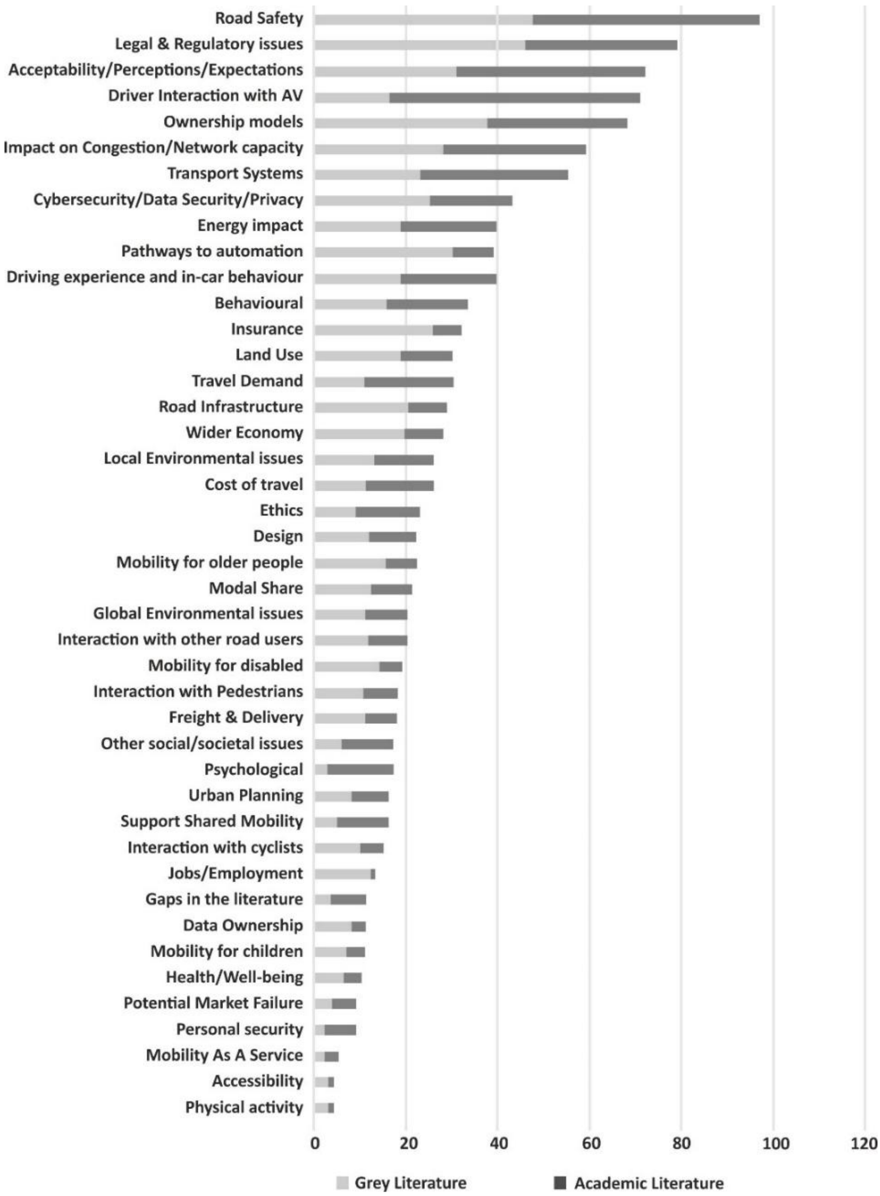

Figure 2. Frequency of different themes in automated driving literature (Cavoli et al. 2017)

Hoadley (2018) concludes that there are many uncertainties about when partially and fully automated vehicles will arrive. In what form will they arrive, e.g. vehicle type, privately owned or shared, autonomous or cooperative, and over what timespan will they do so? Still, she states that while these uncertainties make it very difficult to predict the potential impacts, this should not prevent transport authorities from starting to reflect on them. To avoid any biases, there is a need for coherent research to support the discussion and decision-making.

1.2 Research scope

This Master's thesis aims to take a step towards a better understanding of the potential impacts of automated driving, in the context of transport systems, on health and quality of life. From the very beginning, it was evident that automated driving and its health impacts provide a truly valuable challenge for a young researcher. The topic can be described as extensive and complicated — but above all very interesting and important. The position of this thesis could be related as ex-ante — before the event (Finsterbusch & Motz 1980; Myrdal 1939), since it aims to provide insights into a phenomenon (automated driving) before this phenomenon becomes widely established at its higher, more developed levels.

The thesis defines the concepts of health and quality of life with their different dimensions. In addition, it aims to present a comprehensive picture of the current state of research in the field of transport and its health implications. Furthermore, the objective is to recognize pathways of action and rules of thumb for evaluating health impacts, and to present a conceptual framework for categorizing and exploring the multifold health outcomes of transport. Finally, the results are examined in terms of automated driving and discussed for future activities and research needs.

The scope of this thesis is passenger transport, notably road transport. The health impacts are considered as a part of daily mobility; thus one-off events and special cases are outside the scope of this work. Another important framework here is that in the discussions on automated driving, other factors influencing the transformation of transport are taken as given. In other words, this thesis does not try to include other trends and drivers of change, like changes in motive powers or the sharing economy becoming more common, to avoid vagueness of discussion.

This thesis uses the Society of Automotive Engineers (SAE) International's "Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles" standard J3016 (2018). A summary of automation levels according to SAE is given in Table 1. SAE defines an automated driving system (ADS) as the hardware and software which together are capable of performing the entire dynamic driving task (DDT) on a sustained basis. The operational design domain (ODD) is defined as operational conditions in which a given ADS is specifically designed to function. The operational conditions can include, but are not limited to, environmental, geographical and time-of-day restrictions, and/or the requisite presence or absence of certain traffic or roadway characteristics. In the SAE summary, the object and event detection and response (OEDR) is one of the subtasks of DDT, which includes monitoring the driving environment, e.g. detecting, recognizing and classifying objects and events. In addition, executing an appropriate response to such objects and events is included in OEDR. (SAE 2018)

In this thesis, the focus is on level three or higher in the SAE's (2018) classification for automated driving. Level three is also known as *conditional*, whereas level four is *high* and level five *full* driving automation. In all these levels, the ADS performs the entire DDT while engaged, but the DDT fallback and ODD differ. ADS levels three to five differ significantly from each other, e.g. in technical advancement and how they could impact the driving experience and enable new possibilities for transport and mobility. Still, within the scope of this thesis there is no need for, or sense in, trying to allocate the potential impacts of different SAE levels of ADS. Nonetheless, it is acknowledged that different levels of ADS and penetration levels of automated vehicles in the traffic system will affect the potential impacts they have in both direction and magnitude.

Table 1. SAE (J3016) Automation levels (SAE 2018). DDT = driving task; OEDR = object and event detection and response; ODD = operational design domain; ADS = automated driving system.

Level	Name	Narrative definition	DDT		DDT fallback	ODD
			Sustained lateral and longitudinal vehicle motion control	OEDR		
Driver performs part or all of the DDT						
0	No Driving Automation	The performance by the driver of the entire DDT, even when enhanced by active safety systems.	Driver	Driver	Driver	n/a
1	Driver Assistance	The sustained and ODD-specific execution by a driving automation system of either the lateral or the longitudinal vehicle motion control subtask of the DDT (but not both simultaneously) with the expectation that the driver performs the remainder of the DDT.	Driver and System	Driver	Driver	Limited
2	Partial Driving Automation	The sustained and ODD-specific execution by a driving automation system of both the lateral and longitudinal vehicle motion control subtasks of the DDT with the expectation that the driver completes the OEDR subtask and supervises the driving automation system.	System	Driver	Driver	Limited
ADS ("System") performs the entire DDT (while engaged)						
3	Conditional Driving Automation	The sustained and ODD-specific performance by an ADS of the entire DDT with the expectation that the DDT fallback-ready user is receptive to ADS-issued requests to intervene, as well as to DDT performance-relevant system failures in other vehicle systems, and will respond appropriately.	System	System	Fallback-ready user (becomes the driver during fallback)	Limited
4	High Driving Automation	The sustained and ODD-specific performance by an ADS of the entire DDT and DDT fallback without any expectation that a user will respond to a request to intervene.	System	System	System	Limited
5	Full Driving Automation	The sustained and unconditional (i.e., not ODD-specific) performance by an ADS of the entire DDT and DDT fallback without any expectation that a user will respond to a request to intervene.	System	System	System	Unlimited

This thesis emphasizes qualitative over quantitative approaches to health and quality of life; i.e. the focus is on exploring potential connections to automated driving in the respective field. Thus, the quantitative implications of changes in travel patterns and driving style on transport safety or on emissions are beyond of the scope of this thesis. Specifically, this work focuses on aspects related to (other) physical and mental health implications. Also, there is no attempt to specify exact measures or monetary values for health and quality of life; it is more about pathways of action to understanding the causal connections involved.

To begin with, it was obvious that there is a need for better understanding the multifold health implications of changes in the transport system and travel behavior in general, before rushing into the field of driving automation and its impacts on health. The research questions were formulated cumulatively to support the qualitative study and its objectives, and there is a clear continuum between them. The explorative research questions and their objectives are as follows:

1) What should be included in the concept of 'health of the population' and 'quality of life' when addressing the implications of transport and mobility?
To build the conceptual framework for the thesis.

2) How do transport and mobility choices affect health and quality of life?
To explore and obtain more knowledge of causal relations between transport and mobility, and their implications on health and quality of life.

And finally,

3) How can automated driving impact health and quality of life?
To bring the above into the context of automated driving.

This thesis provides answers to these research questions in three phases. First, the concepts of transport and quality of life and their relation to transport were studied in the literature. Second, based on the comprehensive literature review, the conceptual framework for transport and its implications on health and quality of life was developed, then discussed with specialists to finalize it. Third, the framework was used for identifying and discussing the potential health and quality-of-life implications of automated driving. Finally, the results provide further knowledge on automated driving and its potential health and quality-of-life implications and their assessment.

The next chapter provides the theoretical background to understanding the concepts of transport, mobility, health and quality of life, and their multiform connections in the form of an extensive literature review. It also introduces state-of-the-art research in the field of impact assessment of automated driving. In Chapter 3, the methodological decisions of the study are introduced and rationalized. All the results derived from the comprehensive literature review and specialist interviews are presented in Chapter 4. The discussion and conclusions of the thesis, and the future prospects for health, quality of life and automated driving from the author's perspective are presented in the final part, Chapter 5.

2. Theoretical Background

This section provides an introduction to the concepts of health, quality of life and their assessment in the context of transport, and to the impact assessment of automated driving. The aim is to give an insight into what has been written previously about the causal relationships between transport and mobility, health and quality of life, and to introduce the latest, state-of-art research in the field of automated driving and its impact assessment. It can be said that the premise of a literature review is understanding that knowledge is an incremental exercise. This section introduces how the thesis contributes to the overall understanding of this topic, and seeks to find a common grasp of the research in order to build on it in the future.

2.1 Concepts of health and quality of life

The classic definition of health is “a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity” and it is commonly used interchangeably with the health of the population (WHO 1948; WHO 2005). Typical health indicators are morbidity and mortality (e.g. Larsson & Mercer 2004). Well-being is described as the individual’s experience of health, happiness, and prosperity, which includes having good health, high life satisfaction, and a sense of meaning or purpose (Davis et al. 2013; Diener & Seligman 2002).

Public health is defined as “the art and science of preventing disease, prolonging life and promoting health through the organized efforts of society” (Acheson 1988). Schmitt and Schmitt (2008) support this in their statement: “The ruling principle of public health is to deal with the health of the population in its totality. Public health covers preventive, curative, and rehabilitative actions.” Thus, public health is a multidisciplinary field the goal of which is the overall healthy state of the people and assuring conditions in which they can be healthy (Satcher & Higginbotham). In conclusion, public health can be seen as a governmental approach to health. (e.g. Svalastog et al. 2017)

Health can also be seen as an overlapping subject with quality of life, which is broadly defined as a construct reflecting a subjective and/or objective judgment concerning all aspects of an individual's existence, including health, economic, political, cultural, environmental, aesthetic, and spiritual aspects (Gold et al. 2002). WHO states that quality of life is an individual’s perception of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards and concerns. Hence, quality of life is a broad ranging concept affected in a complex way by the person's physical health, psychological state, level of independence, social relationships, and personal beliefs — without forgetting their relationship to salient features of their environment (WHO 1997).

Kirch (2008) complements WHO’s definition as follows: “In the research and clinical area, quality of life often stands for anything except death and mortality rates.” Further, quality of life can be seen as an overarching concept that covers all aspects of a person's life including, among others, physical, psychological, financial and social well-being. Physical well-being includes e.g. fitness, energy and occupational performance indicators, whereas psychological well-being includes mental health, self-perspection and mood indicators. Social well-being consists of family relationships, friendships, and level of community involment. And finally, economical well-being covers the financial resources and access to job opportunities.

Lee and Sener (2016) have indentified four classes of quality-of-life definitions:

- Objective
- Subjective
- A combination of objective and subjective
- Domain-specific

They emphasize that quality of life is an inherently individualized concept. Thus, objective measures fail to reflect an individual’s perceptions, but serve the purpose of understanding societal impacts. A subjective approach to quality of life attempts to encompass life satisfaction and feelings of positive and negative affects to provide more individual measures. However, Lee and Sener (2016) note that attempts to define quality of life solely through subjective indicators also has it weaknesses, as it fails to capture one’s life state as a whole. For example, Felce and Perry (1995) have stated that human welfare is not entirely reliant on personal satisfaction, because it can not alone represent the individual’s circumstances. Nowadays, the state of art is that quality of life should be interpreted as combination of these two, both objective and subjective (Atkinson 2013).

Domain-specific quality of life definitions are not as universal as those above, and on this account they can be more useful in their respective fields by offering a more precise outline of the ways quality of life is interpreted. This is helpful, for example, to policy and decision-makers when developing quality-of-life related performance measures in different contexts (Atkinson 2013). When discussing the wide dimensions of quality of life, the domain-specific approach supports making them more coherent and easier to use in decision-making (Lee & Sener 2016).

The literature recognizes a more specific concept of health-related quality of life (HRQL), which is a rather established domain-specific quality-of-life approach. Typically, HRQL is referred to as a multi-dimensional concept that includes domains related to physical, mental, emotional, and social functioning. It goes beyond direct measures of population health, life expectancy, and causes of death, and focuses on the impact that health status has on quality of life (Ferrans et al. 2005). One closely related concept of HRQL is *well-being*, which implies the positive aspects of an individual’s life, such as positive emotions and life satisfaction (Diener & Seligman 2002). Kirch (2008) presents well-being as state of human existence in which basic needs are adequately met and satisfied. It also refers to health status, meaning not only the absence of illness, but also quality of health. Within the medical literature, HRQL has been adapted as an established measure for the implications of health conditions on an individual's overall well-being (Bize et al. 2007).

Another adopted vantage point is the current status quo of contemporary psychiatry: the biopsychosocial model. Its founder, Engel (1977), said that "*All three levels of health, biological, psychological, and social, must be taken into account in every health related task. No single illness, patient or condition can be reduced to any one aspect."* This denotes that different dimensions of health are more or less relevant in all cases, at all times. This means that health is a complex entity, where different levels function together inseparably. Here the biological aspect includes, among others, the physical aspect of health. This model has since been accompanied (e.g. Lindau et al. 2003) by the behavioral factors affecting health. This denotes that it is crucial to comprehend that humans are entities where different aspects of health and their factors inextricably affect one another and where one's behavior consists of individual capabilities, opportunities and motivation (e.g. Michie et al. 2011). Because of this, it is not always worthwhile trying to separate the health implications. It is important to consider this when discussing the different health impacts of changes in transport and mobility — a change in one aspect of health will inevitably be seen in others as well.

There is prominent overlapping of the terminology and concepts in this field and no established practice for using them. In this thesis, health is approached from the viewpoint of its typical indicators, morbidity and mortality. Quality of life is approached from the perspective of transport, with its related four dimensions of well-being (physical, mental, social and economic). Figure 3 presents a synthesis of these concepts and definitions and their usage in this thesis.

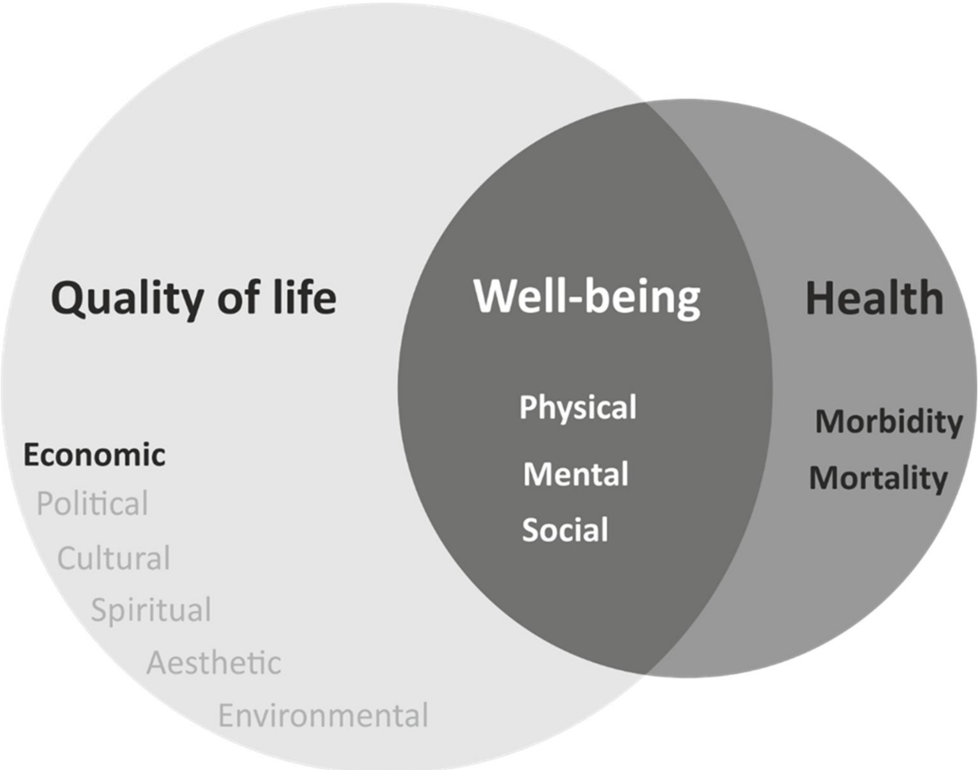

Figure 3. Quality of life, well-being and health concepts in this thesis

2.2 Technology and health impact assessment

New technologies related to transport and mobility are constantly being developed and novel innovations brought to market at a tremendous pace. These technologies are driving progress and change; thus they have the capacity to drastically change our daily lives, and not always for the better. The rapid advances in technologies generate a need for systematic ways to evaluate and assess the potential societal impacts that they may bring, in order to support the respective authorities and decision-making in different fora (Porter et al. 2004). The International Association for Impact Assessment (IAIA 2018) concludes that identifying possible concerns and benefits can alert technology developers and other stakeholders to react to potential issues. Going one step further, successful impact assessment may point out possible mitigation measures to reduce negative and even severe consequences and to enhance the desired impacts. Cohen and Cavoli (2017) conclude that understanding potential implications, both caveats and opportunities — even if this is inevitably speculative — supports more resilient decision-making.

Automated driving (AD) and automated vehicles (AV) are certainly technologies that will radically change, when widely adapted, the world we are living in. The interest around the topic is enormous, which sets a need for evaluating the potential impacts to support the discussion and decision-making. Impact assessment can be conducted for multiple different impact areas including policies, risks, environment, economics, and sustainability (IAIA 2018). In this thesis, the focus is on the health and quality of life impacts of AD.

The fundamental definition of *technology assessment* (TA) is as follows: "*A class of policy studies which systematically examine the effects on society that may occur when a technology is introduced, extended, or modified. It emphasizes those consequences that are unintended, indirect or delayed*" (Coates 1977). The aim of technology assessment is to identify potentially important vectors of change rather than predicting the exact effects or their timing. Rip (2001) denotes that technology assessment attempts to anticipate the future development of technologies, projects and their possible impacts, and feed the assessments back to the relevant stakeholders.

A program theory is one way to assess potential impacts. It is an explicit theory or model of how a project, e.g. technology related, will, or has, caused impact. The fundamental idea is that program theory consists of a sequenced hierarchy of outcomes, i.e. it forms an impact pathway with potential milestones on the route. Usually the hierarchy begins with the project outcome, followed by a chain of intermediate implications, which are then followed by more long-term impacts (Rogers et al. 2000). According to Douthwaite et al. (2003), a program theory is the hypothetical bridge between project outcomes and eventual impacts. Usually it represents a set of hypotheses about what needs to happen for the outputs to be transformed into impacts in the desired impact areas. Program theory evaluation is simply an evaluation guided by the impact pathway.

Health impact assessment (HIA) is a practical approach used to evaluate potential health effects in different sectors. It includes procedures, methods and tools by which a policy, program or project may be evaluated as to its potential effects on the health of a population, and the distribution of those effects within the population (WHO 1999). The aim of HIA is to produce evidence-based recommendations to inform decision-making. The idea behind HIA is the proposition that policies, programs and projects have the potential to change the determinants of health (Taylor & Quigley 2002). WHO (2003) suggests that the most important determinants of health are e.g. food, work, unemployment, stress, social exclusion and *transportation*. By maximizing the positive and respectively minimizing the negative health impacts on these health determinants, the use of health impact assessment aims to improve the health of the population.

HIA outputs are usually both qualitative and quantitative. The need for descriptive results is clear with the subjective nature of health and well-being, but the need for quantitative results in decision-making in different sectors also adds pressure to develop more quantitative HIA models. As Love et al. (2005) denote, successful application of the HIA procedure consists of negotiating the relationship between qualitative and quantitative results each time separately, in order to provide the most appropriate estimations needed in different situations.

WHO's current (2018a) recommendation for the health impact assessment procedure consists of five stages as follows:

1) Screening: Quickly establishing health relevance of the policy or project.

2) Scoping: Identifying key health issues & public concerns, establishing terms of reference and setting boundaries.

3) Appraisal: Rapid or in-depth assessment of health impacts using available evidence, e.g. who will be affected, baseline, prediction, significance and mitigation.

4) Reporting: Conclusion and recommendations to remove/mitigate negative impacts on health or enhance positive.

5) Monitoring: Action, where appropriate, to monitor actual impacts on health to enhance existing evidence base.

For health impact assessment there are several models, which are designed to evaluate transport as a health determinant with different foci. For example,

- Integrated Transport and Health Impact Modelling Tool (ITHIM) (Woodcock et al. 2009)
- Transportation, Air pollution and Physical Activities (TAPAS) model (Rojas-Rueda 2016)
- Health Economic Assessment Tool (HEAT) for walking and cycling (Kahlmeier et al. 2011), or
- Urban and TranspOrt Planning Health Impact Assessment (UTOPHIA) model (Mueller et al. 2017a).

Most of these models are considered to be more suitable as research tools than practical tools. For example, Nieuwenhuijsen et al. (2017) state that there is a need to develop and improve them further, but they have the potential to be used in practice. The current models are rather complicated and require extensive knowledge of use to avoid drawing false conclusions. Thus, there is a need for a comprehensive overview of the modelling of health impacts in order to use the existing models more widely.

The socio-economical model (SEM) (McLeroy et al. 1988) has earned its place in the discussion of health outcomes and the mechanism behind them. SEM is a theory-based framework for understanding the multifold and interactive effects of personal and environmental factors which determine individuals' behavior. SEM is used for identifying behavioral and organizational advantage points for health outcomes and their promotion. It consists of five hierarchical and nested levels, which are presented below with their explanations. In SEM, transportation is recognized as one of the community-level factors that determine individuals' behavior (McLeroy et al. 1988).

- Individual: Characteristics of an individual that influence behavior change, including knowledge, attitudes, behavior, self-efficacy, developmental history, gender, age, religious identity, racial/ethnic/caste identity, sexual orientation, socio-economic status, financial resources, values, goals, expectations, literacy, stigma, and others.
- Interpersonal: Formal and informal social networks and social support systems that can influence individual behaviors, including family, friends, peers, co-workers, religious networks, customs or traditions.
- Community: Relationships among organizations, institutions, and informational networks within defined boundaries, including the built environment, community leaders, businesses, and *transportation*.
- Organizational: Organizations or social institutions with rules and regulations for operations that affect how, or how well, services are provided to an individual or group.
- Policies and Enabling Environment: Local, state, national and global laws and policies, including policies regarding healthcare services, and restrictive policies (e.g., high fees or taxes for health services).

There are several models in the field of cognitive studies for behavior and its taxonomy. For example, Michie et al. (2011) have developed the COM-B model for behavior, which is established in health research. The abbreviation derives from the words capability, opportunity, motivation and behavior. The model is presented in Figure 5. The capability component consists of physical (e.g. strength, skills, stamina) and psychological (e.g. knowledge, skills, stamina) components. The opportunity component consists of physical (e.g. environmental, time, locations, and resources) and social (e.g. cultural norms, social cues) components. In turn, these two affect the motivation, which can be divided into reflective (e.g. brain processes, plans, evaluations) and automatic (e.g. desires, impulses, inhibitions) components. The two-headed arrows between these three and behavior indicate the complicated nature of behavior. To explore the impacts of automated driving on health, one important step is in understanding how it will, or whether it will, change the behavior of an individual and more widely of the population.

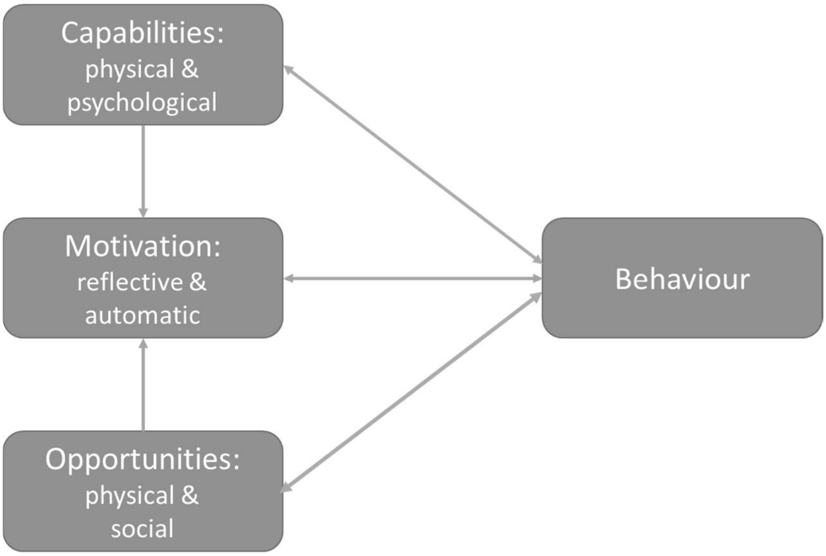

Figure 4. The COM-B model for understanding behavior in health discussion (Michie et al. 2011)

One way to approach individuals' behavior is that it is a combination of their decisions and choices. Thaler and Sunstein (2008) express the common truism as follows: "*We live in a complex world, where no individual choice is made entirely in isolation. Many factors shape our decisions, and our decisions then have consequences in subsequent choices.*" This notation is supplemented by Milne (2012), who brings the discussion into the context of health. His understanding is that behaviors are shaped from so-called cascades of choices, and it is useful to consider how such a cascade, for example in transport, may lead to effects on health and well-being.

To summarize the key findings in this area, it is important to understand the factors that concern individuals' behavior, decision-making and different choices when assessing the potential impacts on health and quality of life. In this thesis, the objective is to explore the qualitative aspects of transport and mobility with their health and quality-of-life implications. Further, the objective is to recognize potential pathways of action from the introduction of automated driving to its implications for health and quality of life. It is important to understand that the introduction of automated driving will not have impacts alone — it also requires change in people's daily mobility and travel patterns, and in the choices behind them.

2.3 Measuring health and quality of life

There are several measures for quantifying impacts on health and quality of life (Carr et al. 2001; Gold et al. 2002); it is useful to have a consistent overview of these when discussing the health implications of changes in transport system and mobility patterns. Table 2 is a practical guide to understanding the basic health-related measures and their connections with each other. The measures are collected from different sources and arranged under the topics of mortality, morbidity and quality of life consistent with this thesis. As can be seen, the mortality measures *years of life lost* and *potential years of life lost* are the easiest to quantify and assign a specific numeric value to. Proceeding further, through the morbidity measures *years lived with disability* and *disability-adjusted life years* and ending with the quality of life measures *quality-adjusted life years* and *healthy life expectancy*, the subjective nature of health and quality of life stands out. The qualitative measures are typically quantified by weighing them with desired factors of health, well-being and quality of life.

Use of the measures *years of life lost* and *potential years of life lost* is fairly straightforward. They are widely used to estimate the impacts of mortality in different cases. Both measures are used for premature mortality, but the difference lies in the concept of '*lost years*'. *Years of life lost* defines a different coefficient for different age groups in order to derive the life expectancy, whereas *potential years of life lost* uses the same age limit for *'full years'* or life (WHO 2004, PHAST 2017). Still, both measures weight the deaths that occur among younger people and therefore are more specific than general mortality rates. *Years lived with disability* is a measure that considers the morbidity aspect of health impacts. It aims to quantify the burden of living with a disease or disability, which is not noted within the *years of life lost* and *potential years of life lost* measures. An alternative for these is to use the *disability-adjusted life years* and *quality-adjusted life years* measures to estimate the effects of both disability and mortality.

Table 2. Health and quality of life measures

Measure	Name	Definition	Calculation	Source
Mortality				
YLL	Years of Life Lost	As an alternative to death rates, YLL take into account the age at which deaths occur by giving greater weight to deaths at younger age and lower weight to deaths at older age.	YLL are calculated from the number of deaths *N* multiplied by a standard life expectancy *L* at the age at which death occurs: YLL = N x L	WHO 2004
PYLL	Potential Years of Life Lost	PYLL take into account the average age of death from condition compared to average life expectancy. As YLL, also PYLL give more weight to deaths that occur among younger people.	PYLL are calculated adding up numer of deaths N_{cause}, due to a particular cause or multiple causes, at each age and multiplying this with the number of remaining years to live *y* up to a selected age limit, which is usually 75. So, PYLL = N_{cause} x 75-y.	PHAST 2017
Morbidity				
YLD	Years Lived with Disability	YLD take into account the number of disability cases by the average duration of the disease or disability, with a weighted value assigned to the type of disability. Sometimes, the opposite of YLD is used to measure the years lived *without* disability YWD.	YLD are calculated multiplying the disability cases *I* by their duration *L* and disability weight *DW*: YLD = I x L x DW. Here derives the formula for YWD = 1-YLD.	WHO 2004
DALY	Disability Adjusted Life Years	DALY measure the overall burden of disease, expressed as the cumulative number of years lost due to ill-health, disability or early death.	DALY are calculated by adding up the years of life lost and years lived with disability: DALY = YLL + YLD	NCCID 2015
Quality of Life				
QALY	Quality Adjusted Life Years	QALY measure both the quantity and the quality of life lived.It assumes that health is a function of length of life and quality of life, and combines these values into a single index number.	QALY are calculated by multiplying the number of years of additional life by an health realted quality of life: QALY = years of additional life x HRQL	NCCID 2015
HALE	Healthy Life Expectancy	HALE takes into account mortality and morbidity.It adjusts overall life expectancy by the amount of time lived in less than perfect health. This is the average number of years that a person can expect to live in 'full health' by taking into account years lived in less than full health due to disease and/or injury.	HALE is calculated by dividing the life expectancy into two factors: $L_{healthy}$ and $L_{disability}$, then multiplying $L_{disability}$ with disability weight *DW*. Now HALE = $L_{healthy}$ + DW x $L_{disability}$. Another way to calculate is to divide the years lived without disability with the number of survivors in the age group *I, then* HALE = YWD/I.	NCBI 2002, NSW 2017

Use of the measures *years of life lost* and *potential years of life lost* is fairly straightforward. They are widely used to estimate the impacts of mortality in different cases. Both measures are used for premature mortality, but the difference lies in the concept of '*lost years*'. *Years of life lost* defines a different coefficient for different age groups in order to derive the life expectancy, whereas *potential years of life lost* uses the same age limit for *'full years'* or life (WHO 2004, PHAST 2017). Still, both measures weight the deaths that occur among younger people and therefore are more specific than general mortality rates. *Years lived with disability* is a measure that considers the morbidity aspect of health impacts. It aims to quantify the burden of living with a disease or disability, which is not noted within the *years of life lost* and *potential years of life lost* measures. An alternative for these is to use the *disability-adjusted life years* and *quality-adjusted life years* measures to estimate the effects of both disability and mortality.

Both *disability-adjusted life years* and *quality-adjusted life years* belong under the concept of *health-adjusted life years* (HALY). *Health-adjusted life years* is the population health-summary measure typically used to estimate the burden of disease. The logic behind it is to weigh morbidity, as in disability, against quality of life by using *health-related quality of life* values and then combining them with the estimates of mortality using life expectancy. The difference between *disability-adjusted life years* and *quality-adjusted life years* is that the *health- related quality of life* values are inverted: *disability-adjusted life years* measures loss of health, whereas *quality-adjusted life years* measures the equivalent number of healthy years lived (NCCID 2015). The variety of *health-adjusted life years* measures is the reason they are increasingly used in the field of public health and *health impact assessment*, because of their ability to take healthy years into account compared to *years of life lost* and *years lived with disability.* The *healthy life expectancy* measure is close to *disability-adjusted life years* and even more so to *quality-adjusted life years*. Although it is not as widely used as these, it is still worth recognizing.

There are also more complex ways to measure quality of life. For example, WHO's globally used WHOQOL-100 and WHOQOL-BREF tools (WHO 2018b) and several domain-related subjective questionnaires (Carr et al. 2001) aim in their respective fields to understand how individuals perceive their current situation, well-being and quality of life.

The measurable and quantifiable impacts that transport and automated driving can have on health and quality of life are mainly outside the scope and objectives of this thesis. Still, it is important to understand how the impacts could be measured, e.g. in potential future activities. In this thesis, the noting of inverted values to well-being of health and quality-adjusted life years is important, as it sets apart the approaches to health and quality of life.

2.4 Transport, mobility and access

The relationship between transport, health and quality of life is complex. When exploring these, it is important to take into account the cognate subjects of mobility and accessibility (access). A fundamental building block of modern transportation planning is the notion that the demand for transportation is derived. This means that people rarely consume transportation for the pleasure of movement per se, but rather travel in order to reach opportunities available at destinations. (Merlin et al. 2018; Meyer & Miller 1984)

There is an ongoing debate over the definitions and their wider semantics, which is outside the scope of this study, but some definitions are useful to bear in mind for later. Usually traffic refers to vehicle movement, whereas mobility refers to the movement of people or goods, and accessibility refers to the ability to reach the desired goods, services, activities and destinations (Litman 2003). This thesis has also adopted the perspective of active mobility (interchangeably active travel), which includes active modes of transport, mostly walking and cycling, in the definition of mobility (e.g. Buehler et al. 2016). Duranton and Guerra's (2016) input to the discussion is that those three concepts are nested: traffic is a subset of mobility, and mobility is a subset of accessibility. This means that access is the widest perspective which should be considered most when discussing impacts in the transport system.

Innamaa et al. (2013) have developed a mobility model in which mobility consists of amount of travel, travel patterns and journey quality. This is shown in Figure 4. In the model, amount of travel consists of the number of journeys, length and duration, whereas travel patterns include timing, mode, route and adverse conditions. Finally, journey quality includes elements like user stress, user uncertainty, feeling of safety and feeling of comfort.

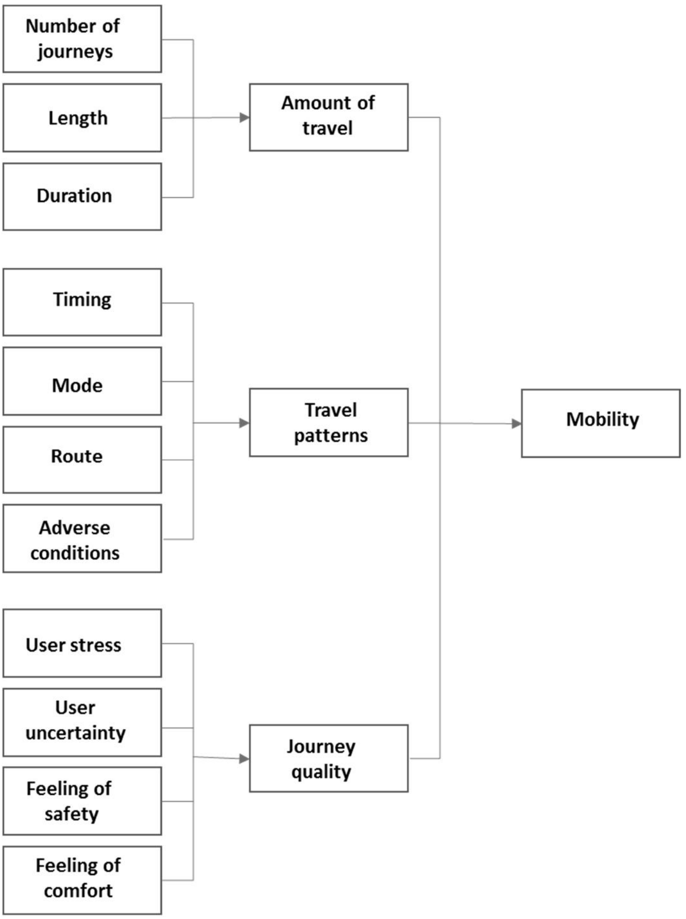

Figure 5. Mobility model (Innamaa et al. 2013)

Personal mobility is a concept which approaches mobility from the individual's point of view. Kuisma (2017) has concluded that personal mobility consists of three sections: personal variables, decision-making and travel characteristics. Personal variables include the individual's background and life situation, personality, identity and preferences, needs, resources and routines. Decision-making includes consideration as a willingness and ability to compromise, estimation of costs and benefits, and perception of opportunities and constraints. Kuisma notes the linkage between first two sections: the personality, identity and preferences of an individual affect the variables of consideration, which leads to decision-making. The third section, travel characteristics, is based on the mobility model presented above by Innamaa et al. (2013). The first two sections together can be seen as the *potential for travel* and the third section as *revealed travel* (Innamaa et al. 2013; Kuisma 2017). The concept of personal mobility has the advantage of approaching mobility from the individual's perspective. A person's choices lead to the revealed mobility, which has causal connections with health implications. Engwight (1993) defines accessibility as the *potential for interaction and exchange*. The notation of interaction is the strength of this definition, and it will be highlighted later when discussing societal health outcomes. Engwight's perspective is also in line with the premise of personal mobility as the *potential for travel* (Kuisma 2017).

In this thesis, mobility is considered as *ease of travel* and accessibility as *ease of reaching desired destinations*, and both are approached from the individual's perspective. Later, when discussing the health implications of transport, mobility and accessibility are clearly important dimensions to consider.

2.5 Transport-related health implications

There are several ways to approach transport-related health implications. Joffe and Mindell (2002) suggest that it is useful to develop a diagram linking the possible causes and effects within the road transport policies and their health implications. In the diagram, the organizing principle is to identify the possible policy interventions at one end, followed by the independent variables found by reviewing the potential causes, and the health outcome variables at the other end. Figure 6 presents the possible pathways of action for the change in traffic volume and speed (as output of policy intervention), ending in the health outcomes.

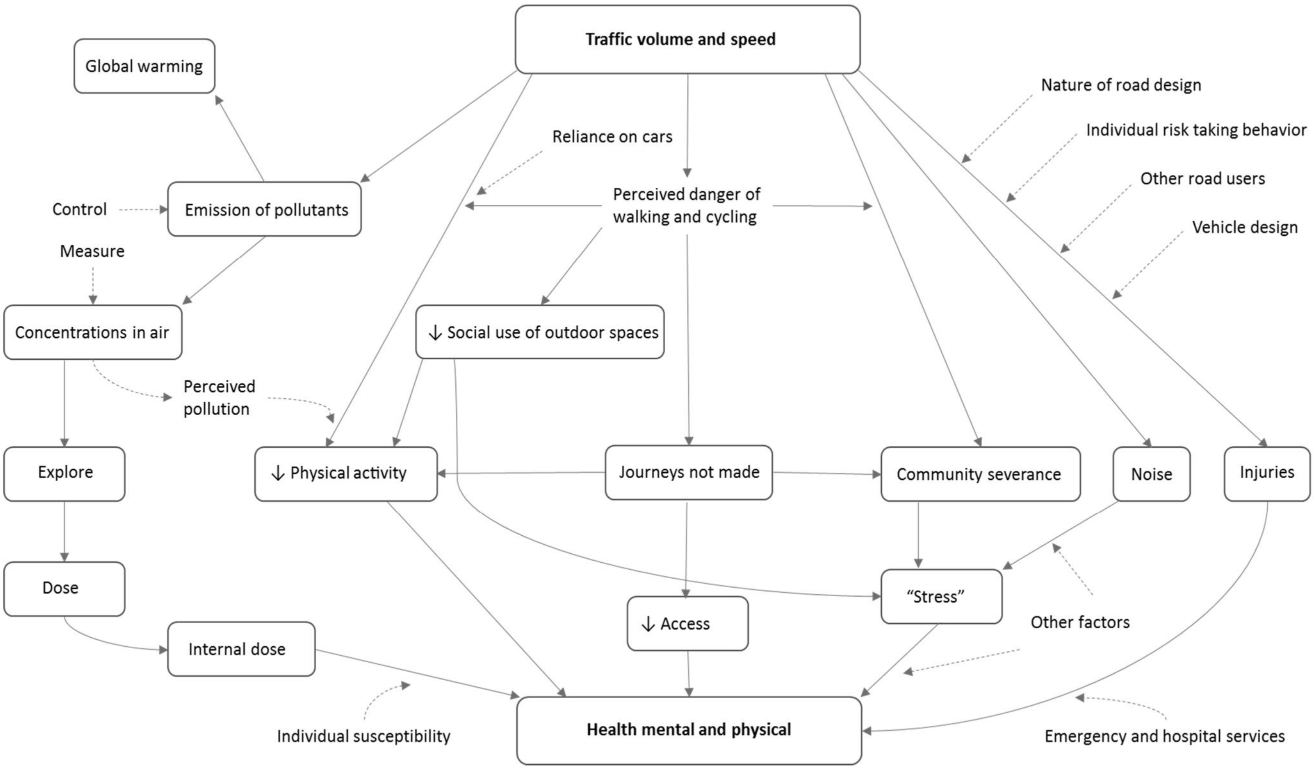

Figure 6. Diagram of pathways from changes in the traffic system to health outcomes (Joffe & Mindell 2002)

According to Joffe and Mindell (2002), this kind of diagram is useful as a reminder that policies typically have a wide range of effects on health, and on other impact areas such as the economy and the environment. They also note that each of the paths corresponding to each type of exposure should be further investigated separately.

The model by Nieuwenhuijsens (2016) suggests that policies, as a trigger for chance, can affect three different components of the system: urban design, activity and travel behavior, and pathways of health determinants. Nieuwenhuijsen concludes that mixed land use, connectivity and density of housing, transport infrastructure, walkability and bikeability and green spaces belong to urban design — whereas behavior consists of choices between indoor and outdoor activities and between different transport modes. Pathways for health determinants are divided into two groups: the first includes environmental factors like air pollution, noise, temperature and UV radiation; the second has other health determinants such as mental health, social contacts and physical activity. The model divides health outcomes into morbidity and mortality. Morbidity is divided further into different health outcomes, e.g. disease burden, and their state as acute or chronic, and mortality is interpreted as premature mortality. The model considers the individual's context by including socio-economic, genetic and nutritional factors into the model. The model is represented in Figure 7.

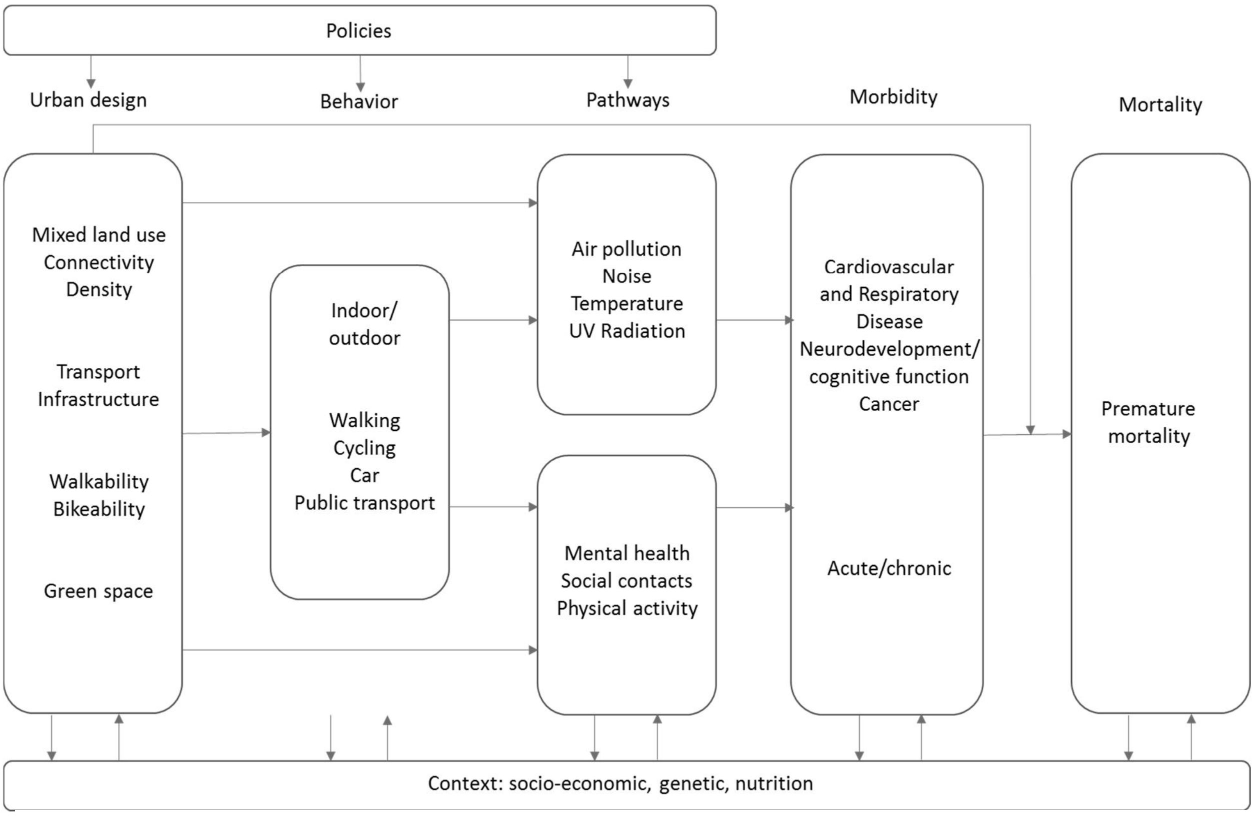

Figure 7. The relation between urban and transport planning, environmental expo-sures and health (Nieuwenhuijsen 2016)

Nieuwenhuijsen's (2016) model is advanced, as it includes the individual's behavior and socio-economic context in the framework of an urban and transport planning system. Naturally, this increases the complexity but it also widens the approach to health impacts and related components of the transport system.

Rojas-Rueda et al. (2013) have also illustrated pathways of action for transport and morbidity in Figure 8. Their model is consistent with the Nieuwenhuijsen (2016) framework. Here, the influences derive from urban transport policy change, which leads to a reduction in car use. In this model, reduction in car use flows either to replacing it with public transport or cycling, which are considered decision variables. This leads to three different approaches to health determinants of morbidity: physical activity, road traffic incidents and air pollution. Naturally, different health determinants have different health outcomes — differing disease burdens and injuries varying from minor to major. Health outputs can be quantified with the *disability-adjusted life years* measure.

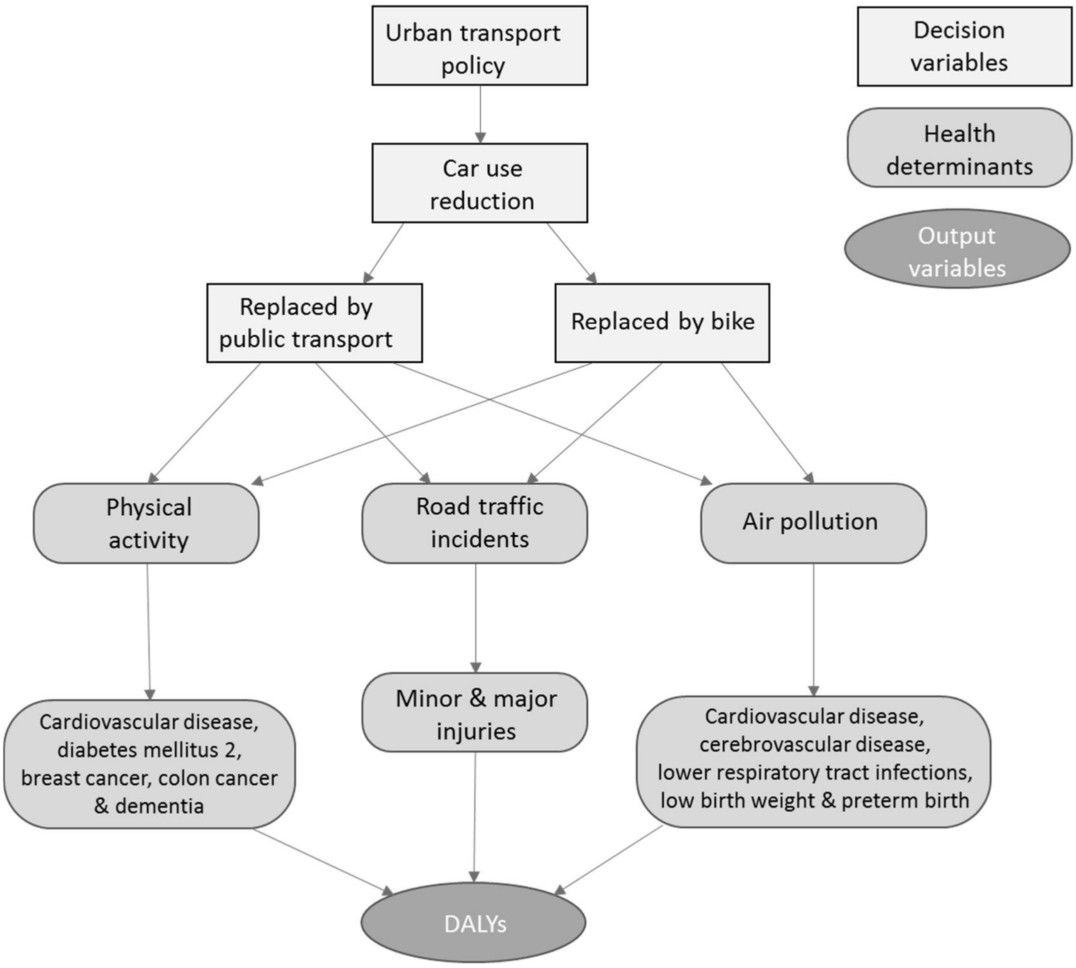

Figure 8. Urban transport policy view and pathways of transport and morbidity (Rojas-Rueda et al. 2013)
DALY = disability-adjusted life years

The above diagram by Rojas-Rueda et al. (2013) is a comprehensive aid to understanding the pathways of morbidity in the context of transport. It proceeds from policy to a change in system, which in turn leads to people's decisions and the corresponding health determinants and finally to outputs, which can be measured with *disability-adjusted life years.*

To summarize the key findings in this area, many frameworks and models for assessing the pathways and other sequential chains of events leading to different health outcomes are usually supposed to start with a change in policy or policies (e.g. Joffe & Mindell 2002; Nieuwenhuijsen 2016; Rojas-Rueda et al. 2013). This is typical of public health research in the field, where different interventions, programs and projects are aimed to change the system and/or behavior to advance the public health objectives (e.g. Acheson 1988; Satcher 2008). Still, the frameworks also support the assessment of different kinds of triggers for change. This thesis considers the introduction of automated driving as a trigger for change in the system, and as a start of the impact pathways leading to the impact areas of health and quality of life.

2.6 Transport-related quality of life

Carse's (2011) initial transport-related quality-of-life model is presented in Figure 9. The model suggests that there are four factors of transport-related quality of life (TQoL) that explain people's experience of public transport: economic, social, environmental or personal. Although the model is presented under the topic of public transport, it provides insight into both the objective and subjective attributes of TQoL, as it combines a number of factors together to explain domain-specific quality of life.

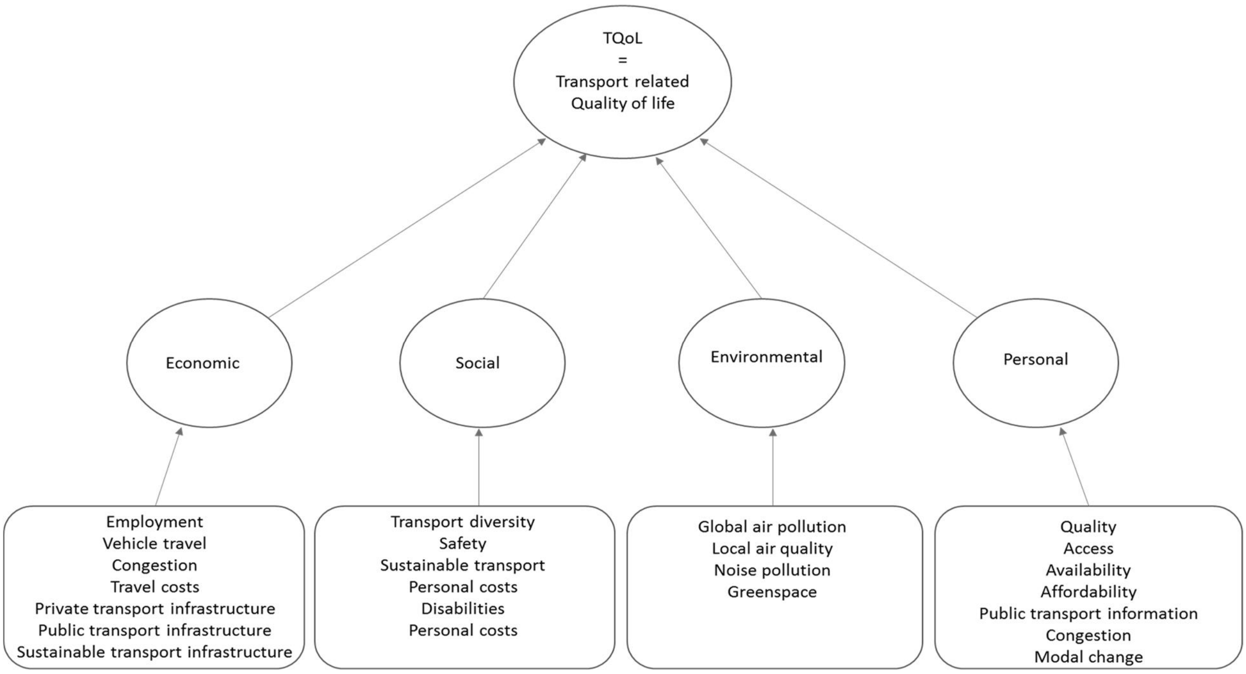

Figure 9. Initial transport-related quality of life (TQoL) (Carse 2011)

Carse (2011) elaborated the model further by re-categorizing the components of TQoL into access and availability in terms of reliability and services access, environment in terms of air quality and noise pollution, sustainable transport in terms of walking and cycling quality, personal safety, and transport costs in terms of travel costs and personal costs. These dimensions include the same indicators as the initial model.

Lee and Sener (2016) created a conceptual framework for transportation and quality of life based on three elements of the transport system: built environment, mobility and accessibility, and vehicle traffic (Figure 10). It adapts Kirch's (2008) division of quality of life into physical, economic (financial), mental (psychological) and social well-being. Lee and Sener stated that the most important building block of quality of life in the domain of transport is mobility and accessibility, thus they placed it at the center of their framework. Mobility and accessibility lead to all four dimensions of quality of life, whereas vehicle travel leads to three of them (physical, mental and social) and the built environment is connected to two (mental and physical). The two-headed arrows also indicate the feedback mechanisms in the model.

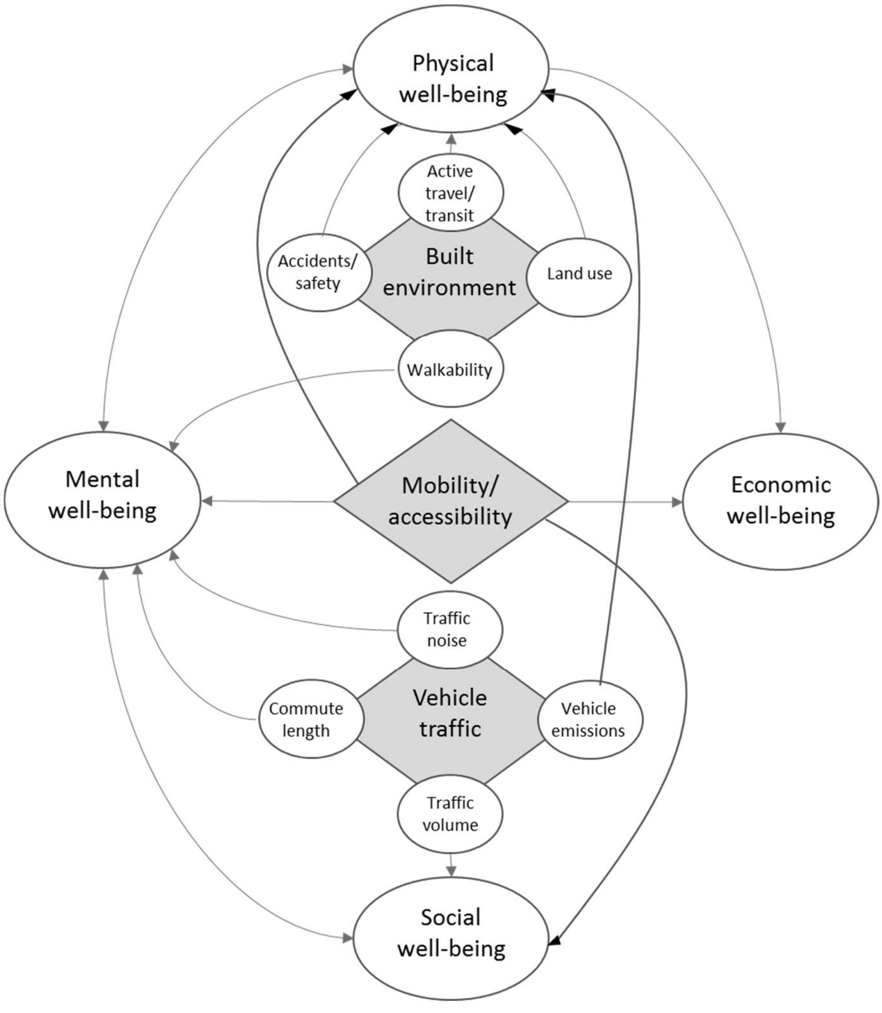

Figure 10. Transportation and quality of life (Lee & Sener 2016)

Comparing the model of Carse (2011) with that of Lee and Sener (2016), the former includes both the individuals' *perceived quality of life* and *travel quality* factors; the latter succeeds in presenting the individuals' quality of life determinants in the context of transport. Lee and Sener's model (2016) can be described as the status quo of quality of life and transport. It includes the broad transport domain-specific conceptualization of quality of life that encompasses both its subjective and objective elements. Thus, it is utilized in this thesis as a basis for understanding TQoL and its assessment.

2.7 Impacts of automated driving

To better understand the potential impacts of automated driving on health and quality of life, it is crucial to understand how automated vehicles can affect the transport system and our travel behavior as a whole. The transport system is a complex entirety, and automated vehicles will add to the diversity when introduced to the markets gradually. There is a growing body of research on the impacts of automated driving, some of which presents the potential impact paths or chain of events behind the suggested impacts. Cavoli et al. (2017) conclude that the potential impacts of automated driving have a significant bearing on consumer and public acceptance, which makes impact assessment highly important.

It is being discussed whether wide adaptation of automated driving could lead to increased travel demand and consequently a rise in vehicle kilometers travelled (e.g. Bierstedt et al. 2014; Fagnant & Kockelman 2015). For example, Bierstedt et al. (2014) estimate that improved driver experience or even no need for a driver, which would increase availability for those who would not otherwise use private vehicles, could increase the vehicle kilometers travelled (VKT) by as much as 35 percent. Even though increased VKT does not necessarily lead to increased congestion, it could well generate more congestion and associated negative impacts and thus offset some of the gained efficiency implications (Cavoli et al. 2017). Fagnant and Kockelman (2015) highlight that it demands comprehensive development of traffic management strategies, which should be implemented at an early stage for automated vehicles to improve traffic flow. One way to approach the impact of automated vehicles on traffic flow is the option to collect data for traffic and asset management. Increasing vehicle intelligence and connectivity is offering the opportunity to create a pool of data that could assist the road authority/operator. For example, anonymized location and destination data generated by the vehicle could enable the road authorities to make better short-term traffic forecasting and distribute vehicles more efficiently over the network (Hoadley 2018).

Also under discussion is whether automated driving could potentially increase highway capacity (e.g. Cavoli et al. 2017). Fagnant and Kockelman (2015) state that the potential to increase highway capacity would be partly enabled by the capacity of vehicles to travel closer to each other and with the use of other traffic-smoothing algorithms. Hoadley (2018) supports the claim that due to their ability to move in platoons with little headway, automated vehicles could enable traffic to flow more efficiently and smoothly. She notes that while platooning may be relatively simple for highway driving, it is less clear in city centers, where road links are short and interrupted by pedestrian crossings and parked vehicles.

Automated vehicles may contribute to increased VKT, which may have negative environmental impacts such as higher emissions, greater gasoline consumption and oil dependence. On the other hand, the trend toward shared mobility and automated vehicles could reduce the number of vehicles in use and therefore fuel consumption and emissions (Fagnant & Kockelman 2015). Thomopoulous and Givoni (2015) also suggest that using automated vehicles to boost car sharing has the potential to reduce environmental impacts. Furthermore, the energy and environmental impacts that automated vehicles are likely to generate will depend on whether they are low- or zero-emission vehicles. Cavoli et al. (2017) conclude that automated vehicles could lead to more energy-efficient driving, smoother traffic flow and reduced energy consumption, but the increase in VKT could garnish some of the benefits.

According to Hoadley (2018), potential road safety benefits are a key driver for automated driving development, which makes them important to assess. The road safety benefits are considered to derive from reducing human error, using technology to tackle driver distraction and enforcing road safety rules, and from safer interaction with non-users of automated vehicles. Cavoli et al. (2017) present that the main controversy in road safety discussions on automated vehicles stems not from the ability of automated vehicles to improve road safety, but the extent of the improvement. Frisoni et al. (2016) point out that the effective safety performance of automated systems has yet to be demonstrated and several technical challenges need to be tackled. This should be done before addressing the potential safety impacts of automated driving, to estimate the likely effects on the frequency and severity of traffic accidents and identify potential risks from improper human behavior. They also note that there is only little evidence available on the potential emergence of new risky situations, e.g. during the different penetration levels of automated driving.

The literature recognizes two major shifts in land use patterns which could be caused by automated vehicles: urban parking and sprawl (e.g. Cavoli et al. 2017; Hoadley 2018). First, it is suggested that once vehicles can drive themselves, a significant amount of both on-street and off-street parking could become needless. The vehicle would be able to drop off its occupants, then either drive off to a convenient parking spot or take on other passengers, cutting the demand for parking space. In other words, automated vehicles could have the potential to considerably reduce the time and energy spent driving around looking for parking spaces (Fagnant & Kockelman 2015; Frisoni et al. 2016). Still, Cavoli et al. (2017) note that the increased efficiency of roads dominated by automated vehicles may cause such an increase in travel demand that the space and capacity that they free up are needed to accommodate this demand. Second, travel time can be seen as a benefit of automated vehicles, since the cars' occupants would be able to spend the trip doing things that are more productive like reading, working or sleeping (Hoadley 2018). Still, if road systems become more efficient, and travel time becomes more comfortable and less demanding due to automated vehicles, people might be encouraged to travel farther distances on a regular basis (Cavoli et al. 2017). Urban sprawl could encourage greater car use to and within cities, leading to an increase in VKT, which is a great sustainability concern (Hoadley 2018). Increase in urban sprawl could have negative results, e.g. including worsening environmental issues associated with increased energy use, and the loss of recent gains for smart-growth urbanism (Cavoli et al. 2017; Frisoni et al. 2015; Hoadley 2018).

Cavoli et al. (2017) have recognized potential impacts of automated driving on accessibility and equity, and they present them as opportunities and limitations. Opportunities include automated vehicles possibly improving accessibility and independence for the elderly, disabled and non-drivers, and for people who live in areas not well serviced by public transport. The limitations include poorer social acceptance and less desire or ability to use automated vehicles among e.g. the elderly, disabled and children. Furthermore, these groups could be the last to benefit from automated driving due to safety standards and other potential requirements imposed on users of automated vehicles. Still, McCarthy et al. (2015) are slightly optimistic that automated vehicles could increase the mobility options and travel horizons for large sections of the population, which could lead to an increase in different economic, social and well-being opportunities. Cavoli et al. (2017) also note that shared mobility could be affordable to many users, creating better equity — although the initial high costs of automated vehicles could restrict their use to the wealthier segment of the population, counteracting this benefit. In addition, Enoch (2015) mentions that certain groups of the population, including the elderly, mobility impaired, young, and ethnic minorities, are usually the last group to benefit from the introduction of a new technology, often for financial reasons.

Fagnant and Kockelman (2015) note that potential economic impacts of automated driving may derive from crash savings, travel time reduction, fuel efficiency and parking benefits. Cavoli et al. (2017), on the other hand, recognize that industries like insurance, automobile repair and maintenance, retail and the health sector with public sector revenues from e.g. parking and other traffic violations may be negatively affected by the uptake of automated vehicles. Frisoni et al. (2016) stress that there could be a negative impact on employment, as professional drivers could become unnecessary. Hoadley (2018) notes that automation does not necessarily mean only losing current jobs, because new types of jobs may emerge. These new jobs are potentially less monotonous and demand diverse skill sets, which creates a need for new expertise. Frisoni et al. (2016) note that industries like automotive, technology, telecommunication and freight transport have the potential to create jobs because of automated vehicles. They also state that education and training will have a crucial role in preparing new generations to work in a more technological society, where new professions potentially replace those that are no longer needed. Cavoli et al. (2017) conclude that whereas lost jobs may be replaced by new ones, there will still be considerable economic disruption as a result of automated driving.

As stated earlier, use of automated vehicles may lead to an increase in VKT, which in turn may cause a drop in physical activity with negative health implications (Fagnant & Kockelman 2015). This is also suggested by Thomopoulos and Givoni (2015). Cavoli et al. (2017) conclude that automated vehicles could cause people to spend more time in their vehicles and less time being physically active. They suggest that the mass use of automated vehicles and its potential implications for walking, cycling and use of public transport should be investigated further. Additional health risks associated with long amounts of time spent sitting in (automated) vehicles include muscle cramps, back and neck pain, spinal disc degeneration and cardiovascular diseases (Bierstedt et al. 2014; Cavoli et al. 2017).

Milakis et al. (2015) use a ripple effect to model the potential and sequential effects of automated driving technology. In the model, policy- and society-related implications of level four driving automation are presented in three circles: the first represents the direct impacts and the second and third show indirect impacts. Different circles also represent different periods for the implications. The model suggests that short-term implications are related to traffic, travel costs and travel choices, whereas mid-term implications are divided into infrastructure, location choices and vehicles. The outermost circle includes the societal implications concerning e.g. health, safety, social equity, congestion, emissions, energy consumption and economy. These are, according to the model, the most challenging to predict, as they are long-term implications and outputs of the continuing and spreading impacts of automated driving from the inner circles. The ripple effect model is presented in Figure 11

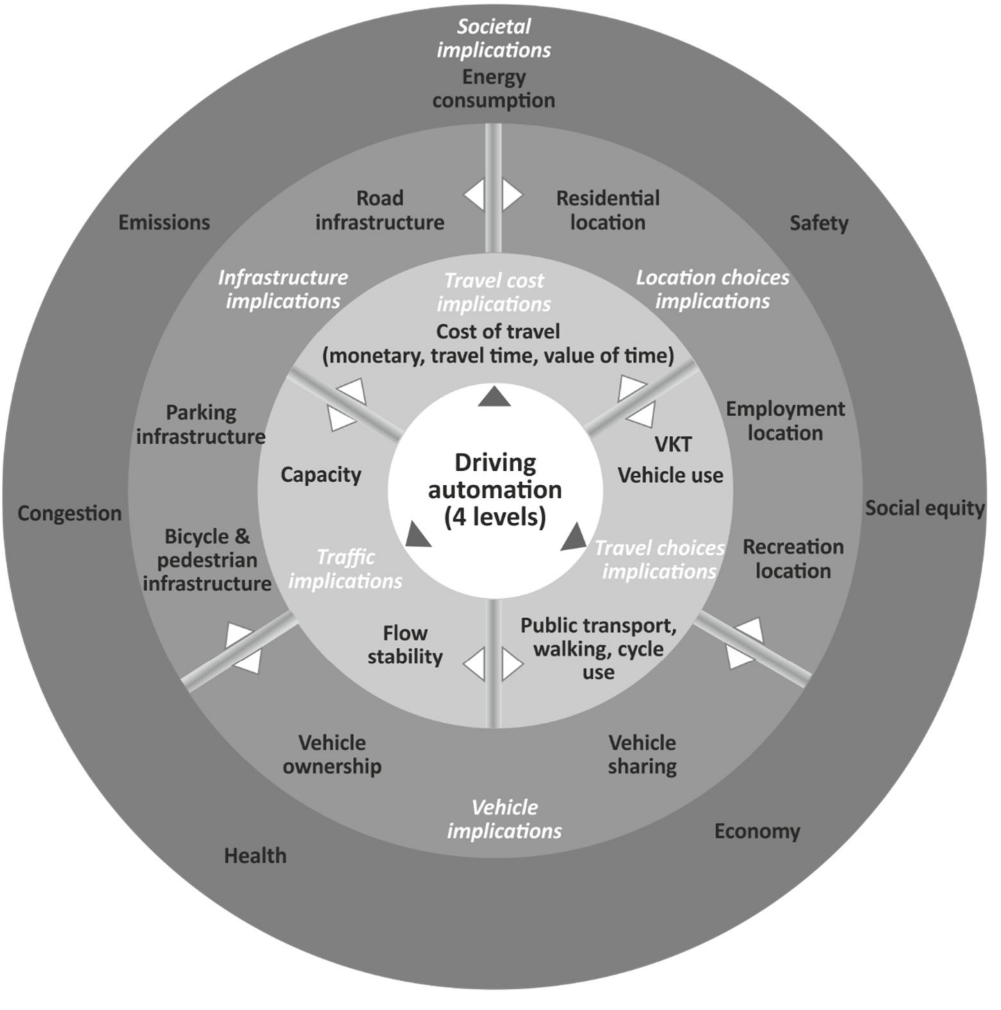

Figure 11. The ripple effect of automated driving (Milakis et al. 2015)

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The ripple effect of automated driving (Milakis et al. 2015) provides an extensive view to the potential implications of automated driving and enlightens the challenges of assessing the impacts: there are various factors to take into consideration, and changes in one will unavoidably affect the others. The authors also note that there can be a feedback mechanism between the different implications, which means that they do not necessarily advance in chronical order from short-term to long-term.

Innamaa et al. (2018) have advanced the assessment of the impacts and identified multiple different impact pathways for automated driving. Their impact paths start from direct impacts on the vehicle operations, driver or traveler, quality of travel, and transport system. They end at different impact areas such as safety, network efficiency, environment, quality of life, equity and public health. In between, stepwise impacts reveal the paths behind the change. Figure 12 indicates the potential pathways from the operation of the ADS to direct impacts and KPIs.

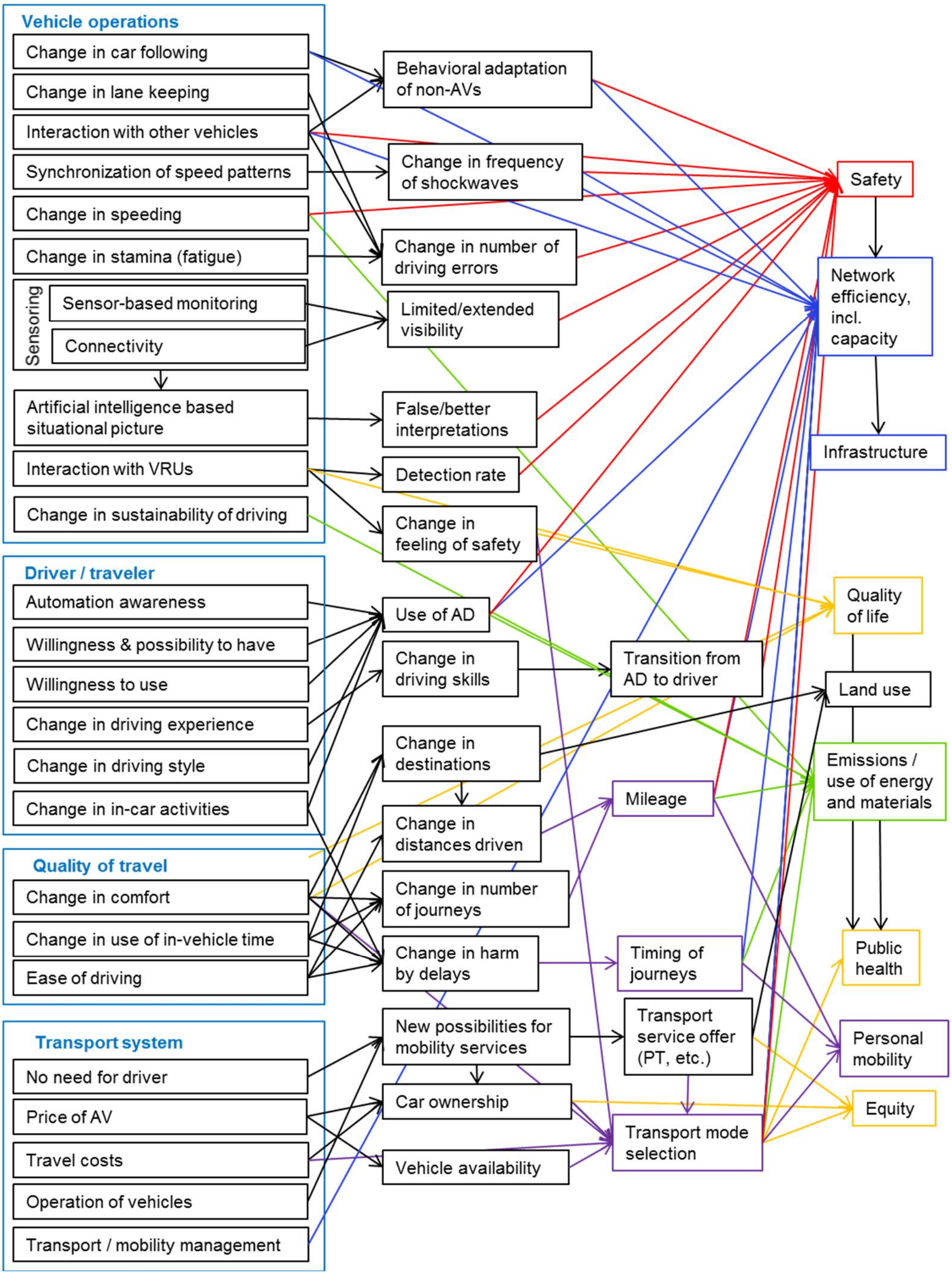

Figure 12. Impact pathways for automation in road transport (Innamaa et al.2018)

Innamaa et al. (2018) point out that the diagram is not inclusive but provides a starting point for systematically going through the impact paths for systems and impact areas of interest. The authors also recommend assessing the indirect links between different impact areas, because those are unavoidably linked together. Another important point is that when assessing the impact pathways, it is helpful to take into account the direction of change in the studied impact areas. This can be done, for example, by adding plus and minus signs to indicate whether there is a potential for increase or decrease.

To summarize the key findings in this area, the potential impacts of automated driving are unmistakably diverse and the linkages between them complex. For example, the impacts may not advance sequentially or chronologically, and there will be feedback mechanisms between different impacts. In this thesis, the impact areas of interest are in particular quality of life and health. These are explored further to better understand the potential impact paths and mechanisms behind them. The impact pathways for automation in road transport by Innamaa et al. (2018) are used as a starting point for recognizing both direct and indirect impacts that automated driving potentially has on the transport system, and other literature is used to support the assessment.

3. Methodology

This thesis was conducted as an *exploratory case study*. It is said that an exploratory study is a valuable means of finding out what is happening and seeking new insights (Robson 2002:59). It is also a good way to pursue a new perspective by asking questions and assessing phenomena in a new light. Its advantage is that it is flexible and adaptable to change (Saunders et al. 2009). Adams and Schvaneveldt (1991) described it as follows: "*Exploratory research can be likened to the activities of the traveller or explorer.*" This could not be truer when exploring the field of health impacts, mobility and automated driving. The methodological background and research design of the study is summarized in Figure 13 as the *methodology onion* by Saunders et al. (2009). The details are discussed more in depth in the following chapters.

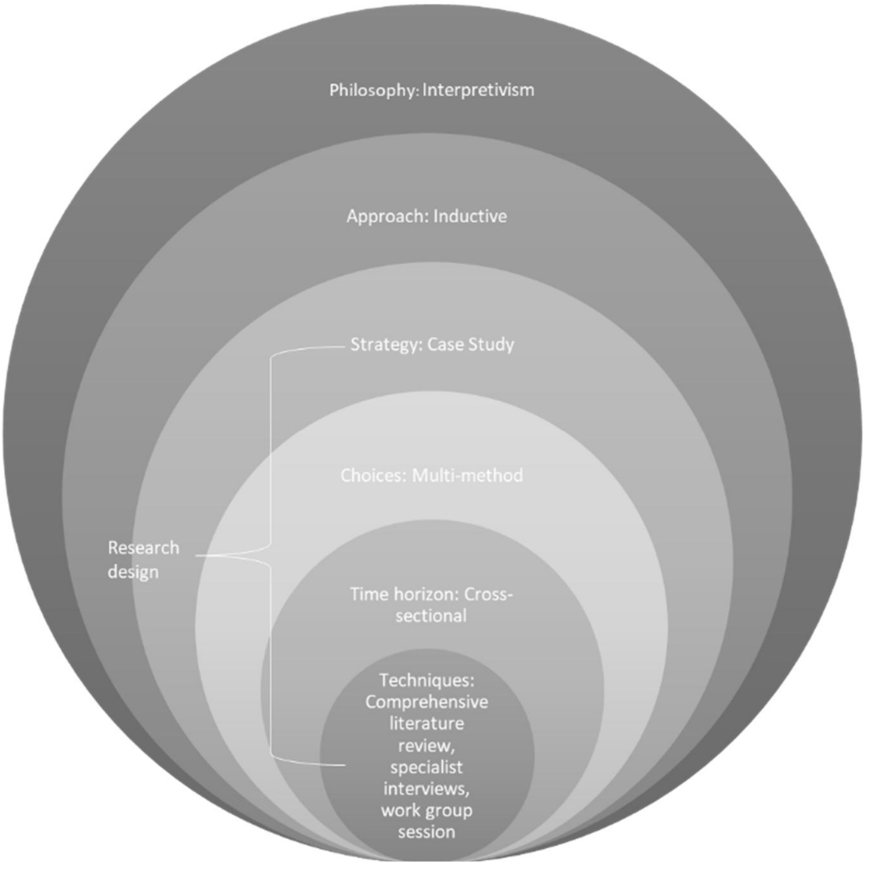

Figure 13. Methodology and research design of the study based on the "methodology onion" adapted from Saunders et al. 2009

3.1 Research philosophy and approach

This thesis has adapted interpretivism as a *research philosophy* with an *inductive approach*. Saunders et al. (2009) define interpretivism as the epistemological position that advocates the necessity to understand differences between humans in their role as social actors. The researcher's view of the nature of reality is thus socially constructed, subjective and may change during the process. The epistemology for interpretivism is that gained knowledge consists of subjective meaning and social phenomena. When adopting interpretivism as a research philosophy, it is important for the researcher to focus on the details of a situation, the reality behind these details, and the subjective meanings and motivating actions. These notations on interpretivism by Saunders et al. (2009) support an exploratory case study well, as flexibility and readiness to change is crucial for success.

The axiology of interpretivism (Saunders et al. 2009) defines that research is value-bound, and the researcher is part of what is being researched and cannot be separated from it. When adapting interpretivism as a research philosophy, most often the data collection techniques involve small samples, in-depth investigations and qualitative methods. Burrell and Morgan (1982) dispense a worthwhile thought about interpretivism and the research: "*…Your concern here would not be to achieve change in the order of things, it would be to understand and explain what is going on."* This thesis aims to understand better and explain the multiform connections of transport systems and health, well-being and quality of life. Flexibility and readiness to change are important in this study, as they exploit the existing knowledge of transport and health implications to the rather new phenomenon of automated driving.

The inductive *research approach* involves developing a theory from observed empirical data. This requires a close understanding of the research context, and usually the collected data is qualitative. Also, an important feature is having a more flexible structure allowing changes of research emphasis as the research progresses, with less concern over the need to generalize the results. (Saunders et al. 2009) The nature of the inductive approach also poses some challenges. Yin (2003) considers that it may be a difficult strategy to follow and may not lead to success for an inexperienced researcher. Saunders et al. (2009) complement this observation: "*This is likely to be the case where you simply go ahead and collect data without examining them to assess which themes are emerging from the data as you progress*."

With this in mind, data collection for this exploratory thesis was conducted as an iterative process right from the start to avoid the recognized (Yin 2003, Saunders et al. 2009) pitfalls. The collected data was analyzed during the process and utilized as collected. Also, the conceptual framework was continuously developed to guide subsequent work.

3.2 Strategy and design

The adapted research strategy in this thesis is a case study. Robson (2002:178) has defined a case study as “a strategy for doing research which involves an empirical investigation of a particular contemporary phenomenon within its real life context.” Yin (2003) also highlighted the importance of context, adding that within a case study, the boundaries between the phenomenon being studied and the context within which it is being studied are not evident. The case-study strategy is also a good option if the objective is to gain a rich understanding of the context of the research and the processes being enacted (Morris & Wood 1991). The case-study strategy also has considerable ability to generate answers to the question of why as well as the what and the how (Saunders et al. 2009).

In this thesis, the *case* is automated driving technology in the *context* of the transport system and its implications on health and quality of life. The case-study strategy is excellent for gaining insight into the various connections behind health and transport. It offers opportunities to find answers to explorative research questions like “How do transport and mobility choices affect health and quality of life?” and “How can automated driving impact health?” It also gives needed flexibility and a great opportunity to explore the phenomena in-depth (Saunders et al. 2009).

Figure 14 shows the *design* of the case study. The *research philosophy and approach* support the whole process and justify the meaning of the methodical choices made during the study. The *case* strategy provides the context and discussion to which this thesis contributes and ties it to the related research. The *techniques* used enable the pursuit of a wide range of qualitative knowledge and exploring the fields of transport, mobility, health and quality of life. The use of multiple techniques promotes the validity and reliability of the achieved results. The *results* were generated throughout the thesis process and all the phases contribute to each other. In addition, the inductive approach is clearly visible — the theory and conceptual framework are gradually developed during the process with the valuable contribution of specialists and a wide range of literature. The iterative process of the thesis writing is indicated by the flow of arrows between techniques and results, supported by the philosophy, approach and case strategy.

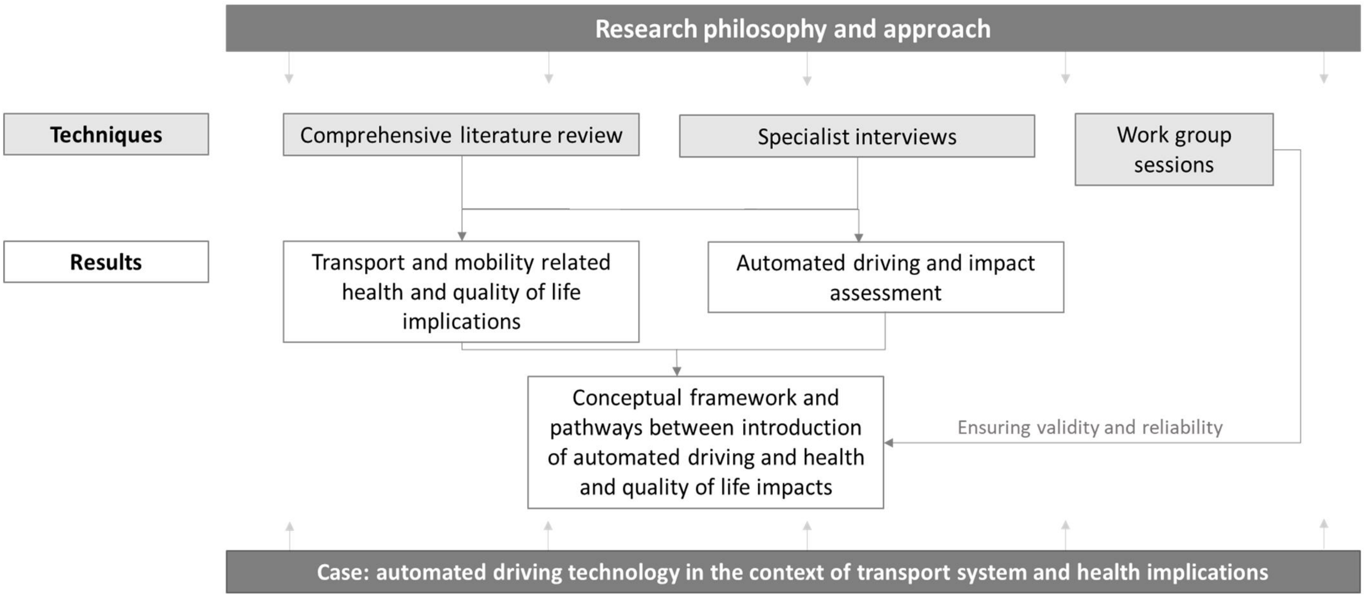

Figure 14. Research design and iterative process of the study

3.3 Technique and procedures

One important choice in this thesis was to conduct it as *a multi-method study*. This means that two *or more* data collection techniques and corresponding analysis procedures were utilized. There are three principal ways of conducting exploratory research: a search of the literature, interviewing specialists in the subject, and conducting focus-group interviews. (Saunders et al. 2009). This thesis conducted a c*omprehensive literature review* as the key element for pursuing knowledge, cross-sectional, *in-depth specialist interviews* to elaborate it further, and finally a working group session to assure the reliability and validity of the results.

The choice of data collection methods was consistent with the objectives of this thesis, which were to better understand how and why the use of automated driving technologies affects health and quality of life. The data collection techniques also support the exploratory nature of the study by gathering preliminary information that will help define problems that are more concrete, identify future research needs, and suggest new hypotheses (Babbie 2007).

The literature review is often seen as a compulsory introduction to the current state of knowledge in the field of interest, and as a summary that gives readers easy access to research on the topic. However, it can also be a method in itself for summarizing past empirical and/or theoretical research to give a more comprehensive understanding of a given phenomenon or problem. This approach is referred to as an integrative review (Broome 1993) or comprehensive literature review (Onwuegbuzie & Frels 2015). Whittemore & Knafl (2005) conclude that the integrative review has the potential to allow diverse primary research methods to become a greater part of research practice initiatives.

Onwuegbuzie and Frels (2015:49) highlight that the information a reviewer collects to form a literature review builds on data extracted from many sources. Thus, the literature review is a data collection tool — a means of collecting a body of information pertinent to a topic of interest. The authors note that the literature review represents a formal data collection process where information is gathered in a comprehensive way. They suggest that a comprehensive literature review should be conducted in three phases: *exploration*, *interpretation* and *communication*. The first phase includes exploring the topic of interest, initiating the search, storing and organizing information, and selecting or deselecting information. The last part of this phase involves expanding the search to include one or more of the following: media, observations, documents, *specialists* or secondary data. Next, the interpretation phase includes analyzing and synthesizing the information, and finally the communication phase consists of presenting the results as a study report.

The conceptual framework of this thesis was constructed in accordance with the three phases above. In the exploration phase, the data was collected from different sources, mostly from large scientific databases such as Elsevier, Springer Link, Scopus and Emerald Insight. The selected articles were all peer-reviewed and pertinent to transport and health outcomes. The gathered information was then formulated into an initial conceptual framework and discussed with specialists in the field. In the interpretation phase, the information obtained from the literature and the interviews was analyzed and synthesized into a final conceptual framework. In the communication phase, the results were reported and discussed. Finally, the prior results were elaborated to identify potential pathways of automated driving and health outcomes, with the support of theoretical background and related state-of-art research.

According to Saunders et al. (2009), in semi-structured interviews the researcher will have a list of themes and questions to be covered, although these may vary from interview to interview and the order of questions may also vary depending on the flow of the conversation. Unstructured interviews are informal and there is no predetermined list of questions to work through in this situation, although it is necessary to have a clear idea of the aspects to explore. The interviewee is given the opportunity to talk freely about events, behavior and beliefs in relation to the topic area, so that this type of interaction is sometimes called 'non-directive'. It has also been labeled as an informant interview, since it is the interviewee's perceptions that guide the conduct of the interview. (Easterby-Smith et al. 2008)

Triangulation refers to the use of multiple methods or data sources in qualitative research to develop a comprehensive understanding of phenomena (Patton 1999). Triangulation has also been viewed as a qualitative research strategy to test validity through the convergence of information from different sources (Carter et al. 2014). In other words, it helps to ensure that the data is telling the researcher what one thinks it is telling (Saunders et al. 2009). This thesis capitalizes both on method triangulation and on data source triangulation. First, both methods are utilized in the data collection, and second, in the in-depth interviews with specialists from different fields of transport, mobility and public health. The interviewees were found mostly through two sampling strategies: purposively searched from earlier studies; and snowballing, e.g. asking previous interviewees for new suitable contacts.

The interviews were conducted one-to-one or in small groups, both face-to-face and online. The interviews were non-standardized, informal and dialogic with elements from both semi-structured and unstructured formats. All interviews were conducted during the fall of 2018. Due to the broad nature of the interviews they were audio-recorded to facilitate note taking. The semi-structured and unstructured structures made it possible to explore in-depth the manifold field of transport, mobility and health outcomes. Table 3 provides some background on the interviews. The main topics were:

- The conceptual framework of the thesis and its components
- Transport, mobility and health outcomes, e.g. different risk factors
- Health assessment, e.g. understanding the concept and different measures
- Potential, and partly speculative, pathways for automated driving and health outcomes

Finally, the results from the comprehensive literature review and specialist interviews were discussed in working-group sessions, once the results had been processed into initial impact pathways. The aim of the sessions was to ensure the reliability and validity of the interpretations and focus on the potential pathways from introduction of automated driving to its implications on health and quality of life. The participants in the working group were principal scientists from the Technical Research Centre of Finland Ltd.

Table 3. Interview background

Interviewee's organization	Interviewee's role in the organization	Interviewee's field of expertise	Date and length of the interview
University of Cambridge School of Clinical Medicine	Senior Research Associate, Ph.D.	Transport, environment and health studies, health impact assessment, risk assessment	31 Oct 2018 1 hr 7 min
VTT Technical Research Centre of Finland Ltd.	Senior Scientist, Ph.D.	Health and well-being services, prevention of lifestyle diseases and self-management of health, evaluation and data-analysis	2 Nov 2018 1 hr 13 min
UKK Institute	Senior Researcher, D.Sc.	Physical activity, physical activity assessment, health project and intervention development and evaluation	2 Nov 2018 54 min
Tampere University	Associate Professor, D.Sc.	Emerging technologies, innovations, impact assessment	5 Nov 2018 1 hr 18 min
National Institute for Health and Welfare	1) Research Professor, MD. 2) Senior Researcher, Ph.D.	1) Public health, health promoting and disease prevention, health governance 2) Epidemiology, physical activity, public health	6 Nov 2018 1 hr 30 min

3.4 Research ethics

Research ethics relates to questions about how a research topic is formulated and clarified, and how the whole research is designed. It is important to take into consideration which are the means to gain access, collect, process and store data. Research ethics also relates to questions about how to analyze data and write up the research findings in a moral and responsible way. In conclusion, it is crucial that the research design is both methodologically sound and morally defensible to all those who are involved. (Saunders et al. 2009) This thesis was conducted under the auspices of Tampere University and VTT Technical Research Centre of Finland Ltd. Both organizations comply with good scientific practice, and both expect and urge researchers to follow the guidelines of ethically sustainable research.

The ethical aspects of in this thesis include the following:

- The interviewees received a short summary of the study, its purpose and objectives before the interview.
- The interviewees participated voluntarily and were asked for permission to conduct the interview.
- The interviewees were asked for permission to audio-record the interviews.
- The interviewees were asked for permission to contact them later if needed and advised to contact the thesis worker if they had any concerns.
- The interviewees were asked to comment on and check the sections including their information and those discussing the results of the interviews.

The collected data was handled by the thesis worker with confidentiality. The anonymity of the participants was assured by processing the recordings and removing all personal data. All the research data are stored according to VTT's Confidentiality and Information Management guidelines until the end of August 2021. In addition, the originality of this thesis has been checked using the Turnitin OriginalityCheck service.

4. Results

The results of this study were generated through an iterative process. First, the impact areas of health and quality of life in the domain of transport were studied based on the literature. From the findings, the potential outcomes and determinants for health and quality of life were formulated into an initial conceptual framework. Next, the specialist interviews were conducted and the conceptual framework updated based on the comments and ideas from the interviewees and supporting literature. Then, the *wheel model of quality of life and health impacts of transport* was finalized. The interviews and previous literature provided qualitative data and worthwhile insights into automated driving also in the context of transport and health impacts. The conceptual framework, previous literature and interviews were used to formulate potential pathways for automated driving and its health and quality of life implications. To assure the validity of the results, they were finalized in a working group session held at VTT Technical Research Centre of Finland Ltd. Thus the process behind the results evolved from insights to actions and impacts.

4.1 Specialist interviews

The specialist interviews provided rich qualitative data on the topic and helped gain a better understanding on health, well-being and quality of life in the context of transport and its transformation. To begin with, it became evident from the interviews that it is challenging to assess the health and quality of life implications of automated driving for several reasons. For example, automated driving and vehicles, along with their potential implications, are such a new phenomenon that there is not much knowledge or data available as yet. Conversely, there *is* a lot of detailed knowledge on transport and its health implications for different risk factors, but a coherent overall picture is lacking, which provides its own challenges for assessing the health implications of transport and its transformations. In addition, typically in health research a topic is more clearly limited in scope and the studied phenomena are more concrete. Furthermore, the interventions, programs and policy impacts are researched following established practice, i.e. with evidence-based interventions with control groups and longitudinal follow-up. There are also several other factors and trends, alongside the introduction of automated driving, which will have their own health implications in the context of transport. Thus, in this case, other trends affecting the transport system are not included to avoid excessive complexity.

The results from interviews were utilized throughout the thesis process — whether to find new viewpoints and support the theoretical background, clarify the conceptual framework building, or develop potential pathways for automated driving resulting in health and quality-of-life outcomes. Thus, the main results are embedded in the study. However, the interviews also yielded interesting insights, which are presented under the topics that emerged.

Every step and minute counts

In every interview there was consensus that each step and minute of added physical activity is beneficial to health, and this does not mean doing exactly 10-minute sessions or more. This is especially true compared to sitting or standing still. The health benefits of adding even modest physical activity are greater for those at a lower starting level, meaning that people who have moved less will gain more noticeable health benefits than those who already exercise regularly. Specialists also agreed that the health benefits of adding physical activity outdo the potential risks, such as increased exposure to emissions and/or injuries during active travel. One of the specialists concluded that from a health perspective, people should prefer active travel whenever possible.

Automated driving can have negative health implications if it affects physical activity and/or active travel, for instance if there is a modal shift away from walking, cycling and public transport. The specialists affirmed the importance of so-called "last-mile walking and cycling" as part of daily activity, and if automated vehicles carry people from door to door this activity is lost. This should be encouraged for people who do not exercise otherwise but are active while commuting between home and work or school. Active travel was also seen as an *easy way* to collect active minutes during the week; for example if a person cycles or walks 10 minutes to work and 10 minutes back five times a week, this equates to 100 minutes of health-beneficial physical activity per week that could be hard to collect otherwise. One specialist concluded that the mortality rate can drop by as much as 20% when an person starts to cycle 5–6 km trips five times a week, for example when commuting.

People tend to seek convenience and comfort

Another fascinating insight was that automated driving and new mobility services could be seen as a blend of private and public transport, as it combines the ease of private travel with the comfort of public transport. The potential change in mobility services (e.g. shared vehicles and mobility as a service) could lead to where a person orders a *robot-taxi* from door to door whenever needed, either for themselves or for underage children or elderly people. Traveling door to door on one's own schedule is characteristic of private transport, whereas public transport offers the comfort of not driving oneself or having to look for parking. This could lead to an increase in perceived convenience, and hence to a growth in mileage and time spent passively sitting in the car.

The specialists agreed that changes in the convenience and comfort of travel could have many other health implications in addition to physical activity. They could increase accessibility for different groups, including the elderly and others with limited mobility for health and other reasons. Increased accessibility can lead to better social relationships, greater self-determination and improved occupational performance, all of which are considered important health factors for any individual. On the downside, one specialist shared an important concern about passive travel and underage children. In certain phases of development it is crucial that children get to explore and take responsibility for themselves appropriately for their age, and independent mobility is a key factor. Walking and cycling to school is a great way to learn responsibility, and if automated vehicles and mobility services change the travel to a passive form, this can affect the development and cognition of children and youth. On the upside, automated vehicles are thought to lead to more efficient driving and congestion management, which would decrease emissions alongside the parallel trend towards transport electrification. Still, the increase in mileage may negate some of these gains if people start shifting to private vehicles from active and/or public transport.

A product of the environment

During the interviews it was clear that a person's environment, i.e. physical, cultural and social surroundings, widely affects their behavior and thus health implications. All the institutions, systems, attitudes and lifestyles joined together create the environment for our daily decisions. One example from the transport field is that in bigger cities young people tend to postpone getting a driver's license for multiple reasons, including cost, effective public transport, a more climate-friendly mindset, cycling becoming more popular, and an infrastructure developed to encourage more active travel. Still, outside these urban areas private transport is crucial to daily mobility. As one of the specialists put it, it is easy to make healthy choices when the environment encourages you to do so. Conversely, it matters little how *mindful* a person is if the environment does not support it. Another insight was what is acceptable in terms of health and quality of life when introducing automated driving. Some of the specialists indicated that weighing of the potential pros and cons and setting a baseline for automated driving and health implications (among safety and ethical issues) is a complicated process. Still, introducing a new radical technology gives everyone a chance to re-think the system as whole.

The arrival of automated driving may work as a trigger for people to assess their behavior and challenge the automatic heuristic behind it. For example, the introduction of automated vehicles and potential new mobility services may change their daily routines and patterns of behavior. However, simply introducing automated driving is not enough to create wider health implications. It is *how* it is done, and the level of acceptance and adaption on the markets, that will change the transport system as a whole. In conclusion, it is important to understand how automated driving and the related services may change the system and the environment for people's daily travel.

Small harm to the individual, great hindrance to the public

The subjective nature of people's perceptions of their own health and especially their quality of life emerged repeatedly in the interviews. One specialist argued that usually, quality-of-life aspects are almost forgotten or are embedded in other transport perspectives like efficiency, mobility and safety. As another concluded, quality-of-life implications are generally a byproduct of other, more concrete, transport planning initiatives, which makes them hard to assess. Still, they have the potential for significant harm for both individuals and the society as a whole. For example, noise, vibration and hurry while traveling or in residential areas may cause stress, annoyance, sleep deprivation and other cognitive impairments, which can be difficult for the individual to recognize but affect occupational performance and well-being significantly. There are also many other quality-of-life implications of transport that are even harder to assess but should be considered. These are well-being as a whole, including social relationships and networks, employment and other self-determination opportunities, access to both requisite and recreational services, and overall satisfaction with daily mobility. Another insight was that people may not think about the health implications until some condition is found or symptoms emerge; preventive steps are not as effective in their eyes as curative action. One specialist concluded that an ideal (transport) system should provide healthy means of travel as a premise, because people in general cannot be trusted to make the required sustainable and healthy choices.

Understanding the indistinguishable health and quality-of-life implications of transport gives great opportunity to take them into account when discussing the potential impacts of automated driving. One specialist thought that since efficiency and safety-related issues are rather well considered nowadays, there is more room to consider quality-of-life aspects and how they could be implemented a little more. All of the specialists interviewed were moderately positive about the potential health and quality-of-life implications of automated driving, provided the pros and cons are taken into account during the development and decision-making phases.

Key learning points

The key learning points from the interviews were:

- Comments received on the initial framework, including the classification of implications
- Input on health terminology and consistency of use
- Comments on the importance of behavior, environment and socio-economic context in health impact assessments
- Vivid discussions and valuable remarks on automated driving and its health implications
- Several tips for further reading.

4.2 Conceptual framework for transport-originated health outcomes

This chapter addresses the first research question "What should be included in the concept of 'health of the population' when addressing the implications of transport and mobility?" with the objective of building the conceptual framework for the thesis.

The foundation for the framework was based on the following observations from the previous literature:

- One way to approach health is via its typical indicators *morbidity* and *mortality* (e.g. Larsson & Mercer 2004).
- Nowadays, also the overlapping concept of *quality of life* and its four dimensions of well-being are more widely recognized together with the health discussion in the context of transport (Lee & Sener 2016; Steg & Gifford 2005).
- Quality of life can be approached via its four dimensions: physical, psychological, social and economic well-being (Kirch 2008).
- *Disability adjusted life years* measure health loss whereas *quality adjusted life years* measure health gain, thus they express an inverse value. (NCCID 2015).

The following chapters present separately the findings from the comprehensive literature review for different indicators of health and quality of life. The aim was to identify different factors and health outcomes in this critical review. The second research question, “How do transport and mobility choices affect health and quality of life?” was also addressed at this stage. This chapter provides some practical examples of the indicators and measures of health impacts in different categories, in support of the discussion presented later.

4.2.1 Mortality

This thesis focuses more on health, quality of life and their intersection in well-being. Still, when discussing health and road transport as a whole, it is important to include mortality to gain a proper perspective of health outcomes. According to WHO statistics (2018c), road injuries killed 1.35 million people globally in 2016, about three-quarters of whom were men and boys. In Europe, the number of fatalities in road accidents was around 25,000 and in the US 41,000 in 2016. By this account, road injuries come eighth among the top ten causes of death worldwide. More than half (54%) of all road traffic deaths are among vulnerable road users: pedestrians, cyclists and motorcyclists. In addition, road traffic injuries are the leading cause of death among children and young adults aged 5–29 years (WHO 2018c, NSC 2017).

In the EU, the recommendation for member states is that natural deaths and suicides should be excluded from road death statistics to harmonize the system regionally (ETSC 2018). Deaths from natural causes while driving are somewhat rare and represent around 2% of all road deaths in Europe. In the EU, the exact scope of suicides in road traffic is unknown but is estimated to range from 1% to 7% of all driver deaths (ETSC 2018). In Finland, suicide accounts for around 16% (Trafi 2016) and in Sweden for around 10% of all driver deaths (Trafikverket 2017).

Key risk factors for fatal road accidents are speeding, driving under the influence of alcohol and other psychoactive substances, and non-use of a motorcycle helmet, seat-belt or child restraint system. In addition, distracted driving, unsafe road infrastructure and vehicles, and inadequate post-crash care are mentioned as marked risk factors. (WHO 2018c)

4.2.2 Morbidity

Morbidity is an untoward event or complication in the health of a person, which under optimal conditions would not be a natural consequence of that person's disease or treatment (Zaoutis & Chiang 2007). In this thesis, morbidity is interpreted as having a condition or symptom(s) of a disease.

Several studies suggest that urban transport and its different aspects have myriad connections to morbidity. Motor vehicle crashes alone cause minor and major injuries, traumas, post-traumatic stress and other indirect impacts including less active travel and physical activity (e.g. Bhalla et al. 2014; Khreis et al. 2017). For example, Rissanen et al. (2017) state that today's reductions in road fatalities are in concurrence with the increased likelihood of surviving serious crashes. Thus, in many high-income countries the burden of road traffic injuries has shifted from premature death to injury and disability with long-term consequences. Moreover, the number of serious road traffic injuries has not been dropping as fast as the number of fatalities in some countries, and has even been on the rise in others (Berecki-Gisolf et al. 2013; OECD/ITS 2011).

Physical inactivity can lead to undesired effects like cardiovascular disease, type-2 diabetes, dementia, breast cancer, colon cancer and obesity (Hamer & Chida 2009; Harriss et al. 2009; Jerrett et al. 2014; Monninkhof et al. 2007). In addition, physically active adults are likely to have less risk of a hip or vertebral fracture. Moreover, even small increases in exercise training can minimize the decrease in spine and hipbone mineral density and enhance skeletal muscle mass, strength, power and intrinsic neuromuscular activation (Bauman & Craig 2005; Rassioukov et al. 2009; Warburton et al. 2007).

Table 4 provides examples of physical activity and health outcomes on morbidity listed by Rojas-Rueda et al. (2013). The values are derived from a systematic review and the method for analyzing health outcomes is the dose-response model, where for a given level of exposure a certain effect will result. In this, the dose is a physical activity and the response is the health outcome with respect to various diseases as listed in Table 4. The unit for physical activity is given as hours, calories or the commonly used metabolic equivalent of task value (MET). One MET is roughly equivalent to the energy expenditure of sitting quietly at rest. The dose-response model gives the coefficient for the original probability (without the physical activity) of having the condition or illness. For example, 3 hours per week at 3 km/h (equivalent to 7.5 METs) lowers the probability of getting cardiovascular disease by 16% (with 95% confidence interval 0.79–0.9) (Hamer & Chida 2009; Rojas-Rueda et al. 2013). Several studies suggest similar results for morbidity in urban traffic (e.g. Kreish et al. 2017; Maizlish et al. 2013; Woodcock et al. 2011).

Table 4. Physical activity and health outcomes (Rojas-Rueda et al. 2013)

Health determinant	Outcome	Dose–response model and 95% confidence interval	Unit	Reference
Physical activity				
	Cardiovascular diseases	0.84 (0.79–0.9)	3 h per week at 3 km/h: 7.5 METs	Hamer and Chida (2008)
	Dementia	0.72 (0.6–0.86)	33 METs per week (> 1657 kcal per week)	Hamer and Chida (2009)
	Type 2 diabetes incidence	0.83 (0.75–0.91)	Per 10 METs per week	Jeon et al. (2007)
	Breast cancer women	0.94 (0.92–0.97)	For each additional hour per week	Monninkhof et al. (2007)
	Colon cancer men	0.8 (0.67–0.96)	Per 30,1 METs per week	Harriss et al. (2009)
	Colon cancer women	0.86 (0.76–0.98)	Per 30,9 METs per week	Harriss et al. (2009)

Physical activity is clearly a crucial factor within transport and its outcomes on health. The connection between physical activity and morbidity has long been known, and physical activity is recognized as an important component in preventive, curative and rehabilitating processes against morbidity. WHO provides global recommendations on physical activity for health, which local authorities are expected to put into practice. For example, the widely recognized rules of thumb for retaining and advancing health provided by WHO (2010) are:

- Adults aged 18–64 should do at least 150 minutes of moderate-intensity aerobic physical activity throughout the week or do at least 75 minutes of vigorous-intensity aerobic physical activity throughout the week or an equivalent combination of moderate- and vigorous-intensity activity.
- Aerobic activity should be performed in bouts of at least 10 minutes' duration.
- For additional health benefits, adults should increase their moderate-intensity aerobic physical activity to 300 minutes per week, or engage in 150 minutes of vigorous-intensity aerobic physical activity per week, or an equivalent combination of moderate- and vigorous-intensity activity.
- Muscle-strengthening activities should be done involving major muscle groups on two or more days a week.

Urban transport and specifically road transport have several impacts on the environment, leading to further health implications. The most common health determinants of transport in the context of the environment are air pollution, noise, heat, and land use including green spaces and walkability (Khreis et al. 2017; Mueller et al. 2017b). Rojas-Rueda et al. (2013) have studied air pollution with $PM_{2.5}$ as a health determinant of urban transport. Table 5 shows a similar composition to those above for physical activity (Table 4). As can be seen, air pollution causes its own disease burden with vascular and respiratory diseases and also has effects on preterm birth and low birthweight. Many similar results are found in the literature (e.g. Brugge et al. 2007; Maizlish et al. 2013). For example, an estimated 4.2 million premature deaths globally are linked to ambient air pollution, mainly from heart disease, stroke, chronic obstructive pulmonary disease, lung cancer, and acute respiratory infections in children (WHO 2018d).

Table 5. Air pollution PM2.5 and health outcomes (Dadvand et al. 2013; Dominici et al. 2006; Mustafic et al. 2012; Rojas-Rueda et al. 2013; Sapkota et al. 2010)

Health determinant	Outcome	Dose–response model and 95% confidence interval	Unit
Air pollution ($PM_{2.5}$)			
	Cerebrovascular disease	1.0081 (1.003–1.0132)	10 µg/m^3
	Lower respiratory tract infections	1.0092 (1.0041–1.0143)	10 µg/m^3
	Preterm birth	1.15 (1.14–1.16)	10 µg/m^3
	Low birth weight	1.1 (1.03–1.18)	10 µg/m^3
	Cardiovascular diseases	1.025 (1.015–1.036)	10 µg/m^3

Health outcomes from land use and lack of greenspace can have effects on the immune system, asthma and allergies (Dadvand et al. 2013; Hanski et al. 2012). Lack of greenspace also causes premature mortality (Gascon et al. 2015; Mitchell and Popham 2008;). Noise exposure is linked to annoyance and sleep disturbance, high blood pressure, tinnitus and multiple different vascular and respiratory diseases (Basner et al. 2014; Kreish et al. 2017; Mueller et al. 2017b).

In conclusion, most health outcomes on morbidity in the context of transport derive from physical activity, road accidents and pollution, which makes them important risk factors to consider. To understand how changes in the transport system and travel behavior affect morbidity as a health outcome, it is also crucial to understand the decision-making process of the individual, as stated earlier by Nieuwenhuijsen (2016) and Michie et al. (2011).

4.2.3 Quality of life

There are some studies on causal relationships between transport and quality of life to be found, but there is no overarching definition and the approaches vary greatly. Given the lack of agreement on the dimensions of transport-related quality of life, multiple disciplines and different scales are used, and the comparison between different results from the literature is challenging. Due to this, some examples of findings from the literature are presented under Kirch's (2008) dimensions of quality of life, which is also the foundation for Lee and Sener's (2016) transportation and quality-of-life framework presented earlier (Figure 10). ¨

Physical well-being

Numerous researchers (e.g. Brown & Werner 2007; Rissel et al. 2012) have examined the ways that active travel can improve physical well-being by the same mechanisms, as discussed earlier under morbidity and physical activity. For example, some studies recognize that public transport users have significantly higher levels of physical activity than those who use private transport, i.e. private vehicles (Rissel et al. 2012). The results also suggest that use of public transport directly generates new physical activity, which is not shifted from other physical activity, e.g. other exercise (Miller et al. 2015). Different physical health indicators like blood pressure, body-mass index and inactivity are negatively related to commute distance, and this is likely because the probability of use of active modes of transport for commuting decrease with longer commute distances (Hoehner et al. 2012). In addition, greater land use mix, walkability, and accessibility are also correlated with increased physical activity and a decreased incidence of obesity (Frank et al. 2007; Lee & Sener 2016).

Mental well-being

Transport can affect people's perceived quality of life via noise pollution, which causes several types of cognitive disruption such as sleep disturbance, annoyance and stress (Botteldooren et al. 2011; Dratva et al. 2010). Walkability and bicycling have also been related to positive mental well-being (Berke et al. 2007; Crane et al. 2014) and especially with older adults, it is recognized that a lack of active travel and mobility affects mental well-being negatively. Individuals may also perceive feeling unsafe from road traffic accidents, which affects daily life (Geurs et al. 2009). In addition, Rissanen et al. (2017) state that non-fatal injuries can have a major impact on the quality of life of a crash survivor and their relatives, both physically and mentally.

There are also several studies available on commuting and its implications on mental well-being. For example, duration of travel to work has been related to increased stress and decreased life satisfaction. (Evans & Wener 2006; Stutzer & Frey 2008) Further, commuting mode is likely to affect mental well-being as well: individuals who travel by car have reported higher levels of stress and annoyance than those who commute by train (Wener & Evans 2011). Walking and bicycling have also been linked to greater levels of travel satisfaction than driving or taking public transit (Olsson et al. 2013).

Physical activity can have mentally desirable benefits too. The relationship works the other way round also; poor mental well-being has been related to negative physical outcomes (Lee & Sener 2016). For example, physical activity has been tied to a lower risk of depression, reduced stress, and improved social well-being (Fox 1999). Depression and its causal relationships with premature mortality and different diseases, e.g. an increased risk of stroke and cardiovascular diseases, are recognized in the literature (e.g. Van der Kooy et al. 2007) and depression is also associated with cognitive impairment (Pan et al. 2011).

Land use and lack of greenspace evidently also affects mental well-being. For example, Maas et al. (2006) noted a connection between land use and self-reported general health, and multiple studies have recognized impacts on mental health, behavioral problems, cognitive functions, sleep patterns and even recovery from illness (Dadvand et al. 2015; Gascon et al. 2015; Kreish et al. 2017).

Social well-being

Lee and Sener (2016) state that mobility and accessibility are the primary mechanisms behind the social well-being impacts of a transportation system. Church et al. (2000) have studied the wider impacts of social exclusion and implicate transport as an important determinant of social exclusion, through lack of accessibility and mobility. Lucas (2012) posits that social exclusion is a combination of transport disadvantages (e.g. high costs, lack of information, poor public transit) and social disadvantages (e.g. small incomes, unemployment, lack of skills or poor health), which can together lead to transport poverty. Transport poverty means difficulties accessing services, goods and social networks, leading to social exclusion. Stanley et al. (2011) have reported similar results and conclude that social exclusion is more common among those who conduct fewer trips. Khreis et al. (2017) also consider that lack of access to active and public transport may lead to reducing social interaction. Older adults are especially the focus of mobility-based reductions in the context of social well-being. Elderly mobility and accessibility are identified as one of the most important factors of quality of life (Martinez-Martin et al. 2012).

Economic well-being

In the context of economic well-being, improvements in a person's perceived quality of life can be derived from improved access to necessary services, which is a result of increased mobility. (Kolodinsky et al. 2013; Lee & Sener 2016; Thoreau & Mackett 2015). Increased mobility can also improve access to employment and recreational services (Fan et al. 2012; Thoreau and Mackett 2015). Lucas (2012) also states that transport poverty is an important determinant for not accessing essential services and employment. A causal connection has also been studied between vehicle availability and job access. Vehicle availability significantly affects the stability of employment for welfare clients, which indicates a causal relation of the transport system and residential location to job security and permanence (Thakuriah and Metaxatos 2000).

4.2.4 The wheel model quality of life and health impacts of transport

Based on the literature review, the health implications of transport were divided into two categories: *Impact areas* — health and quality of life, which are placed in the inner circle of the model. These are divided further into subsections of different indicators referred to as *outcomes:* mortality, morbidity, physical well-being, mental well-being, social well-being and economic well-being. In this model, the health and quality of life *determinants* are presented in the outermost circle. In the model, disease burden one includes conditions like cardiovascular disease, dementia, type-2 diabetes, breast cancer (women) and colon cancer. Disease burden two includes cerebrovascular disease, lower respiratory tract infections and cardiovascular diseases according to the literature (e.g. Maizlish et al. 2013; Rojas-Rueda et al. 2013). The framework for this thesis is presented in Figure 15.

Figure 15. The wheel model of quality-of-life and health impacts of transport

For instance, according to the model, health determinants like disease burdens from lack of physical activity and exposure to emissions, with injuries and annoyance, can lead to health outcomes as morbidity within the impact area of health. Determinants like active transport, injuries and obesity can affect a person's physical well-being, which affects the quality of life as the impact area.

When interpreting the framework, it is important to note that it aims to present some of the important factors for health and quality-of-life impact areas identified from earlier research, rather than all the potential factors behind them. Also important to remember is that in reality the different categories and subsections strongly overlap, and that change in one factor often leads to change in others as well. Some of the factors, like various diseases and injuries, clearly will lead to both morbidity and eventually mortality. There is also a feedback mechanism between different categories; e.g. typically, active travel is not considered to be a main determinant for mental well-being, but previous literature has demonstrated how physical well-being can indirectly affect a person's state of mind and self-perception and vice versa.

4.3 Impact pathways for automated driving, health and quality of life

This section answers the final research question, "How can automated driving impact health and quality of life?" and brings previous findings into the context of automated driving. The foundation for exploring the potential pathways for automated driving and health outcomes for this thesis derived from observations in the earlier literature cited below.

- Hierarchy begins with the 'trigger', followed by a chain of intermediate implications, which are then followed by more long-term impacts (Rogers et al. 2000)
- The components from *the relation between urban and transport planning, environmental exposures and health* (Figure 7) (Nieuwenhuijsen 2016)
- The components from *the pathways of transport and morbidity* (Figure 8) (Rojas-Rueda 2013)
- Potential pathways for automated driving and different impact areas: *Impact assessment for automation in road transport* (Figure 12) (Innamaa et al. 2018)
- Other AD impact assessment literature (chapter 2.7)
- The conceptual framework of this thesis, *the wheel model of quality of life and health impacts of transport* (chapter 4.2.4)

The identified pathways were also discussed in a working group session with transport and mobility specialists from Technical Research Centre of Finland Ltd. The session aimed to ensure the validity of the sketched pathways of impact.

In this thesis, the *trigger* is introduction of automated driving at the higher levels of SAE's (2018) taxonomy (level three or higher). Under the *system* are the direct impacts that the introduction of automated driving may have on the (road) transport system. *Mechanism* can be described as the process which leads to health and quality-of-life implications. *Determinants*, *outcomes* and *impact areas* are derived straight from the thesis' conceptual framework *wheel model quality of life and health impacts of transport*. *Output measures* are added to clarify the difference in approaches to health and quality of life. Figures 16 to 20 illustrate the identified potential pathways from introduction of automated driving to the impact areas of health and quality of life. For clarity, the implications for quality of life are presented separately under the different categories of well-being: physical, mental, social and economic. Different colors are used to accentuate the pathways from potential changes in the transport system to certain determinants of health and quality of life.

The introduction of automated driving can have several system-level impacts, which could have different health outcomes. Changes in interaction with other vehicles and with vulnerable road users, technology development enabling an artificial intelligence-based situational picture and lane keeping could lead to false and/or better interpretations and change in the number of driving errors. This could affect the number of fatalities and severe long-term injuries, which are determinants for mortality and morbidity. Changes in driving style could lead to changes in the use of energy and materials, which combined with mileage could bring about an increase of emissions, which in turn has been negatively associated with various diseases. Other potential impact paths from the introduction of automated driving could include system-level impacts such as ease of driving and change in comfort, which could lead to a change in mileage, use of active transport modes, feeling of safety and relaxation and/or tension. These in turn could affect physical activity and stress, which both have health implications in the form of disease.

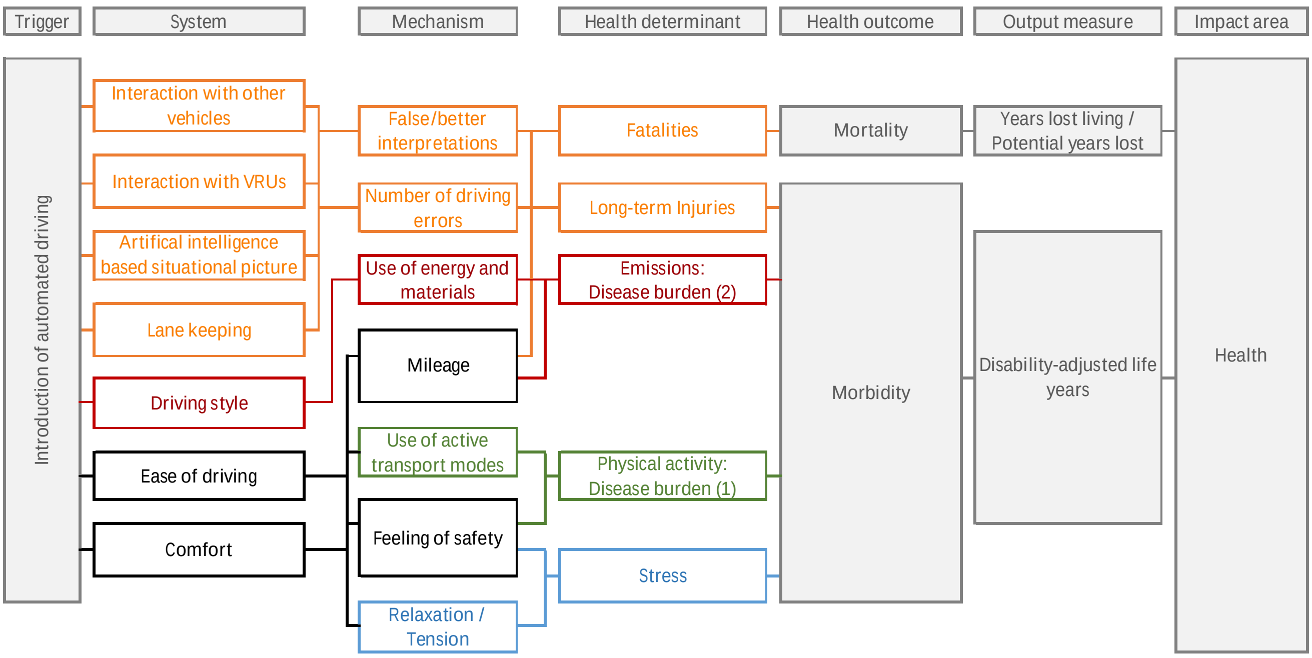

Figure 16. Potential pathways for introduction of automated driving and health implications

Automated driving and physical well-being are connected mostly through transport mode selection. Changes in the transport system level, including comfort, ease of driving, vehicle availability, new possibilities for mobility options and use of in-vehicle time, have a causal relation both with the transport mode selection and change in the number of journeys. Transport mode selection is connected with all three determinants, identified earlier, of physical well-being: short-term injuries, obesity and use of active transport modes, whereas a change in number of journeys is connected with short-term injuries. In addition, driving style as a transport system-level impact is known to affect feelings of safety, which could lead to changes in the use of active transport modes and impact physical well-being. Introduction of automated driving and mental well-being are linked by myriad connections. Vehicle availability, ease of driving, change in comfort, transport mode selection and no need for a driver could lead to determinants of mental well-being such as implications on cognition and feelings of safety and security. In addition, transport system-level impacts, such as transport and mobility management with new mobility services, could lead to changes in infrastructure and land use, which could be seen as a change in accessibility and walkability; this in turn can have impacts on mental well-being in terms of depression.

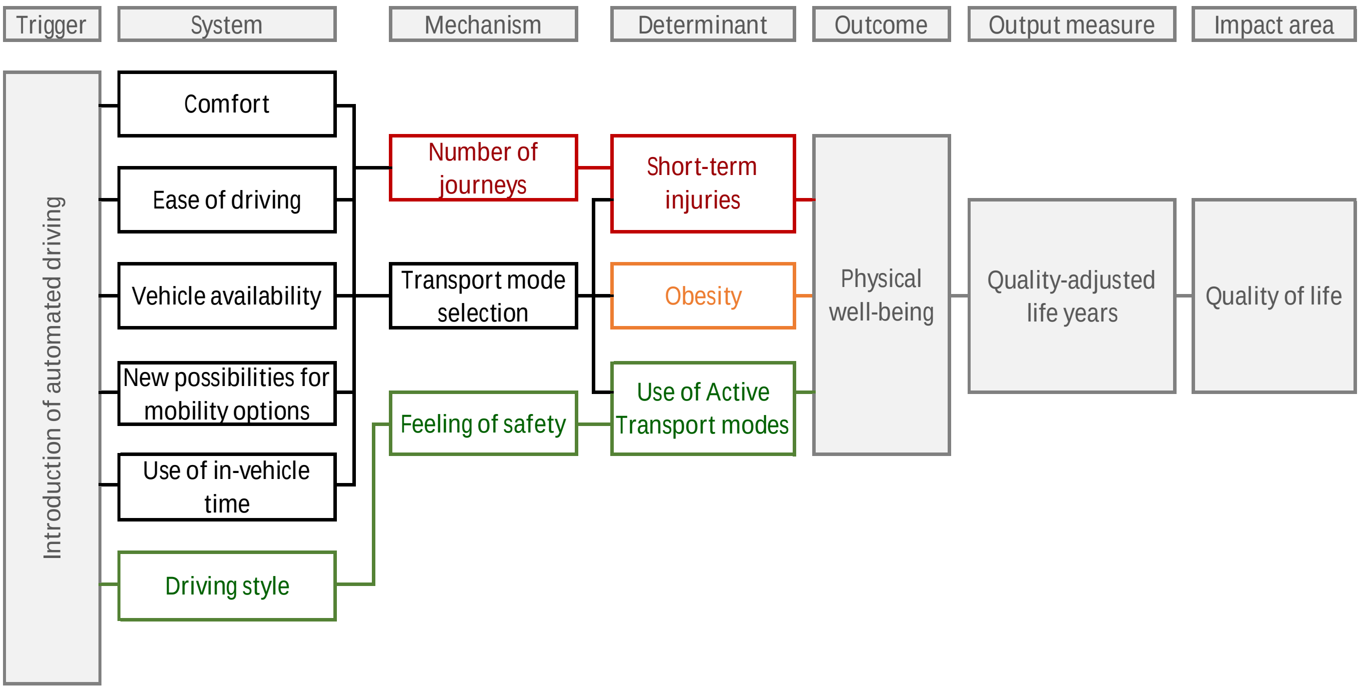

Figure 17. Potential pathways for introduction of automated driving, physical well-being and quality-of-life implications

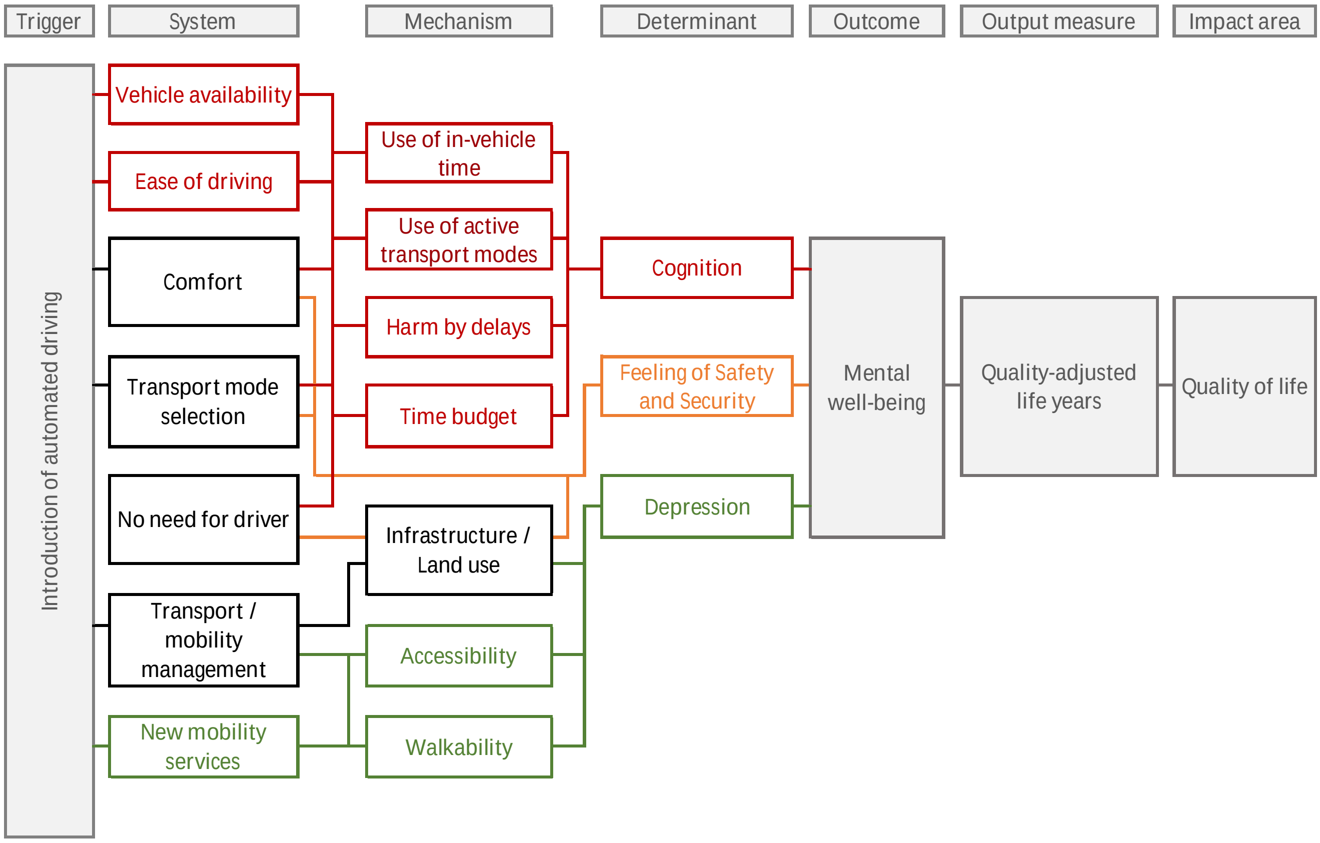

Figure 18. Potential pathways for automated driving, mental well-being and quality-of-life implications

System-level impacts from the introduction of automated driving on social well-being might include factors such as no need for a driver, travel costs, ease of driving, change in comfort, vehicle availability and new possibilities for mobility services. These could lead changes in destination and number of journeys, which have their own implications on accessibility as a potential change in community severance and social relationships. In addition, the possibility and willingness to use automated vehicles is also an important mechanism for social well-being implications, particularly as it relates to the group of non-drivers like the elderly, the disabled and children.

Finally, economic well-being and automated driving are related via system-level impacts including the price of automated vehicles and other travel costs, new possibilities for mobility services and transport/mobility management. These can lead to changes in car ownership, vehicle availability and transport service availability, which could have implications for access to jobs and services. This accessibility, both requisite and recreational, is an important factor for people's economic well-being as discussed earlier in this chapter. Other system-level impacts include no need for a driver on the one hand, and the ongoing need for further development of automated vehicles and driving systems on the other, all of which may require new skillsets on the part of employees. Multiple industries could face drastic changes as automated driving becomes more widely adopted, with consequent possible upheavals in the dynamics of employment and finance.

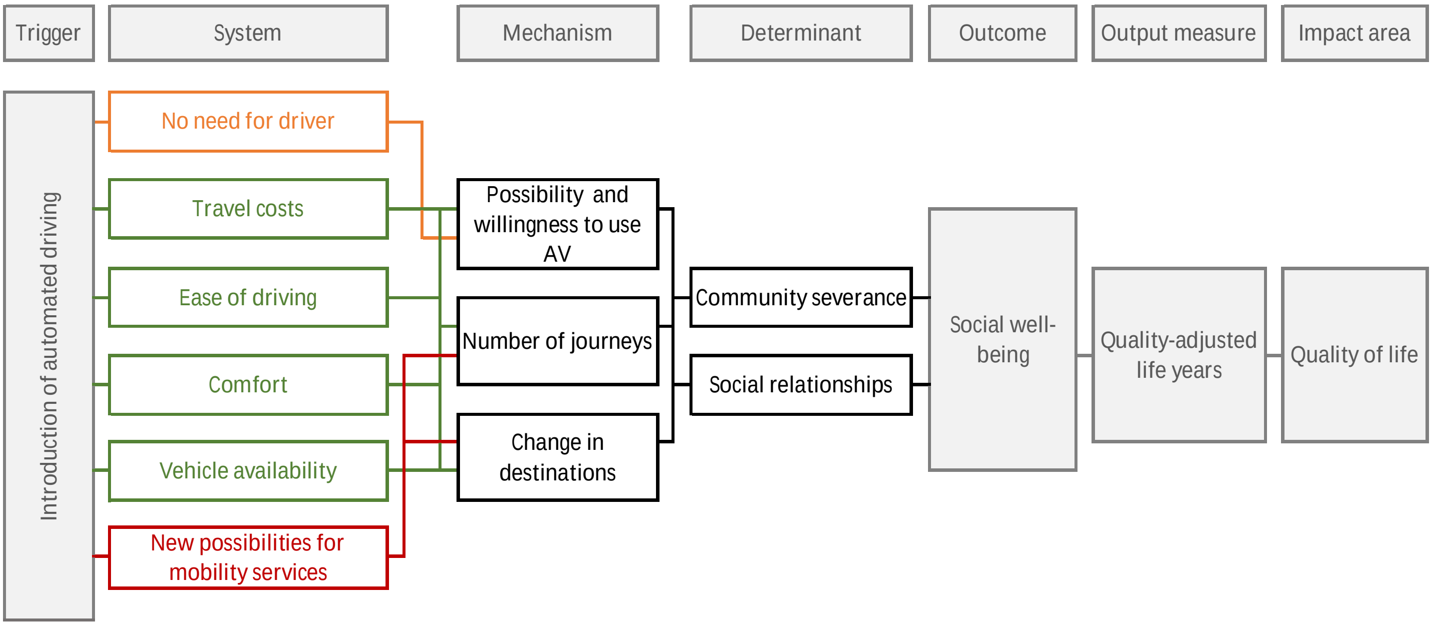

Figure 19. Potential pathways for automated driving, social well-being and quality-of-life implications

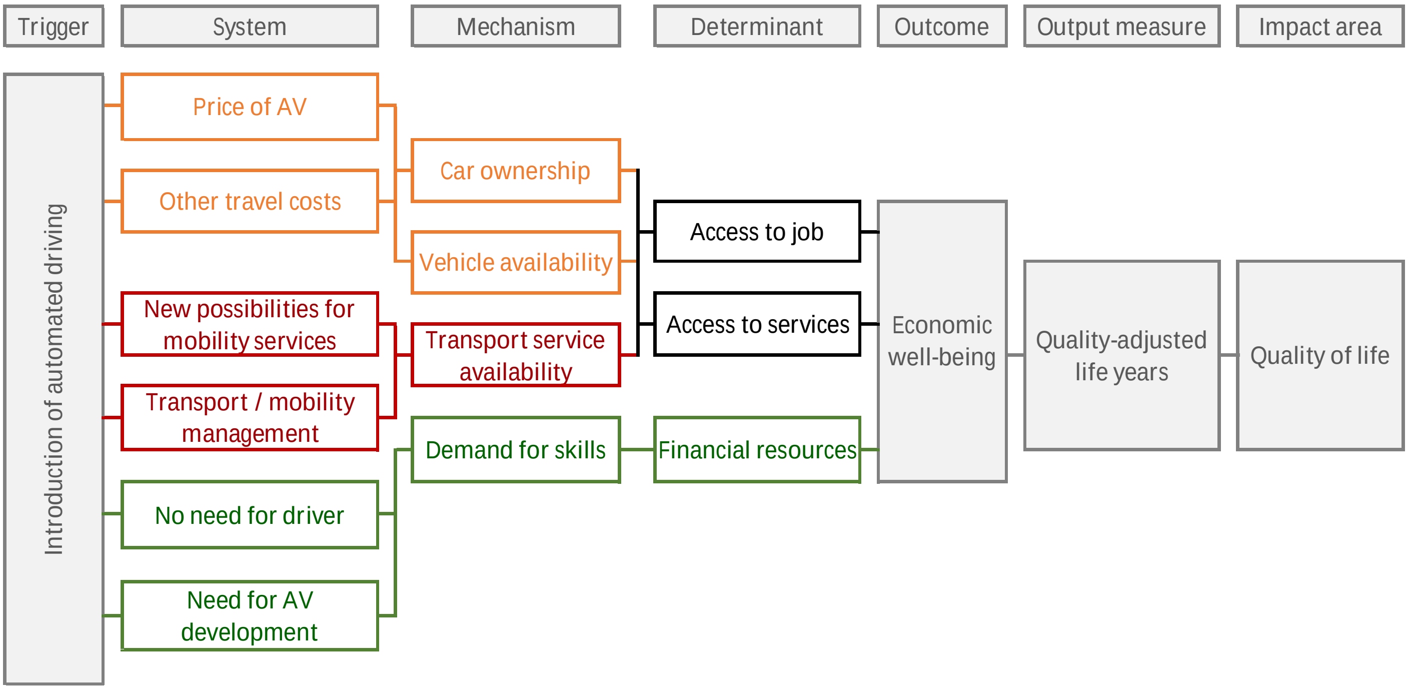

Figure 20. Potential pathways for automated driving, economic well-being and quality-of-life implications

It is important to note that the recognized impact paths include only a few potential chains of events that automated driving could cause — both in a positive and negative way. The potential impact pathways should be considered as suggestive and introductory rather than all-inclusive. It is also important to consider the dimension and magnitude of the changes in order to assess the potential implications that automated driving could have on health and quality of life. Thus, the identified impact pathways provide only a starting point for evaluating the health and quality-of-life impacts of automated driving in greater detail.

5. Discussion

The motivation for this study arose from previous assessments of the impacts of automated driving carried out at VTT Technical Research Centre of Finland Ltd. and the will to better understand the implications of automated driving on well-being. The principal aim of the case study of the thesis was to increase knowledge on the implications of automated driving in the context of health and quality of life. Specifically, the objective was to explore more and understand better different dimensions of health and quality of life from the point of view of transport and mobility. The objective was approached in three phases: First, exploring the health and quality-of-life implications of transport; second, building a conceptual framework for the work; and finally, exploiting the results from previous phases to the introduction of automated driving.

5.1 Key results

The key results of the thesis are discussed under the research questions. The questions were formulated cumulatively to support the explorative study and its objectives. They were processed during the iterative process, which included a comprehensive literature review, specialist interviews, and working sessions with more experienced researchers to ensure the validity and reliability of the results.

1) *What should be included in the concept of 'health of the population' and quality of life when addressing the implications of transport and mobility?*

The concept of health includes complete well-being and not merely the absence of disease or infirmity, and as a term, *health* is commonly used interchangeably with the term *health of the population* (WHO 1948; WHO 2005). Mortality and morbidity are typical indicators of health in the respective research area (Larsson & Mercer 2004). *Well-being* is described as the individual's experience of health, happiness, and prosperity, which includes having good health, high life satisfaction, and a sense of meaning or purpose (Davis et al. 2013; Diener & Seligman 2002). Quality of life is broadly defined as a construct reflecting a subjective and/or objective judgment concerning all aspects of an individual's existence, including health, economic, political, cultural, environmental, aesthetic, and spiritual aspects (Gold et al. 2002). Quality of life can also be seen as an overarching concept that covers all aspects of a person's life, which includes, amongst others, physical, psychological, financial and social well-being (Kirch 2008). The concept of well-being is strongly included both in health and quality-of-life concepts, but the approach to well-being differs. This can be seen from the typical health and quality-of-life measures of quality-adjusted life years (QALYs) and disability-adjusted life years (DALYs). DALYs measure the health loss and QALYs the health gain, thus they express an inverse value (NCCID 2015).

This thesis suggests that the typical indicators of health — morbidity and mortality — should be included when discussing the health implications of transport and mobility. These indicators are also recognized in other transport-related research, for example by Nieuwenhujsen et al. (2016) and Rojas-Rueda et al. (2013) in their studies on the risk factors and health determinants of transport. Based on a comprehensive literature review (chapters 4.2.1.-4.2.2.), mortality in road transport can be divided further into fatal accidents, suicides and natural deaths, where fatal accidents represent the major share. For example, in Europe it has been found that of all road deaths roughly 2% occur as natural death and 1–10% from suicide (ETSC 2018). Morbidity can also be divided further, and its foremost health outcomes can be said to derive from physical (in)activity, road accidents and pollution (e.g. Maizlish et al. 2013; Woodcock et al. 2011), which makes them important risk factors to consider. In addition, it seems that stress is less studied in the field as a transport-related risk factor for health, but it can have serious implications for health in terms of cardiovascular disease and cognitive dysfunction (Basner et al. 2014; Kreish et al. 2017; Mueller et al. 2017b).

In terms of transport and mobility, this thesis suggests the use of Kirch's (2008) division for quality of life in physical, mental, social and economic well-being, which is also used in Lee and Sener's (2016) transport-related quality-of-life studies. Based on the comprehensive literature review (chapter 4.2.3), this thesis categorized the quality-of-life implications further as follows: Physical well-being can have transport-related determinants like physical activity, obesity and short-term injuries, whereas mental well-being can have determinants like cognition, depression, and feeling of safety and security. Social well-being is mostly affected by accessibility and mobility, and it can have determinants like social relationships and community severance. Finally, economic well-being can be divided further into access to job and services, and (other) financial resources.

The conceptual framework for this thesis is called *the wheel model of quality of life and health impacts of transport* (chapter 4.2.4.) and it brings together the health and quality of life determinants and outcomes, which should be included when addressing the implications of transport and mobility. The framework includes the impact areas of health and quality of life and it is based on typical indicators of health such as mortality and morbidity, and the four types of well-being — physical, mental, social and economic — for quality of life.

2) *How do transport and mobility choices affect health and quality of life?*

Mobility can be seen as a combination of amount of travel, travel patterns and journey quality (Innamaa et al. 2013), and personal mobility consists of three sections: personal variables, decision-making and travel characteristics. Travel characteristics include the same components as mobility (Innamaa et al. 2013; Kuisma 2017). The first two sections together can be seen as the *potential for travel* and the third, travel characteristics, as *revealed travel* (Kuisma 2017). These notations are important, because it is evident that transport and mobility choices affect health and quality of life, so it is worthwhile understanding the components behind mobility as revealed travel. It is also important to understand that people's choices can affect some parts of mobility, but not all. For example, different limitations such as journey length and duration, vehicle availability, and people's capabilities and motivation, affect the possibilities for different transport and mobility choices. When discussing the health and quality-of-life implications, it is also important to recognize that both health and quality of life are complex entities, and to comprehend that the different aspects of health and quality of life inextricably affect one another. In addition, a person's behavior affects the health and quality of life. Behavior consists of that individual's capabilities, opportunities and motivation to make (healthy) choices (Michie et al. 2011).

There are several models for transport-related health implications which include similar components. For example, Nieuwenhuijsen's (2016) model suggest that policies, as trigger for change, can affect three different components of the transport system: urban design, activity and travel behavior, and pathways of health determinants. In the model, urban design includes different transport system-level choices, whereas activity and travel behavior include individual-level choices. These choices lead through different health determinants to morbidity and mortality. The model also considers the individual's context by including socio-economic, genetic and nutritional factors into the model. In this thesis, the *trigger* was chosen as the introduction of the automated driving into the higher levels of SAE's (2018) taxonomy. The trigger was followed by the *system*-level impacts that introduction of automated driving may have on the (road) transport system, followed by different *mechanisms,* which lead to health and quality-of-life implications. D*eterminants*, *outcomes* and *impact areas* were derived straight from the thesis' conceptual framework. *Output measures* were added to clarify the difference in approaches of health and quality of life.

There are also several studies available on travel and mobility choices and their implications for different aspects of well-being. For example, some studies recognize that public transport users have significantly higher levels of physical activity than those who use private transport, i.e. private vehicles. (Rissel et al. 2012). The results also suggest that using public transport directly generates new physical activity that is not shifted away from other physical activity, e.g. other exercise (Miller et al. 2015). Different physical health indicators like blood pressure, body-mass index and inactivity are negatively related to commute distance, and it is likely because the probability of using active modes of transport for commuting decrease the longer the commute distance (Hoehner et al. 2012). In addition, the duration of travel to work has been related to increased stress and decreased life satisfaction (Evans & Wener 2006; Stutzer & Frey 2008). Further, commuting mode is likely to affect mental well-being as well: individuals who travel by car have reported higher levels of stress and annoyance than those who commute by train (Wener & Evans 2011). Walking and bicycling have also been linked to greater levels of travel satisfaction than driving or taking public transit (Olsson et al. 2013). As one of the specialists concluded, it can be said that from a health perspective, people should prefer active travel whenever possible.

In this thesis, the objective was to explore the qualitative aspects of transport and mobility with health and quality of life implications. Still it is important to recognize the quantified aspect also. Love et al. (2005) denote that successful application of the health impact assessment procedure consists of negotiating the relationship between qualitative and quantitative results each time separately, in order to provide the most appropriate and most intelligent estimations needed in different situations.

During the interviews, an important observation emerged that it is easy to make healthy choices when the environment encourages it, and vice versa; it does not matter how *mindful* a person is if the environment does not support it. Another insight was that people may not think about health implications before some condition is found or symptoms emerge. Thus, an ideal transport system should provide healthy means of traveling as a premise; people generally cannot be trusted to make sustainable and healthy choices.

3) How can automated driving impact health and quality of life?

Wider adaptation of automated driving can impact health and quality of life in numerous ways. Several studies suggest that the adoption of automated driving could lead to increased travel demand and a rise in VKT (e.g. Bierstedt et al. 2014; Fagnant & Kockelman 2015). This in turn may lead to different health and quality-of-life implications, for example via physical (in)activity and emissions. Automated driving may also cause changes in comfort and ease of driving and traveling, which could have implications for mobility and accessibility, important determinants for well-being. In addition, technological advances are expected to provide improvements in road safety, which could have implications for both short-term and long-term injuries and mortality.

Cavoli et al. (2017) conclude that automated vehicles could cause people to spend more time in them and consequently less time being physically active. Multiple studies have shown that physical inactivity can lead to undesired effects like cardiovascular disease, type-2 diabetes, dementia, breast cancer, colon cancer and obesity (Hamer & Chida 2009; Harriss et al. 2009; Jerrett et al. 2014; Monninkhof et al. 2007). There are also other health caveats related to long amounts of time spent sitting in (automated) vehicles, including muscle cramps, back and neck pain and spinal disc degeneration (Bierstedt et al. 2014). The interviewed specialists also agreed that automated driving can have negative health implications if it affects physical activity and/or active travel. They felt that so-called “last-mile walking and cycling” are important factors in daily activity and that if automated vehicles carry people from door-to-door, this activity is lost.

Increased VKT is linked to negative environmental impacts such as increased emissions and greater gasoline consumption (Cavoli et al. 2017). On the other hand, the trends toward shared mobility and automated vehicles could together reduce the number of vehicles in use and therefore mitigate the environmental shortcomings (Fagnant & Kockelman 2015). Furthermore, the related trends affect the energy and environmental impacts of automated vehicles, including whether or not they are low- or zero-emission vehicles (Cavoli et al. (2017). The specialists also concluded that automated vehicles could lead to more energy-efficient driving, smoother traffic flows and reduced energy consumption, but that the increase in VKT could counteract some of the health and environment benefits.

The specialists also agreed that changes in the convenience and comfort levels of travel could have many other health implications. They could increase accessibility for different groups such as the elderly and others with limited accessibility for health and/or other reasons. Greater accessibility could lead to better access to jobs and services and encourage social relationships and community involvement, which are considered important factors for any individual in terms of well-being, self-determination and occupational performance. Cavoli et al. (2017) have also recognized the potential impacts of automated driving on accessibility and equity. Automated vehicles could improve accessibility and independence for the elderly, the disabled, non-drivers and people living in areas not well connected to public transport. On the other hand, there are limitations related to social acceptance, the desire and the ability to use automated vehicles among these users.

Hoadley (2018) states that potential road safety benefits are one key driver for automated driving development, which makes them important to assess. The road safety benefits are considered to derive from reducing human error, using technology to tackle driver distraction and enforcing road safety rules, and from safer interaction with non-users of automated vehicles. Cavoli et al. (2017) presents that the main controversy in road safety discussions on automated vehicles stems not from their ability to improve road safety, but the extent of the improvement. The interviewed specialists also indicated that weighing the potential pros and cons, and setting a baseline for automated driving and health implications among safety and ethical issues, is a complicated process.

During the interviews one specialist raised an important concern about passive travel and underage children. In certain phases of development it is crucial that children get to explore and take responsibility for themselves appropriately for their age, and independent mobility is a key factor. In addition, the introduction of automated driving may act as a trigger for someone to assess their behavior and challenge the automatic heuristic behind it. For example, automated vehicles and potential new mobility services may change the daily routines and patterns of a person’s travel behavior.

This thesis confirmed some potential impact pathways from introduction of automated driving to health and quality-of-life implications (chapter 4.3). These impact paths bring together transport and mobility-related health and quality-of-life implications with the rather new phenomenon of automated driving and its potential impacts on the transport system. The impact paths are presented separately for different categories of health and quality of life, to be consistent with the conceptual framework of the thesis and previous literature in transport and health research.

In conclusion

This thesis has three key results. First, the conceptual framework: the wheel model of quality-of-life and health impacts of transport, which provides insights into the realm of transport and its health and quality-of-life implications. The framework consists of three tiers representing the impact areas, outcomes and determinants of health and quality of life in the context of transport and mobility. Second, the impact pathways, which illustrate the different sequential and causal relations, or hypothetical bridges, between introduction of automated driving and health and quality-of-life implications. Finally, as a third key result this thesis provides a comprehensive overview of the concepts of health and quality of life in the field of transport and mobility.

5.2 Scientific implications

All the key results of this thesis have scientific implications. The conceptual framework *wheel model of quality of life and health impacts of transport* illustrates clearly that there are several factors to take into consideration when discussing transport and its potential impacts on health and quality of life. The framework becomes useful when categorizing and scoping different sectors of health and quality of life in the domain of transport and mobility. For example, the health and quality-of-life implications can be discussed from one single determinant viewpoint to a viewpoint including whole impact areas of health and quality of life.

The second key result is the identified potential pathways from the introduction of automated driving to its impacts on health and quality of life. The pathways combine transport system-level impacts, both direct and indirect, with impact areas of health and quality of life. Understanding the potential pathways will aid development work and decision-making by emphasizing relevant factors and areas of focus. The pathways also help identify future research needs in the context of automated driving, and can be seen as a starting point for more detailed research and impact assessment in this area.

Finally, and perhaps most importantly, this thesis delves comprehensively into the concepts of health and quality of life and discusses them in the context of transport and mobility. The broadness of these concepts is well known, but there is no consistent way of using all the different concepts in transport research. The overview presented here can hopefully be used to support future discussion and research.

5.3 Assessment of the approach and design

According to Saunders et al. (2009), reducing the possibility of getting the study results wrong means that attention has to be paid to two particular goals in research design: reliability and validity. Reliability refers to the extent to which data collection techniques or analysis procedures will yield consistent findings, and validity is concerned with whether the findings are really about what they appear to be.

An inductive approach was taken in the design of this research. As discussed earlier (chapter 3), an important feature of this approach is its flexibility in structure, which permits changes of research emphasis as the research progresses and understanding develops, while being less concerned with the need to generalize the results. In this exploratory case study, flexibility was needed as new findings from both the literature and interviews guided the subsequent work. The reliability of results was concerned with the multi-method choice, i.e. triangulation of the data collection techniques. Careful selection of the literature set, combined with a broad range of knowledge from participating specialist interviewees, made coherent conclusions possible. However, it is acknowledged that an inductive approach may also be a difficult strategy to follow and may not always lead to success for an inexperienced researcher, e.g. by decreasing the research validity. The potential lack of validity was tackled through the iterative process, where the initial results were discussed in specialist interviews and compared with the existing literature, and vice versa. The conceptual framework was also developed gradually in several phases. In addition, after the comprehensive literature and interview results were analyzed, the results were reviewed and validated in a working group session with more experienced researchers.

The main challenges of this thesis process derived from strong overlap of the health and quality-of-life terminology and concepts, and lack of consistency in their use in the context of transport and mobility. In addition, there is a certain level of abstractness and ambiguity in the topic of automated driving and its impacts, such as the number of different automation levels and concepts, uncertainties related to the timeframe for wider adoption, different levels of penetration, possible new business and service models, etc. It was decided that given the scope of this thesis there was no need for, or sense in, trying to allocate the potential impacts of different SAE levels of ADS. It was also acknowledged that different levels of ADS and the penetration levels of automated vehicles in the traffic system may affect their potential impacts in both direction and in magnitude.

Challenges related to the research design were associated mostly with scoping out the relevant literature and presenting the findings consistenly. For example, there are a lot of health and transport-related studies to be found and numerous ways of categorizing transport-related health implications. The selected literature included mostly peer-reviewed and cited articles from recognized scientific sources, and recommendations and definitions were derived from established health organizations. Lastly, the talkative nature of the interviews provided rich qualitative data but made it a challenge to keep the discussion within the scope of the thesis. However, there was plenty of time for discussion so the occasional spread of the subject was not a problem.

Overall, this thesis succeeded in combining the new intriguing phenomenon of automated driving with extensive research on transport and its health implications. The research questions were addressed in depth, and the results include a practical and illustrative framework and pathways for automated driving and its impacts on health and quality of life, and a comprehensive review of relevant fields to exploit further.

5.4 Future research needs

As stated in the methodology (chapter 3), the nature of exploratory research and the data collection techniques used in this thesis made it possible to gather preliminary information that helped to define problems that are more concrete and to suggest future research. This thesis managed to bring together the rather new phenomenon of automated driving with the established health impacts of transport. Still, it provides only a starting point for evaluating the health and quality-of-life impacts of automated driving in greater detail. In order to gain more concrete knowledge on the pathways, mechanisms and quantitative values behind automated driving and its implications for health and quality of life, it is important to consider the following aspects, among others:

- Different pathways from the introduction of automated driving to its impacts on health and quality of life should be investigated further and separately, in order to gain a deeper understanding of the various determinants and mechanisms behind the impacts.
- Assessing the direction and magnitude of the potential impacts of automated driving will be necessary in the future, both at transport-system level and in the realm of quality of life.
- As automated vehicles gradually become more ubiquitous, it will be important to understand how different penetration levels of automation technology in road vehicles affect the impacts on health and quality of life.
- The behavior, decision-making and mobility patterns behind people's travel needs and their relation to health provide a fascinating topic for automated driving impact assessment research.
- Socio-psychological parameters seem to be less studied than physical and mental impacts in the context of transport and mobility. Still, they are recognized as important factors of people's well-being and quality of life, which provides a fruitful topic for future research.

In addition, automated vehicles and driving tend to hover at the top of the hype cycle and are driving much of the discussion and research. During this thesis process it became evident that new, fascinating research is constantly being published, which made it challenging to scope the final literature set and select the data for the analysis. It is vital that we continue to produce consistent and comprehensive research and advance it further in the context of automated driving, impact assessment and health and quality-of-life implications.

6. Literature

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Title	**Impacts of Automated Driving on Health and Quality of Life**
Author(s)	Reetta Mäkinen
Abstract	Automated driving is one of the current hype phenomena generating widespread interest. Automated vehicles are a growing topic of discussion in both the academic and gray literature. Although fully automated vehicles are still far in the future, various levels of automation-featured vehicles are gradually gaining groud in road traffic. Impact assessment of automated driving promotes the development of automated systems and support decision-making in the field of transport. VTT Technical Research Centre of Finland Ltd. has studied the impacts of transport and mobility for decades, and has produced impact analyses with a broad scope in this field. The impact assessment of automated driving has recently seen further developments; this thesis continues the work and expands it to the themes of health and quality of life. This thesis aimed to explore the impacts of transport and mobility on individuals' health and perceived quality of life and, further, to exploit the findigs under the domain of automated driving. One of the main objectives was to identify potential pathways of action from the introduction of automated driving to its health implications. The study was conducted in three phases: First, a review was done of the extant literature. Second, a conceptual framework for transport and its implications for health and quality of life was constructed with the help of a literature study and insights from specialists in diverse fields of health and transport. Third, the framework and supporting literature were used to formulate the potential pathways of action mentioned above. Finally, the results were discussed in a work group to ensure the validity and reliability of the results. The thesis process was iterative; i.e. the results from the literature and specialist interviews were utilized throughout the work right from the start. This thesis has three key results. First, it provides a comprehensive and worthwhile overview of the concepts of health and quality of life in the context of transport and mobility, which can be used to support future discussion and research. The second key result is the illustrative conceptual framework, which provides insights into transport and its health implications. Finally, potential pathways from the introduction of automated driving to its impacts on health and quality of life are presented. Understanding these pathways to impact will not only support further development and decision-making; it will also help pinpoint future topics of research. One of these will be assessing the direction and magnitude of the potential impacts of automated driving.
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