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Opportunities and Challenges for Implementing Smart City Solutions in Finnish Municipalities

Viewpoint of Sustainable Transportation

School of Technology and Innovation
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Tiivistelmä:
Kaupungistumisen kiihtyvä maailmanlaajuinen trendi on aiheuttanut haasteita kaupunkien liikennöinnin järjestämiseen. Älykkäiden kaupunkien älykkäät liikenneratkaisut pyrkivät nyt ratkaisemaan erilaisia haasteita ja kehittämään liikennejärjestelmiä kaupungeissa. Älykkäitä liikennejärjestelmiä on luonnehdittu merkittäväksi tekijäksi, jotta tulevaisuuden kaupunkien liikennejärjestelmistä saadaan tehokkaampia ja kestävämpiä. Esineiden internet on ollut tärkeä osa älykkäiden ratkaisujen läpimurrossa ja nopeassa kehityksessä. Tämä tutkielma tutkii älykkään liikenteen ratkaisujen käyttöönoton mahdollisuuksia ja haasteita Suomen kunnissa. Tutkielman tutkimuskysymys on: *"Mitkä ovat pääasialliset mahdollisuudet ja haasteet Suomen kunnissa liittyen älykkään kaupungin ratkaisujen käyttöönottoon näkökulmana kestävä liikenne?"*

Tutkielman teoreettinen viitekehys perustuu kansainvälisiin akateemisiin tutkimuksiin, jotka koskevat älykästä kaupunkia ja sen kestävyyden ulottuvuuksia, älykästä liikennettä ja kestävyyteen liittyviä seikkoja ja esineiden internetiä. Sen lisäksi eri saatavilla olevien eri toimijoiden julkaisemien lähteiden perusteella on tutkittu Suomen kuntien älykkäisiin kaupunkeihin liittyvien ratkaisujen kehitystä ja älykkään liikenteen kehityksen nykytilaa. Tutkielman tutkimusosa koostuu puolistrukturoiduista haastatteluista, joissa on haasteltu viittä eri älykkään liikenteen asiantuntijaa eri sektoreilta. Koska haastateltavat olivat eri sektoreilta, saatiin tutkimustavoitteiden ja -kysymyksen kannalta monipuolinen ja kokonaisvaltainen katsanto.

Tutkielman perusteella älykkään liikenteen kehityksen nykytila Suomen kunnissa on edelleen pitkälti kokeellinen, vaikkakin erilaisia ratkaisuja on jo otettu käyttöön monissa kunnissa. Yleinen ilmapiiri älykkäitä liikenneratkaisuja kohtaan on positiivinen ja kunnissa ollaan tietoisia älykkääseen liikenteeseen liittyvien ratkaisujen mahdollisuuksista. Pääasialliset mahdollisuudet älykkään liikenteen ratkaisujen käyttöönotossa oli tutkielman perustella niiden hyödyntäminen kulkumuotojakauman muuttamisessa, ajoneuvojen käyttövoimajakauman muuttamisessa ja liikennejärjestelmän kokonaisvaltaisessa kehittämisessä tehokkaammaksi ja turvallisemmaksi. Sen sijaan yksi pääasiallisista haasteista liittyi siihen, että uusien älykkään liikenteen ratkaisujen pitää olla melko pitkälle kehitettyjä, jotta ne voidaan ottaa osaksi liikennöinnin ekosysteemiä muun muassa eri lait ja standardit huomioiden. Lisäksi haasteiksi on koettu älykkään liikenteen ratkaisuihin vaadittavien resurssien sisällyttäminen osaksi kuntien budjetointia, uusien sensoreiden sähkön saanti ja uusien älykkäiden liikenneratkaisujen bisnesmallien rakentaminen toimivaksi.

AVAINSANAT: älykäs kaupunki, älykäs liikenne, kestävyys, esineiden internet, kunta

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ABSTRACT:
Global trend of accelerated urbanization has caused challenges for the transportation systems of cities. A smart city's smart transportation solutions are now thriving to solve different defects and develop the overall transportation system operation in cities. The smart transportation solutions have been considered as a robust part of developing the future transportation system in cities more efficient and sustainable. Internet of things has been a remarkable rendering factor on the development of these new smart solutions. The thesis examines the opportunities and challenges for implementing smart city solutions in Finnish municipalities from the viewpoint of sustainable transportation. The research question of the thesis is *"What are the main opportunities and challenges for Finnish municipalities when implementing smart city solutions for sustainable transportation?"*

Conceptual framework of the thesis is based on literature of recent international studies which were systematically selected. The literature review consists of reviewing the concept of smart city and sustainability dimensions of it, concept of smart transportation and the sustainability concerns of it, and internet of things in the smart transportation. In addition, contemporary state of smart transportation development in Finnish municipalities is reviewed. Methodology of this thesis was conducted through semi-structured interviews with five different experts of smart transportation sector in Finland. The interviewees were from different operators and organizations which offered versatile and comprehensive view of the topic and gave high quality answers to the research question and complemented the research objectives.

Based on this study, the contemporary state of smart transportation development in Finnish municipalities is still in tentative stage even though there has been implemented concrete solutions already. However, the overall atmosphere towards smart transportation development is affirmative and there is knowledge of the possible opportunities of utilizing different smart technologies. Main opportunities for implementing smart transportation solutions for Finnish municipalities were to promote a change in modal split, to promote a change of the power source of vehicles, and to make the city transportation more efficient and safer for citizens. The main challenges of implementing smart transportation were that the solutions need to be rather far developed before they are capable of functioning in the transportation ecosystem, to get these solutions fitted in to the budgets of municipalities, when assembling new sensors there can be difficulties to acquire a power source, and business models for the new solutions can be challenging to develop.

KEYWORDS: smart city, smart transportation, sustainability, Internet of Things, Finnish municipalities

Contents

Pictures

Figures

Tables

Abbreviations

AI	Artificial Intelligence
AV	Automated vehicle
C-ITS	Cooperative Intelligent Transport System
D2D	Device to device
EV	Electrical vehicle
HCI	Human-Computer Interaction
ICT	Information and Communication Technology
INKA	Innovative cities program
IoT	Internet of Things
IoV	Internet of Vehicles
ISO	International Organization for Standardization
ITS	Intelligent Transportation System
LoRaWAN	Long range low power wide area network
MaaS	Mobility as a Service
ML	Machine learning
NB-IoT	Narrowband Internet of Things
RFID	Radio Frequency Identification
SC	Smart city
SOV	Single occupied vehicle
ST	Smart transportation
TPM	Transportation performance metric
UAV	Unmanned Aerial Vehicle

V2V	Vehicle to Vehicle
WSN	Wireless Sensor Network

1 Introduction

In this chapter, background of the study will be introduced, research gap expressed, and research question and objectives stated. Then the keywords definitions and limitations will be explained, and finally the structure of the thesis will be presented.

1.1 Background

Globally, accelerated urbanization has caused challenges for cities to manage transportation of goods and citizens (Chen et al, 2021). Increased number of goods transportations, private and public vehicles have led to severe congestions, pollution, reduced safety, and shortage of land resource for instance (Rodrigue, 2020, p. 192). A smart city's *smart transportation* solutions are now thriving to solve these defects in transportation with optimal management of resources and make this way the transportation of cities better and more sustainable by means of modern technology (Chen et al, 2021). Efficient transportation system plays essential role in development of society and urban productivity in modern cities nowadays (Rodrigue, 2020, p. 191). The smart transportation solutions are considered as a robust part of making the transportation more efficient and sustainable in the future (Javed et al, 2022).

Internet of Things utilization is an essential part of connecting different data sources in smart cities and is one of the most critical reasons for recent rapid development of smart city solutions (Perera et al, 2017). In fact, Internet of Things can be considered as an inevitable factor of a smart city. (Azgomi & Jamshidi, 2018). Also, in smart transportation, Internet of Things is in central part because it is involved in almost every different technology solution used (Xia et al, 2012; Azgomi & Jamshidi, 2018).

Sustainability dimension and its development is many times strongly associated with transportation (Öberg et al, 2017, p. 6). In the smart transportation context, sustainability is often considered as acts of public organizations and companies to decrease

negative effects which transportation causes for society and environment. (Borglund et al, 2021, p. 89). Moreover, for decreasing negative effects, sustainability is much about continuity which means that current production needs cannot destroy the opportunities to reproduce the corresponding needs in the future (Castells, 2000, p. 118). This leads to wider scale of sustainability goals of smart cities than just improving local citizens well-being (Ahvenniemi et al, (2017).

At the moment, some smart transportation solutions have already implemented in the biggest municipalities of Finland (6Aika, 2022; Forum Virium, 2023). Public organizations and projects have had a leading role in igniting innovation platforms, ways of working and creating business opportunities for private sector regarding smart city solutions (Ylipulli & Luusua, 2020). Municipalities' co-operation with local and international parties, has already achieved significant development in this rather new field of activity. (Valtiovarainministeriö, 2017). Finnish municipalities have a strong focus to reduce carbon emissions, land use and air pollution of the transportation in addition for efficiency development. Ministry of transport and communications in Finland has settle goals in which transportation emissions will be reduced by halve till 2030 compared to level of 2005 emissions and zero emissions till 2045. (Valtioneuvosto, 2019)

As stated in the beginning, the focus on smart transportation internationally is often on population growth, but in Finland, as a post-industrial society, the motivator is mostly the economic growth and cost savings which could be achieved (Ylipulli & Luusua, 2020). Rapidly ageing population together with minuscule population growth affects to public finance in a way that public sector cannot sustain the current services as they are in the becoming decades without developing its operations. Finnish municipalities employ approximately 17% of total employed labour force (Valtiokonttori, 2020) and have a prevalent role of providing services. This has for one's part rendered public organizations to gather much data from several sectors, such as from transportation. Finnish municipalities have been called as data-rich operators who have a long legacy of statistical usage for administrative decisions (Statistics Finland, 2010). So, starting point for utilising smart

transportation solutions is on track because especially a lot of static data is available and the technology for connecting different devices is usable.

In this thesis, the main opportunities and challenges of implementing sustainable smart transportation solutions in Finnish municipalities will be considered and studied. First, the contemporary state of smart transportation solutions in Finnish municipalities will be considered such as what different issues impacts to implementation of these solutions. After that, follows the literature review which consists of recent international research publications relating to smart cities, smart transportation, and internet of things. With the help of the literature review, the empirical part aims to find the main opportunities and challenges of implementing sustainable smart transportation solutions in Finnish municipalities through interviews participated by branch experts of different sectors.

1.2 Research gap, question and objectives

Smart city as a concept is relatively new and regarding to Jucevicius et al. (2014) only after year 2010 number of publications of smart cities have increased considerably. In the beginning of this thesis work in January 2023, a Gap analysis for thesis' keywords was made to three different databases: Elsevier ScienceDirect, IEEE Xplore and ProQuest ABI/INFORM. The publishing timespan was settled for years 2017-2023 and document type was restricted for only scholarly journals. The keywords used for this analysis were smart city and smart cities, smart transportation and sustainability. In the Table 1. below, results of the analysis can be seen.

Timespan	2017-2023
Document type	Scholarly journals
Other requirements	Full text and peer viewed

Keywords	Database	Hits
In title: smart city OR smart cities	Elsevier ScienceDirect	1128
	IEEE Xplore	493
	Proquest ABI/INFORM	380
	SUM	2001
In title: smart transportation	Elsevier ScienceDirect	51
	IEEE Xplore	42
	Proquest ABI/INFORM	18
	SUM	111
In title: smart transportation AND In title, abstract, keywords: sustainability	Elsevier ScienceDirect	7
	IEEE Xplore	1
	Proquest ABI/INFORM	1
	SUM	9

Figure 1. Research gap analysis

The keyword “smart city” search gave some reference to how many smart city-titled researches has been published in recent years in general. The “smart transportation” keyword itself relates to smart city so it was unnecessary to add Boolean for smart city keyword. Search with “smart city and transportation” gave also much more irrelevant studies than the “smart transportation” when keeping in mind the topic of this thesis. When it came to adding sustainability keyword, searching only from titles gave hardly any hits, so it was reasonable to expand the keyword search to abstracts and keywords.

When dividing smart city keyword hits altogether with sum of smart transportation hits the percentual proportion is roughly 6%. Of course, this is not the whole truth about the

proportion of smart city studies relating to smart transportation, but it gives some approximation. To compare a bit, Boolean "smart energy" gave noticeably more results in all these databases than smart transportation, so it seems that the transportation dimension is less studied topic than energy at the moment. When it came to smart transportation and sustainability the hits drop tremendously even though the sustainability keyword was expressed also in abstract or in keywords in the research. In Finland and Nordic countries, there has been done research relating to smart transportation and what it for example could be, but now when there has been implemented some concrete solutions in recent years, studying this topic is relevant.

The research question of this study is *"What are the main opportunities and challenges for Finnish municipalities when implementing smart city solutions for sustainable transportation?"* With the help of research objectives, research question will be answered. The research objectives are:

- Identify contemporary state of smart transportation development in Finland.
- Review contemporary features of sustainable smart transportation based on recent international studies.
- Conclude the main opportunities and challenges of sustainable smart transportation solution implementations in Finnish municipalities on basis of literature review and executed interviews.
- Present recommendations for municipalities.

1.3 Definitions and limitations

To begin with, as Tantarimäki considers in his article *"Smart municipal where are you?"* (2020), what do we actually mean with the term "*smart*". He states that it needs to be considered what it requires to be smart and what for when talking about these "smart" solutions. In this thesis, where term smart is used repeatedly, it is reasoned to also consider it a bit first.

Jucevicius et al. (2014) presented an outline of smartness in smart city context which can be seen from the Figure 2. This figure represents different dimensions of smartness which all can be applied in smart transportation. The circles around the core are the main characteristics of being smart in this smart city context. The ellipses are then the most remarkable features of being smart. In other words, without being digital, agile and intelligent for instance, the transportation solutions cannot be called smart.

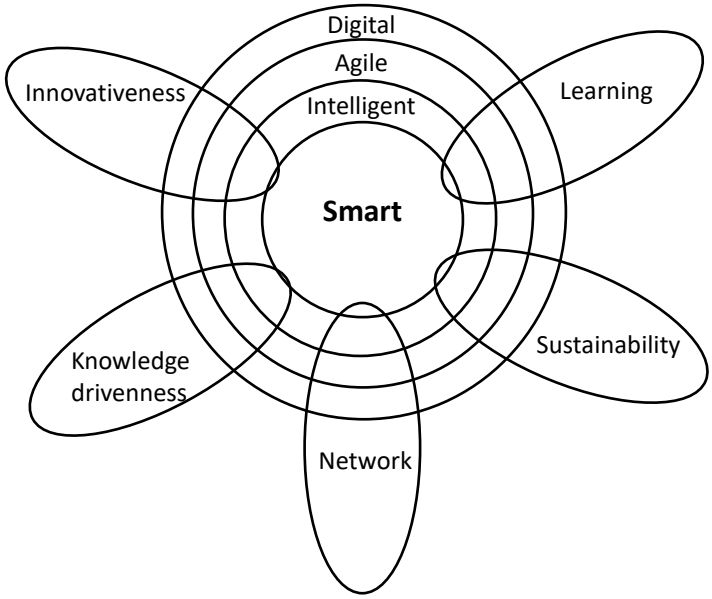


Figure 2. Smartness model by Jucevicius et al. (2013)

When considered the features listed in the ellipses: learning, sustainability, network, knowledge drivenness and innovativeness the best possible result will be achieved. Steven Alter (2019) considered in his research essay the definition of smart "things". Regarding to him National Science Foundation (2014, p. 5) had the most covering and uniting definition in this information and communication technologies context smartness:

> *"A "smart" service system is a system capable of learning, dynamic adaptation, and decision making based upon data received, transmitted, and/or processed to improve its response to a future situation. The system does so through self-detection, self-diagnosing, self-correcting, self-monitoring, self-organizing, self-replicating, or*

> *self-controlled functions. These capabilities are the result of the incorporation of technologies for sensing, actuation, coordination, communication, control, etc."*

Alter (2019) adds that socio-technical aspect through intensive involvement of users is a major principle of smartness on many occasions. In this thesis the term smart relates to digitalization and the use of IoT to make better decisions for citizens relating to sustainable transportation.

Smart city as a term relates to the new modern urban environment, which performance is designed through information and communication technologies as well as other types of physical capital. As a concept smart city aims to offer higher quality of life, reduce waste, and improve economic circumstances with intelligent management of resources. (Stimmel, 2018, p. 4) This intelligent management of resources requires for instance cross-sectional integration. The European Commission (2022) highlights the integration on different sectors with definition: *"A smart city is a place that integrates physical, digital and human systems in traditional networks and services to better use energy resources and reduce emissions to the benefit of citizens and businesses".*

First, *transportation* is move of things and masses to one place to another. Often the excellence of transportation is accomplished when used time and resources are minimized. On some occasions collective system for transportation achieves the optimal state when assessing benefits of different parties. (Cooley, 1894, p. 15) Extensively *smart transportation* in urban areas consists of two main subareas: smart traffic control and smart vehicles. Smart traffic control aims to offer optimized environment were vehicles, traffic signs, and control bases share and utilize data. Smart vehicles' goal is to fully automate the driving with interconnected surrounding environment. (Azgomi & Jamshidi, 2018, p. 5; Chen et al, 2021) Regarding to Mohanta et al. (2022, p. 723) use of Internet of Things, cloud computing, artificial intelligence and machine learning have led to creation of term smart transportation. As Cooley stated already in 1894, still today the most important issues of smart transportation relate to time and energy (Azgomi & Jamshidi, 2018). In this thesis, the focus is on road transportation in urban areas.

Generally, *sustainability* has been described as a concept where society and companies use and interact with the natural resources and ecosystems. Going a bit further to history, sustainability has been seen as capability of human society to sustain changing environments and adapt to it. (Borglund et al, 2021, p. 89) Nowadays, sustainability and sustainable development whereas relies on humanity and will of achieve required current needs without compromising future generations' needs (The World Commission on Environment and Development, 1987). This compromising means that current production of needs cannot destroy the opportunities to reproduce the corresponding needs in the future (Castells, 2000, p. 118). Regarding to Wang and Zhou (2022, p. 2), most scholars want to take account also on economic and social dimensions when talking about sustainability moreover for environmental point of view, and those are also seen as inseparable parts of urban sustainability. In the smart transportation context, sustainability is often considered as acts of municipalities and companies to decrease negative effects which transportation causes for society and environment and secure the continuity of the transportation operations. (Borglund et al, 2021, p. 89). These acts are balancing between the three main dimensions of sustainability (Reyes-Rubiano, 2021).

Internet of Things (IoT), also known as Internet of Objects, refers to the networked interconnection of physical objects which are integrated with embedded systems (Xia et al, 2012; Azgomi & Jamshidi, 2018). Most of IoT infrastructures are consisting of multiple sensor-fitted devices which are connected to a big data platform for further analytics (Ahmed et al, 2017). As stated before, IoT utilization can be seen as an inevitable factor of smart cities and is the primary cause for recent rapid development of different smart solutions (Azgomi & Jamshidi, 2018; Perera et al, 2017). As smart transportation solutions also rely heavily on data utilization, the IoT generated data is in the main position (Perera et al, 2017).

In Finland all areas of habitation are called "municipal". Term "city" is just a branding term for more a citylike structure and it needs to be applied. Municipalities' duty is to offer statutory services and in addition other self-governing services and these are

conducted from Local Government Act of Finland (Kuntalaki 410/2015). (Paikkala, 2009; Finlex, 2023) In 2022, there were 309 municipalities in Finland and 108 of those used term “cities” from themselves (Kuntaliitto, 2023).

1.4 Structure of the thesis

The thesis consists of five different chapters: introduction, Finnish municipalities and smart transportation, literature review of key concepts, methodology, and discussion and conclusion. Introduction chapter includes thesis subject’s background, research gap analysis, research question and objectives, and definitions and limitations.

In chapter 2, there is reviewed the contemporary state of smart transportation implementations and in Finnish municipalities. In addition, there is some legal aspects and history covered which gives a bit overview what has led to the current situation. This review is based on academic journals and grey literature such as Ministry papers, sites of public organizations and EU workpapers.

In chapter 3, there is literature review of smart cities and sustainability, smart transportation and sustainability and internet of things. After reviewing the journals, the framework of the sustainable smart transportation is established keeping in mind the scope of this thesis.

In chapter 4, the methodological part of the thesis will be executed. First there will be the research process, design and data collection presented. Then there will the data analysed. Finally, validity and reliability of the research process will be assessed.

In the final chapter, there will be the discussion and conclusion. The research results and key findings of the research will be concluded, recommendations presented for municipalities and future research topics suggested. In the end, there are references listed and appendices added.

2 Finnish municipalities and smart transportation

In this chapter there is first a bit background of smart city development in Finland and introduced possible negative effects and challenges that smart transportation solutions thrive to conquer. Then governmental matters will be presented relating to the implementation and development of smart transportation solutions. Lastly there are already finished and still ongoing smart transportation projects in Finnish municipalities presented.

2.1 Background of smart city development in Finland

As stated in the introduction, public organizations have had a leading role for igniting new business opportunities for private companies in the smart city industry in Finland (Ylipulli & Luusua, 2020). Public organizations' most important roles have been being a neutral facilitator and coordinator. This includes for instance authorisation processing, citizen inclusion, opening new operations and acting as a customer and procurer. (Työ- ja elinkeinoministeriö, 2017, p. 51)

In Finland, municipalities are rather small economic areas and low populated compared to most other cities in Europe. To bring together different operators and to pool resources and experts, the Ministry of employment and economy in Finland launched program in 2014 called innovative cities program (INKA). The INKA has ended already in 2017 but the program has had positive effects for innovative atmosphere between public and private sector in developing and implementing next generation technologies till this day. (Työ- ja elinkeinoministeriö, 2017)

Cities that were chosen for INKA program in Finland were Vaasa (sustainable energy), Oulu (future healthcare), Joensuu (bioeconomy), Jyväskylä (cybersecurity) and Tampere (smart city and renewable manufacturing). From these cities, Tampere's smart city

program had a smart transportation project called CityTrack (Työ- ja elinkeinoministeriö, 2017).

The main goal of INKA was to strengthen regional innovation centres with development platforms and lead markets. More extensively, goals of INKA were developing operation models and development platforms such as open innovation platforms, creating lead markets for testing platforms and initiatives in different innovation ecosystems, to combine public and private sector to achieve innovative public acquisitions, and take advance of internationality through strategic partnerships and external networks. (Työ- ja elinkeinoministeriö, 2017)

Ministry of employment and economy in Finland published a summarization of the INKA program in which there were the major achievements of this program considered (Työ- ja elinkeinoministeriö, 2017). The biggest benefit of the program was that completely new ways of working were founded where the mutual work with different sectors were more concrete and the cooperation was highlighted. Other benefits that municipalities achieved, and in some extent did not predict, were enhanced vitality of the city and profile raising as an interesting innovative city. INKA program gave an example how these new innovative projects can be organized, and as can be noticed later in this chapter, the smart transportation programs have continued with these same well-advanced policies. To sum up, the INKA program can be seen as a starting point for smart city development in Finland.

There are several inconveniences in Finnish municipal urban areas that smart transportation solutions thrive to solve. Generally speaking, the most notable problems of road transportation are traffic congestion, negative environmental impacts, land use, safety risks, high energy consumption and high maintenance costs (Rodrigue, 2020, p. 192). These problems are rather universal and apply in most places in the world, also in Finland. When it comes to the economical point of view, maintenance costs are peculiar high after winter in Finland because of frozen ground which causes impairment in the road

structure and for example turns out as holes on roads (Malmivuo, 2023). In addition, studded tires strip the road surface rather fast. Regarding Traficom (2023), maintenance backlog is increasingly growing because of increased costs and reduced funding for repair work. Hence, the roads are in worse condition after each year, and this is one of the major challenges for sustainability of transportation infrastructure in municipalities.

Lehtomäki et al. (2021) made research considering health effects affected by transportation in Finland. The three most negative effects causing things were traffic accidents, air pollution and noise pollution. In this research of Lehtomäki and others the biggest municipalities of Finland were taken into a specific examination. There were also considered positive effects in addition for the negative effects. Positive effects were for instance physical activities such as walking and cycling. Then the positive and negative effects were compared in such a way that is it worthwhile to cycle and walk when taking account on the pollution caused by other traffic on behalf of health. The result was that it was still twice as much beneficial for health to walk or cycle one place to another even though there will be exposing to air pollution. Chen and Hoek (2020) studied in their research long-term exposure for these particulates caused by traffic that float in the air of cities. On basis of their literature review, there was clear evidence found from the international pollution publications of increased amount of mortality and visceral diseases relating to these particulates.

Noise pollution has been found to be a significant environmental health risk factor, especially in bigger Finnish municipalities (Lehtomäki et al, 2021; Asikainen & Hänninen, 2016). Regarding to the World Health Organization (WHO) publication of Environmental Noise Guidelines (2018), noise pollution causes for instance: concentration difficulties, sleep disturbances, children’s cognitive development diminution and a list of different physical complaints. In a survey made by Turunen et al. (2021), the noise occurred by road transportation was experienced as a most disturbing noise in everyday life among Finnish citizens in the main capital region. Approximately 5% of the sample thought that

road transportation noises disturb significantly. Other choices for origin of the noise in the survey were railways, trams, air traffic, industries, and neighbours for example.

2.2 Governmental matters of smart city solutions in Finland

In Finland, when implementing smart city solutions, governmental matters must be considered. These are norms, legal regulations, electronical communication codes, different acts, EU directives and land use contracts for instance. Regarding to Korpisaari et al. (2021), when implementing smart city infrastructure and solutions, legal regulation impacts on both enabling factors and possible barriers. Modern technology can rise major concerns regarding to citizens data security and privacy which highlights the importance of steady legislation in terms of citizens to feel safe and companies to have courage to invest. Without credible data security legislation, citizens can have doubts when utilizing new services and negligently designed systems can be fragile for security breaches. (Korpisaari et al, 2021, p. 159)

Data privacy and protecting personal data are in the central point of planning smart city solutions (Liu & Yan, 2022). Utilizing 5G network in smart city IoT system revolutionises the locating and positioning individual objects with high accuracy. Especially in smart transportation where intelligent traffic system is using device to device (D2D) and vehicle to vehicle (V2V) communication via 5G network for accurate positioning, the data protection must be considered carefully. In 2016, EU published General Data Protection Regulation (GDPR) to protect individuals' data protection (Regulation (EU) 2016/679, 2016). The GDPR pays particular attention to data processing, data controlling and sets limits for data using.

To comply with the GDPR in smart city IoT environment, data anonymization and pseudonymisation must be used efficiently to protect personal data of citizens. Anonymous information means that it cannot be traced to identify natural person and it begins with appropriate data gathering manner. (Alen-Savikko et al, 2020, p. 166) Pseudonymisation

whereas relates to a process where the data cannot be no longer attributed to the original data subject and identified without additional information (Regulation (EU), 2018/1725 (16)).

In Finland, sustainability norms that matter in smart city planning are UN Sustainability development goals (UN SDGs 2015), Key Guidelines on Corporate Social Responsibility by Ministry of Economic Affairs and Employment in Finland, OECD Guidelines for Multinational Enterprises (2011) and UN Global Compact: Guide for General Counsel on Corporate Sustainability Version 2.0 (2019) (Korpisaari et al, 2021). These norms are legally non-binding and so called soft-law style standards and are used as guidelines and recommendations (Ristaniemi, 2020, p. 4). These norms are also contributed to developing smart transportation and for example in standard planning (ISO, 2023).

As stated before, legislation influences both development and implementation of smart city solutions. For instance, relating to the smart vehicle development in Finland only testing a fully automatized vehicle in real conditions is allowed in Finland (Ajoneuvolaki 493/2023, 116 a §). However, there are work groups organized by Ministry of Traffic and Communications investigating new guidelines and law modifications relating to autonomized road transportation. These new modifications should promote the development of transportation automatization. (HE 291/2022, p. 4)

International Organization for Standardization (ISO) has published several standards for different sections of smart cities, also for smart transportation. There are already many standards for different occasions available for urban smart transportation solutions. (ISO, 2023) These standards are concluded in the Table 1. These ISO standards are contributing to the UN sustainable development goals (SDGs), and the organization is promising that the standards are reviewed in every five years. (ISO, 2023) Generally speaking, standards aim to improve products' compatibility and protect both the customer and environment. Standardization is also an important developer of new businesses and

helps especially smaller companies to scale up their production and to enable easier access to the international trade. (Finnish Standards Association, 2020)

Table 1. ISO standards for smart transportation

Standard	**Use case**
ISO 37157:2018 Smart community infrastructures — Smart transportation for compact cities	Offers criteria for organising smart transportation in compact cities which have declining population.
ISO 37182:2022 Smart community infrastructures — Smart transportation for fuel efficiency and pollution emission reduction in bus transportation services	Offers criteria to save fuel and decline emissions for engine driven busses.
ISO 37181:2022 Smart community infrastructures — Smart transportation by autonomous vehicles on public roads	Describes the concept of autonomous vehicles in smart transportation. Focusing on actual use on public roads and safety.
ISO 37167:2021 Smart community infrastructures — Smart transportation for energy saving operation by intentionally driving slowly	Describes how traffic speed modifications helps to save energy occurred in the operation.
ISO 37162:2020 Smart community infrastructures — Smart transportation for newly developing areas	Focuses on arranging smart transportation for developing areas to connect with already existing city centres.
ISO 37163:2020 Smart community infrastructures — Smart transportation for parking lot allocation in cities	Focuses on installing and organizing smart parking lot allocation in congested cities.
ISO 37158:2019 Smart community infrastructures — Smart transportation using battery-powered buses for passenger services	Introduces the usage of battery-powered buses in smart transportation.
ISO 37168:2022 Smart community infrastructures — Guidance on smart transportation by Electric, Connected and Autonomous Vehicles (eCAVs) and its application to on-demand responsive passenger services with shared vehicles	Guidance for implementing eCAVs in smart transportation and thrives to accelerate innovation in this application model.
ISO/TR 4286:2021 Intelligent transport systems — Use cases for sharing of probe data	Presents how vehicle probe data can be used in ITS data sharing model and there are gathered examples of installations around the world.
ISO 20529-2:2021 Intelligent transport systems — Framework for Green ITS (G-ITS) standards — Part 2: Integrated mobile service applications	Identifies cost-effective technologies and related standards required to apply Green ITS technologies.

In Finland, standardization is in major role in the development of smart transportation (Konkarikoski, 2021). Ministry of Employment and the Economy has designated Finnish Standards Association (SFS) to participate smart transportation standardization development with European Committee for Standardization (CEN) and International

Standardization Organization (Konkarikoski, 2020). By contributing to the international standardizing processes, Finnish organizations keep up with the latest advancements and even get the possibility to influence the decisions through working groups (Reini, 2016). In smart transportation, cooperation among different standardizing organizations ensures that technological specifications are harmonized and interoperability between countries is possible (Finnish Standards Association, 2020).

2.3 Smart transportation programs in Finnish municipalities

Between 2014-2020, 6Aika-strategy projects in Finland aimed to develop performance of municipalities with smart solutions. The projects were executed together by citizens, private companies, and research sector. The projects were complying with municipalities' overall strategies and aimed for instance carbon neutrality. These projects were all about co-creation and learning among different stakeholders. The name came from "6 cities" which were to Helsinki, Espoo, Vantaa, Turku, Tampere, and Oulu. (6Aika, 2023)

More precisely, 6Aika projects critical elements were open data, open interfaces, open participation and customership. To get these critical elements into concrete usage: customer-orientated co-development had been emphasized, access to needed data had been granted and opened, and there had been developed and tested the new solutions in real environment. (6Aika, 2023)

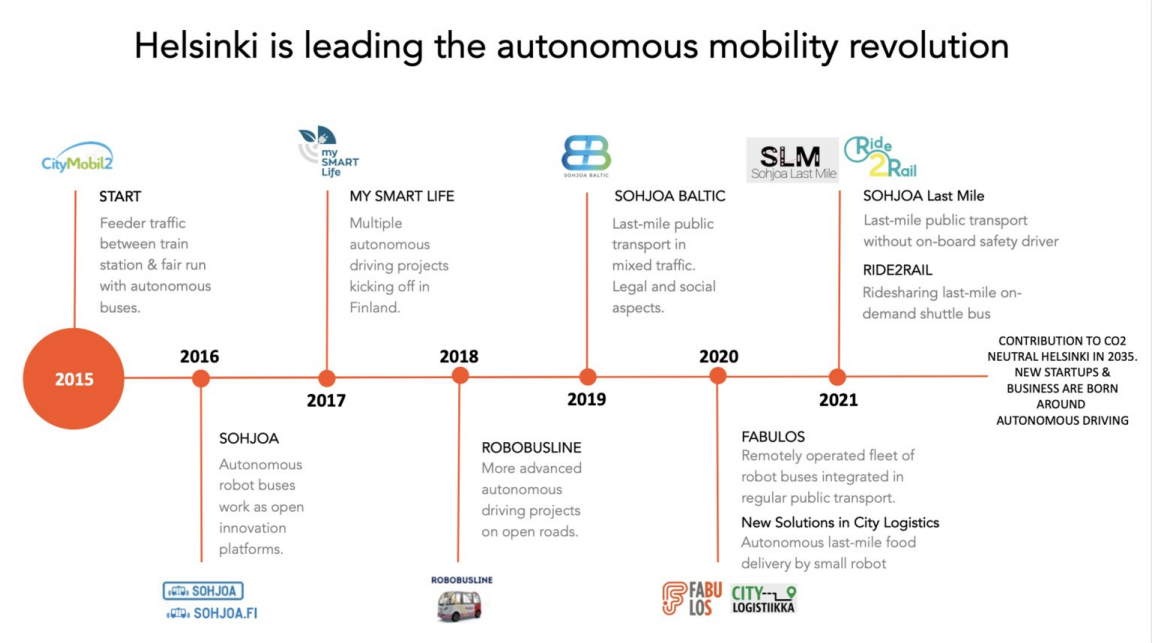
European Cohesion Policy was a great supporter for this sustainable urbanization strategy of 6Aika. Over 50 projects of 6Aika concerned in some way or another every third Finnish citizen. And over 100 million euros were invested in these projects. (Euronews, 2019) In 6Aika, there were projects that can be seen to have belonged in the sector of smart transportation. In the Table 2, there are listed transportation related projects executed by 6aika. Especially project SOHJOA concentrated on automatic little buses, and in the project, they managed to test them in the real environment which offered real competitive advantage for companies in the industry. This project aimed to increase

traffic safety in terms diminishing human errors with automatized transportation. (6Aika, 2016; Nissin & Åman, 2018)

Table 2. 6Aika smart transportation projects

Name	**Objective**	**Duration, partners, and funding**
Low-carbon mobility with traffic hub	Creating new kind of mobility service and developing trip chains.	**D:** 8/2019-1/2022 **P:** City of Espoo, Business Tampere, City of Oulu, Turun AMK, City of Turku
Smart waterborne traffic in a city - ÄlyVESI	New concepts of waterborne mobility. For instance, autonomic passenger ferry and smart dock.	**D:** 1/2016-5/2018 **P:** City of Turku, Aalto University, Turun AMK, Novia AMK. **F:** EU regional development fund, National traffic security agency in Finland, City of Helsinki and Espoo
SOHJOA-project	Automatic little robot busses testing in real city environment.	**D:** 6/2016-5/2018 **P:** Metropolia AMK, Aalto University, Forum Virium, Maanmittauslaitos and Tampere Technical University **F:** EU regional development fund, Liikennevirasto, Trafi

Forum Virium is an innovation company owned by City of Helsinki. Its operation also relies on co-development with different organizations and citizens. Forum Virium operates mainly with external funding which are directed to projects and this way acts as a non-profit company (Forum Virium Helsinki, 2023b). One of the most well-known concepts of Forum Virium is Mobility as a Service (MaaS). The main idea of MaaS is to bring together different transportation providers into single platform and offer efficient alternative for private car ownership for citizens (Future Mobility Finland, 2023). From the Picture 3 the timeline of the concept development of MaaS can be seen. (Forum Virium Helsinki, 2023c) The MaaS concept also includes for example travel planning features, vehicle sharing, real-time traffic management, smart parking, and centralized payment system.



Picture 1. Forum Virium MaaS development (Forum Virium Helsinki, 2023c)

Below in the Table 3 have been gathered the ongoing projects relating to transportation of Forum Virium (Forum Virium Helsinki, 2023a). As can be noticed, many of them considers data and its processing. In their website, they state that open data and IoT technology are the most important strengths when developing new solutions. There is a separate unit called Helsinki Region Infoshare (HRI) which is concentrated on offering data of capital region for open use (Helsinki Region Infoshare, 2023).

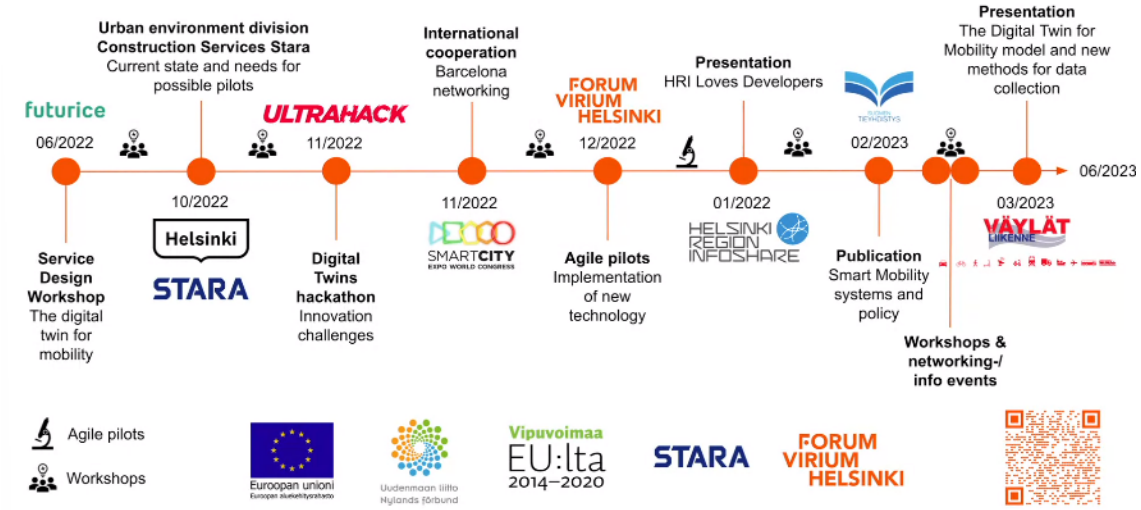
Table 3. Ongoing smart transportation projects administered by Forum Virium

Name	**Objective**	**Duration, partners and funding**
AutoMod-project	Create a next generation ecosystem for mobile carriage service robots which thrive to solve circular economy challenges in future smart cities.	**D:** 2021–2023 **P:** Metropolia Ammattikorkeakoulu, Espoon kaupunki **F:** EAKR (Uudenmaan liitto), City of Helsinki
Liidi2	Create a model for Digital Twin of mobility. Developing data gathering and smart transportation market potential in the region.	**D:** 2021–2023 **P:** Forum Virium, Stara **F:** Forum Virium, EAKR (EU), REACT-EU

Name	Objective	Duration, partners and funding
LIDO - Liikenteen datan haltu-unotto (Transporta-tion Data Gathering)	Goal is to be able to offer knowledge and data of Helsinki's traffic to active use for city transportation designers and promote live description of traffic state.	**D:** Part of Älyliikenne-ohjelma 2030 **P:** Forum Virium, Kau-punkiympäristön toi-mialan liikennesuunnit-telu (KYMP) **F:** EU Horisontti2020 funded URBANITE and SmashHit
URBANITE	Aims to strengthen traffic ecosystem in Hel-sinki from the data and knowledge point of view. Transpose data from separate holders to one shared data centre.	**D:** 2020–2023 **P:** Forum Virium **F:** EU Horisontti2020
RIDE2RAIL	Creates solutions and tools to combe car-pools with scheduled public transportation. The goal is to make finding and comparing different mobility options easier for citizens.	**D:** 2019–2023 **P:** Forum Virium, Met-ropolia Ammattikorkea-koulu. The main coordi-nator is International Association of Public Transportation (UITP) **F:** Shift2Rail and EU Horisontti2020

In the Liidi2 project the aim is to benefit from digital twin modelling in a built environment thrives to develop smart mobility and create new kind of services (Forum Virium Helsinki, 2023c). In short, digital twin is *"a virtual representation of a physical system (and its associated environment and processes) that is updated through the exchange of information between the physical and virtual systems"* (VanDerHorn & Mahadevan, 2021). In this context, digital twin describes the traffic infrastructure and environment. It can be used for better analysis via simulation of real time urban environment, for example changes in real environment updates immediately to the digital environment. This offers opportunities for proactive maintenance and predictive analysis of possible future state of the traffic (Rinne et al, 2022). From the Picture 4 can be seen what phases Liidi2 have had till now and get an example how many and what kind of stakeholders are involved in these projects.

Liidi2 timeline



Picture 2. Liidi2 scheme for mobility development projects (Kultanen, 2023)

In the field of intelligent transportation systems and services, ITS Finland is working as a forum for cooperation to develop sustainable and user-oriented transportation systems for Finnish municipalities (ITS Finland, 2023). At the moment, ITS Finland is involved in a work group called ITS Factory which develops an environment for the intelligent transportation system, and it is placed in the city of Tampere (Business Tampere, 2023).

To conclude, there are and have been several projects and operators in Finland for developing smart transportation solutions. Connective aspect of these is the use of digitalization to create more functional and sustainable transportation for citizens. Without forgetting the idea of creating new business possibilities and enabling scalability for international use.

3 Literature review

This chapter contains a literature review of smart cities and sustainability, smart transportation and sustainability, and Internet of Things. The key features of these key topics will be covered for assembling the framework. This literature review aims to support the general theory of *smart transportation solutions are robust part of making the transportation more efficient and sustainable in the future.* This literature review has a deductive approach which goes through the cycle of smart cities' smart transportation framework to revise the general theory (Saunders et al, 2007, p. 125).

3.1 Smart cities and sustainability

A smart city lives from innovativeness and intelligent use of technologies. The main goal of smart city is to improve quality of life of its citizens. This better quality of life comes from efficiency of the operations and services, respecting the continuity ensure, and sustainability of economic, social, and environmental aspects (Pashchenko, 2021). Because the smart city is much about focusing on the citizens, the development highly depends on their needs (Mohanty et al, 2016). Mohanty et al. (2016) highlights the importance of connectivity of different resources in a smart city to achieve the improvement of collective intelligence, hence the utilization of Internet of Things can be considered as a "backbone" of a smart city.

Mohanty et al. (2016) presents a smart city model which consists of main themes, attributes, and infrastructure. After these aspects, it narrows down to the components of the smart city. There are several variations of key components of smart city to which it can be divided. For example, it can depend on the development state of the city what it considers as the most important components for itself. Duan et al. (2020) proposed the six most general components of a smart city which were smart management, smart energy, smart transportation, smart infrastructure, smart health, and smart citizen. The

components of a smart city are not strictly obtained to a certain theme, rather they are all interconnected. In addition, the interaction between the components is critical and through a core network they can exchange information.

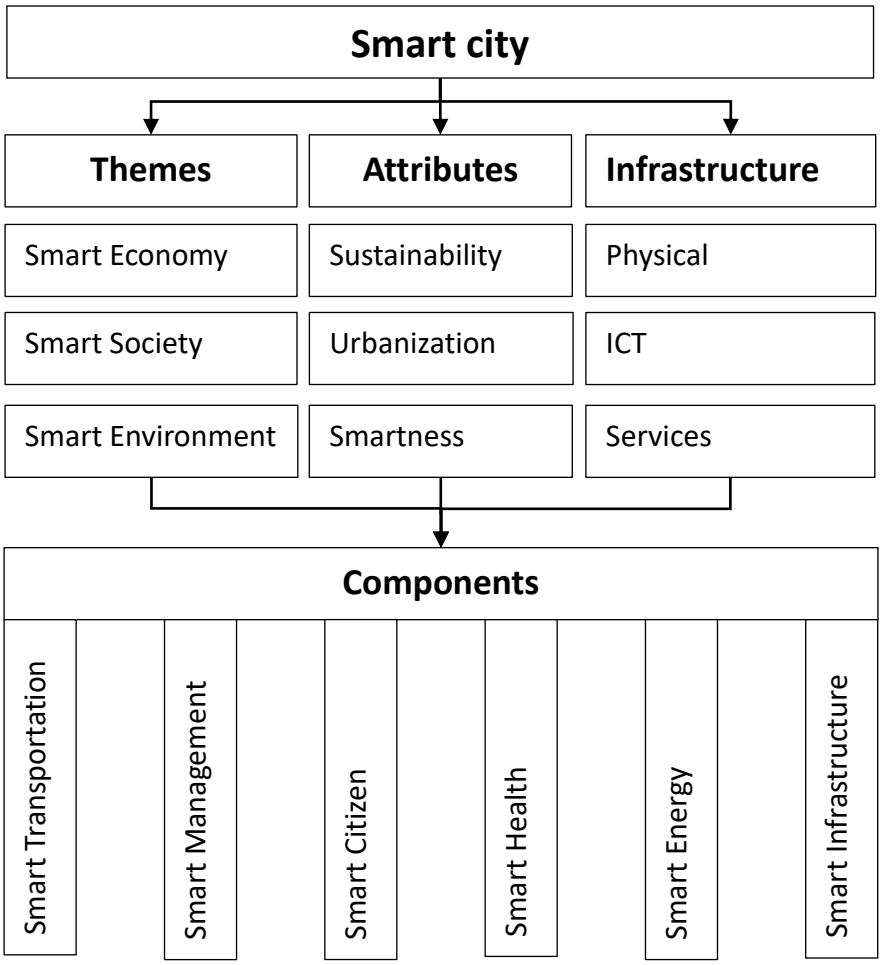


Figure 3. Smart city model (Modified from: Mohanty et al, 2016)

As Mohanty and others (2016) presented, also other next generation smart city models propose that the smart city is based on the three main themes: smart society, smart economy, and smart environment (Supangat et al, 2016). These themes can be also called as service domains. From these themes, smart society focuses on improving citizens' lives through intelligent use of digital technology. The use digital technology means for instance helping citizens to be more productive and release time to use for things that really matter for people's wellbeing. This theme signifies most that the city is for

the citizens. Smart economy aims to that the city is capable to grow economically utilising the technology. This includes for instance capability to offer jobs for citizens and offer companies propitious environment to operate. Smart environment whereas focuses most on environmental aspects such as assuring that city remains liveable and is able to operate without compromising the needs of future generations. To achieve to these environmental goals in smart city, smart technology solutions are utilized. (Mohanty et al, 2016)

The attributes listed in Figure 3 have an influence in the concept of smart city. The key attributes were sustainability, urbanization, and smartness. The sustainability in the smart city concept is often connected to the use of resources, pollution, and social and economic issues. Urbanization relates to the urban population growth and the challenges it occurs. Smartness whereas relates to the improvement of environmental, social, and economic standards through collaborative use of resources and use them as efficiently as possible. (Mohanty et al, 2016).

The concept of smart city builds on the infrastructure which is about the physical environment of the city, internet and communication technologies, and services (Mohanty et al, 2016). The integration of these smart city components through sharing information is a relevant aspect and it is a major efficiency and optimization opportunity for cities (Javed et al, 2022). The main requirements for the efficient data sharing systems are interoperability, scalability, fast deployment, robustness, eco-friendliness, and multimodal access.

From the smart city components, smart transportation component aims to offer sustainable mobility methods for citizens and develop the overall efficiency of the traffic system (Duan et al, 2019). How cities thrive to achieve these urban transportation development goals, will be reviewed in the next subchapter more closely.

Smart management relates to city governing through utilising advanced ICT solutions to achieve efficient planned actions which are based on monitoring and modelling the operations for example (Duan et al, 2019). Pashchenko (2021) proposes in his paper a list of critical mechanisms that smart management in a smart city should have: able to simultaneously solve various tasks of different nature and complexity, dynamically adapt into changes which can happen within the system or outside, ability to scope links with limitations and concretization, optimizing managerial levels, anticipate and prevent complications in a system, matching the costs of management to the capabilities and goals, and aim for simplicity in management system.

Smart management plans the operations for different terms of time and aims to intelligent use of resources. For smart transportation, changes in budgeting, resource allocation or restrictions on emissions can have an influence for instance. Also, management of the overall quality of living relates strongly to the efficient transportation system. (Raschmawati, 2019)

Smart energy is about new energy system implementations, operation monitoring and optimization of the consumption. Smart energy solutions are in key point when cities take the shift towards to renewable energy sources and take actions according to sustainable development principles (Lewandowska et al, 2020). One of the future goals of smart energy system is advanced automatized operation with the help of algorithms (O'Dwyer et al, 2019). The algorithms should be able to use historical data of consumers and usage profiles to optimize and coordinate interconnected use of different energy sources.

The smart energy component has many unifying factors with the smart transportation because the transportation sector highly depends on the functioning energy distribution. In the other way, energy sector can prepare for changing energy demand with data offered by smart transportation. The smart energy also has important role on development of different renewable energy sources for the use of transportation in cities. The

subsector of smart energy “smart grid” is also a unifying aspect between smart energy and smart transportation, especially if the electrical vehicles will get increasingly common. Smart grid aims to offer intelligent solutions for fluctuating renewable energy supply in interconnected power systems. (Lund et al, 2017)

Regarding to Duan et al. (2019) *smart infrastructure* provides the foundation for all smart systems. Smart infrastructure is based on Internet of Things and consists of huge number of different sensors, actuators, and equipment to gather data for processing (Slavisa, 2019). One of the key principles of smart infrastructure regarding to Slavisa (2019) is that the infrastructure supports heterogeneous transmission on various technologies and this way render the collective data sharing. So, the smart infrastructure offers the environment for all smart components to operate, also for smart transportation. With the smart infrastructure, the different smart components can utilize the same sensors and actuators for their own use through mutual network. This renders the even more efficient use of the whole infrastructure and highlights the scalability.

Smart health aim to offer more intelligent healthcare services with efficient ICT solutions and corresponding to changing healthcare demand of urban citizens (Duan et al, 2019). In addition to patient information system development, individual health monitoring devices are utilizing IoT based solutions in patient monitoring system such as sensor based, smartphone based and microcontroller-based health monitoring systems (Rahaman et al, 2019). Smart health has unifying measures with smart transportation for instance in emergency vehicle route optimization and getting information of possible emergency situations. Smart transportation sensors can offer for example critical real-time information of collisions.

Smart citizen is about citizens who are willing to use the technology provided to utilize smart city solutions and are engaged to the development process of the environment (Frank & Fernandez-Montesinos, 2020; Vaquero-Garcia et al, 2016). Regarding to Simonofski et al. (2017) many authors have highlighted the importance of citizen

participation in smart city solutions. These participation fields can be for example being as an ICT users, democratic participants, and co-creators. Smart citizen component plays important role in development of smart transportation solutions. In addition, for participating in the development process, citizens have an important role on adoption of new smart transportation solutions and using them after the implementation for further development.

Sustainability in smart city

Regarding to Bednarska-Olejniczka et al. (2019, pp. 331–332), sustainability in context of cities have many different perceptions depending on the approach chosen. They are presenting a definition for sustainability in a city as *"a sustainable city is one which succeeds in balancing economic, environmental and socio-cultural process through processes of active citizen participation"*. They add that sustainability in cities include the universal goals of sustainability as providing vital needs of citizens without compromising future generations living conditions.

When precising the sustainability definition into smart cities, Ibrahim et al. (2018, p. 531), introduces a definition published by International telecommunication Union for sustainable smart cities as *"an innovative city that uses Information and Communication Technologies (ICTs) and other means to improve quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social and environmental aspects".* A well-founded definition for sustainable smart city could be a mixture of these two definitions which takes account on the balancing between the sustainability dimensions, active participation of citizens and continuity point of view.

These three dimensions economic, social, and environmental are widely use as the most relevant dimensions of sustainability also in a smart city (Bifulco et al, 2015, p. 137). Martin et al. (2018) specified these dimensions in smart city context with economic

dimension concerning most the economic development, social concerning most the equity among citizens, and environmental concerning most the protection of the environment. This “three spheres of sustainability” model can be seen in the Figure 4. Regarding to Zak (2015) the sustainable development relies on balancing between these three dimensions.

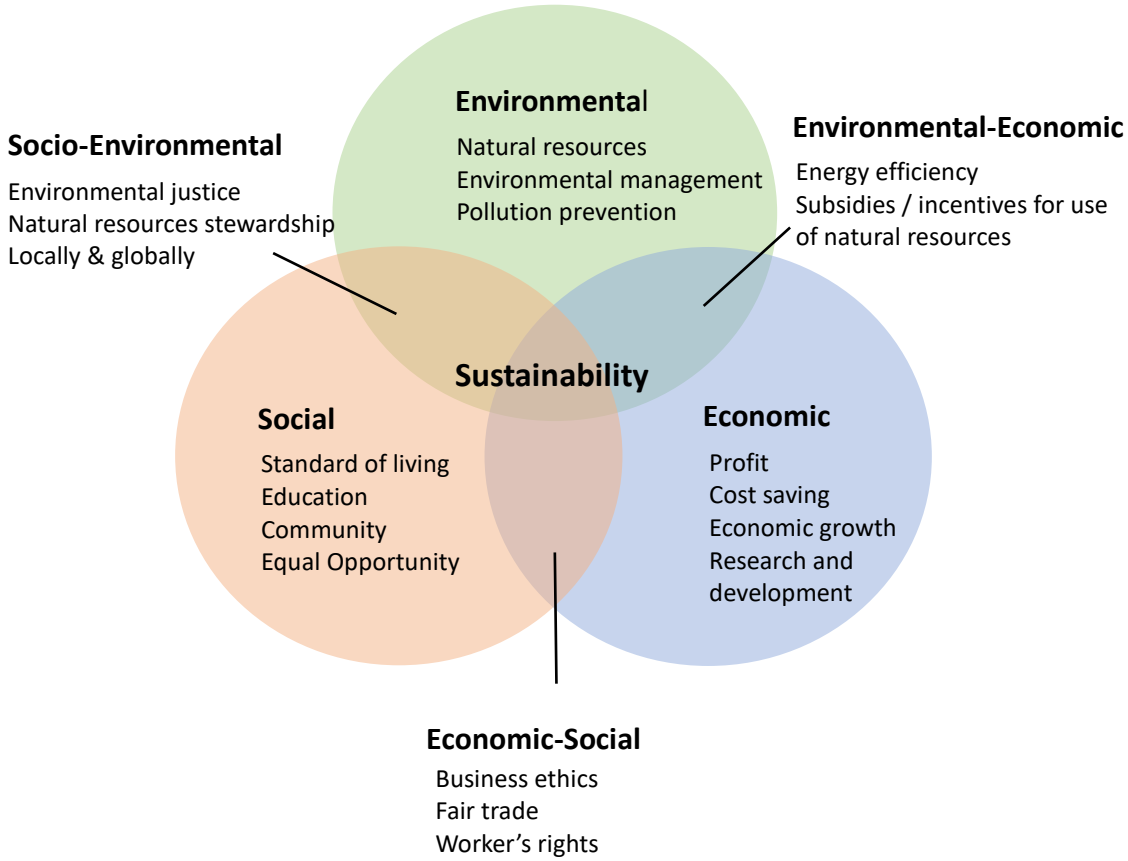


Figure 4. Three spheres of sustainability (Zak, 2015)

Suganda and Favaro (2022) studied from what the social sustainability dimension in smart cities consists of. Regarding to them, the main themes are social capital, social infrastructure, social equity, social inclusion, and collaborative planning. These themes are very much similar as on the Zak’s general model’s social sphere in the Figure 4. In addition, the environmental and economic spheres consist of similar key points in

sustainability of smart city. Shamsuzzoha et al. (2021) present in their study that economic sustainability in a smart city is also much about providing opportunities to improve the human productivity in the future. This improve of productivity could be achieved with smart city economic systems through efficient use of assets.

Martin et al. (2018) studied the tensions between smart city development and sustainability goals. More precisely it considered that can the digitalized smart city vision deliver sustainable solutions whilst especially taking account on social equity and environmental protection aspects of urban sustainability. Regarding to their study in North America and Europe the economic development is many times the primary goal of the smart city initiatives which can underrate and neglect the importance of social and environmental sustainability matters. Whereas Marsal-Llacuna (2017) presents in her study that economic and environmental sustainability aspects are more tangible which for one's part can explain the larger attention to these dimensions than to social aspects which are principally intangible. Marsal-Llacuna uses the ISO standards amount distortion as an example because there are mostly economic and environmental relative standards created.

3.2 Smart transportation and sustainability

This subchapter imitates the traditional scoping literature review to discover latest journals relating to sustainable smart transportation for assembling the framework. The traditional scoping review differs from systematic review in its strictness and goals. The traditional scoping review aims to flexibly explore latest research of the subject whereas the systematic literature review can be seen more as a research method which aims to find evidence and answer certain research questions through accurate guidelines (Jensson et al, 2011).

To achieve transparency and objectiveness to this review of the latest journals, the selection process has been presented in the Figure 3. After testing different Boolean

commands, the *"smart AND transportation AND sustainab*"* string offered the most useful studies. In addition, the string had to be included in the title of the journal because using them in a keyword search gave vast amount of unrelating journals. This string offered documents from a wider scale than the GAP analysis presented in the introduction which in turn aimed to seize exact smart transportation studies. Detaching words smart and transportation gave more options for publisher to place the words in the title. Using *"sustainab*"* command allowed the use of both sustainable and sustainability words in the results. However, to achieve better overview of the topic, larger amount results were demanded and therefore more databases were included also.

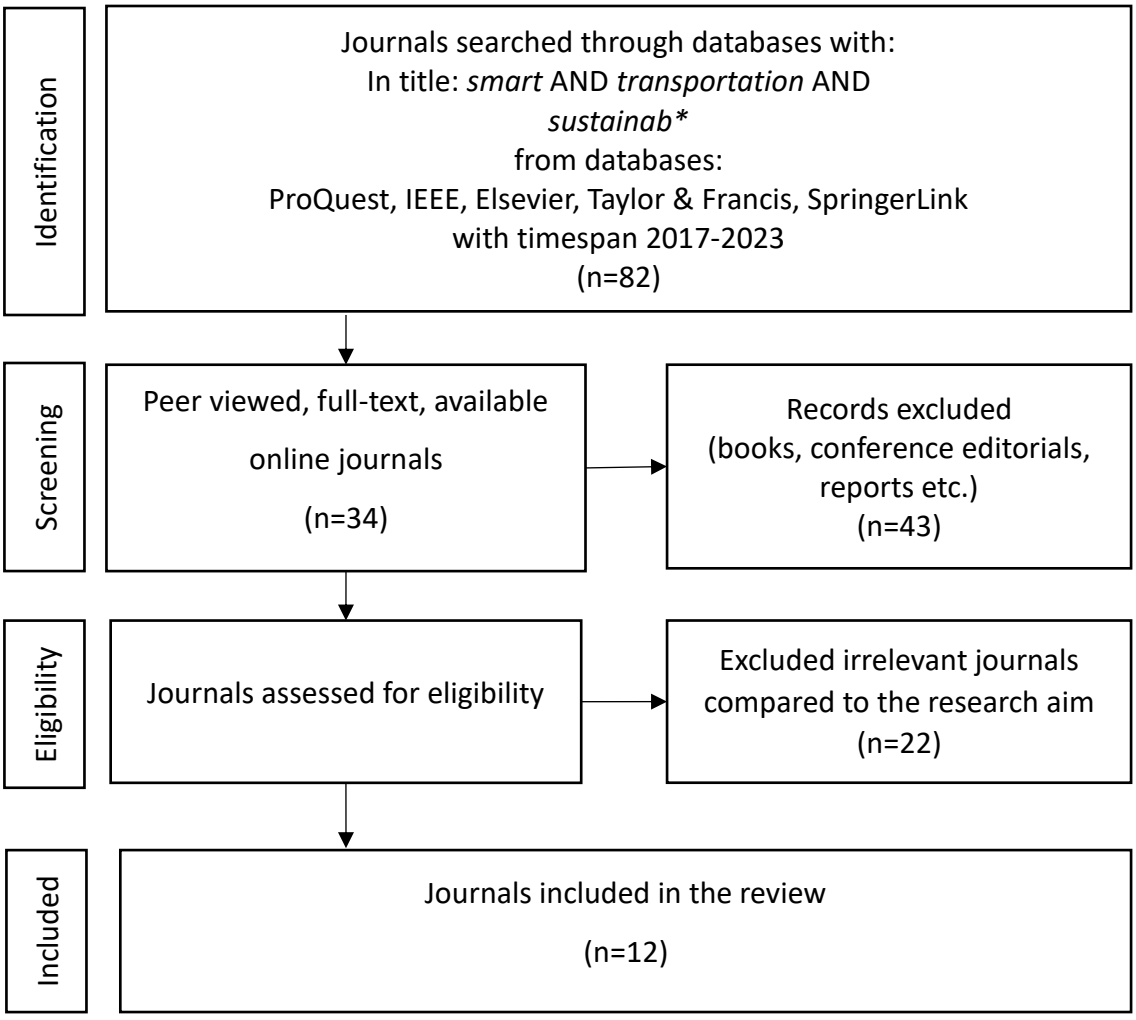


Figure 5. Journal selection process

From total amount of 84 publications, after screening and eligibility evaluation, 12 of these journals were included in a closer review. In the Table 4 the 12 included journals are summarized. These journals will be considered more precisely in this chapter.

Table 4. Selected journals for review

Reference	Title	Summary
Aloqaily et al. (2022).	An adaptive UAV positioning model for sustainable smart transportation.	Research presents the benefits of using drones for better cover of wireless network and offering data from traffic congestions. This research aimed also to offer adaptive positioning model which optimizes the height and energy consumption of the drone.
Zheng et al. (2022).	Towards a sustainable monitoring: A self-powered smart transportation infrastructure skin.	Research represented self-powered bionic sensors which are fitted in the road surface. In other words, these sensors do not need external power supply, which shortens the payback time of the implementation. The sensors' data is then processed in a mutual cloud platform.
Liu et al. (2023)	Multi-scale urban passenger transportation CO_2 emission calculation platform for smart mobility management.	This research offered data comparisons of different urban transport methods relating to time, emissions and trip quantities. The data aims to render smart mobility management in terms of route planning and $C0_2$ monitoring tool.
Vicuna et al. (2019).	A Generic and Flexible Geospatial Data Warehousing and Analysis Framework for Transportation Performance Measurement in Smart Connected Cities.	Research presents different transportation performance metrics (TPM's) and platforms. With the help of an example case, the framework and implementation phases of traffic performance measures has been created. The finished dashboards in conclusions showcase in concrete from the application of the TPM's.

Reference	Title	Summary
Wallsten et al. (2022).	The Role of Local Public Authorities in Steering toward Smart and Sustainable Mobility: Findings from the Stockholm Metropolitan Area.	Study sheds light on how too different sized municipalities, Stockholm and Botkyrka, are concerning smart mobility and sustainable transportation in a governmental level.
Musa et al. (2023).	Sustainable Traffic Management for Smart Cities Using Internet-of-Things-Oriented Intelligent Transportation Systems (ITS): Challenges and Recommendations	Presents key features of sustainable smart traffic management with ITS-based devices. Framework and performance measures has been suggested for planning and monitoring for smart traffic management.
Sitinjak et al. (2023).	Assessing Public Acceptance of Autonomous Vehicles for Smart and Sustainable Public Transportation in Urban Areas: A Case Study of Jakarta, Indonesia	Research studied citizens of Jakarta their expectations and opinions of automated vehicles (AV). Results showed that significant proportion of attendees had positive attitudes towards AV's and demographic characteristics had less influence on public acceptance of AV's than expected.
Lu et al. (2022).	Exploring the Key Priority Development Projects of Smart Transportation for Sustainability: Using Kano Model	Research studied smart transportation projects' quality satisfaction through Kano Model with online questionnaires. Model indicates the presence of customers intuition and is useful in the product development.
Reyes-Rubiano et al. (2021).	The Sustainability Dimensions in Intelligent Urban Transportation: A Paradigm for Smart Cities	Study in holds great consideration of sustainability in smart city transportation. Study also reviews urban freight transportation sustainability problems.
Chen et al. (2021).	An Intelligent Platooning Algorithm for Sustainable Transportation Systems in Smart Cities	This study concerns vehicular platooning technology for ITS. The platooning model is most about optimization on fuel consuming, traffic efficiency and safety measures.
Tripathy et al. (2020).	WeDoShare: A Ridesharing Framework in Transportation	Considers problems in urban transportation and mutual pitfalls in ridesharing systems.

Reference	Title	Summary
	Cyber-Physical System for Sustainable Mobility in Smart Cities	Presents a rideshare IoT network especially focusing on to lower proportion of single occupied vehicles (SOV's) in the traffic.
Balasubramaniam (2017).	Comparative Analysis of Intelligent Transportation Systems for Sustainable Environment in Smart Cities	Introduces sustainable transportation from Internet of Vehicles (IoVs) point of view. Presents a comparative analysis about which features of sustainable transportation are existing in the methodologies in the literature with the timespan of 2009-2016.

Several recent smart transportation relating studies start with the statement of population growth as a challenge for future transportation in cities (Musa et al, 2023; Chen et al, 2021). Regarding to the latest UN report of World Population Prospect (2018), in year 2050 there will be nearly 10 billion people in this planet. Regarding to Djahel et al. (2018) this 2 billion increases in population till 2050 means also 2,9 billion extra vehicles. When it comes to urbanization, these 2 billion increases in population redirects completely to the cities (UN, 2014). This increase in population and vehicles is going to cause severe challenges in cities such as congestions, air pollutions, health issues and wastes (Lu et al, 2022).

Intelligent transportation systems (ITS) are anticipated to solve complex transportation questions in constantly growing cities. Intelligent transportation system relates to comprehensive integration of transportation systems and smart vehicles. The ITS can provide for instance intelligent path planning and navigation, and this way decrease traffic congestion probability and make the traffic flow more efficient. ITS application relies on IoT data generation and uses it to advanced data analysis scheme of current conditions. It can for instance sense the traffic flow density, traffic speed, weather conditions, duration of congestions. (Lin et al, 2020) In addition, ITS can suggest optimal travelling modes in the current situation and on the basis of passenger's preference (Chand & Karthikeyan,

2018). Regarding Musa et al. (2023) artificial intelligence has been a driving factor for enabling these optimal travelling modes and managing the overall transportation environment.

Vicuna et al. (2019) presented transportation performance measurement metrics for smart transportation analysis. Many metrics relates to average of monitored space for example travel time, speed, delay, queue, and density of vehicles. In addition, metrics such as travel-time variance and travel time reliability are critical to consider. The travel-time variance and reliability metrics require an integrated operating smart transportation network, whereas the other metrics can be created through singular measuring links and points.

Traffic congestions are one of the most serious problems when it comes to transportation in cities and minimizing them is in the central point of making the transportation more sustainable (Musa et al, 2023). Congestions cause a lot of unnecessary direct impacts such as accidents, additional emissions and fuel waste, and major indirect impact such as decrease in productivity when travellers' time is wasted. Lin et al. (2020) were examining in their research a spatiotemporal congestion-aware path planning where the path forecast can be modified with time constraints to minimize congestions. The algorithm calculates the probability of congestions within the chosen timeseries and uses the current IoT data in real time to find the optimal route to the destination. Lin and others warn that these kinds of complex rerouting applications can cause severe loss of resources if not done right. At the moment, for instance Google Maps can modify the route if there are informed road works or accidents that prevents using the road normally and suggest some other route if it is more optimal in that case (Chavhan, 2022). But this kind of real-time traffic flow route modifying is not so commonly in use as Lin and others proposed. Although, Google Maps can predict the time required to reach the destination in the current time-series, but it do not have an efficient context-aware real-time path planning.

When considering the sustainability of the smart transportation system, question such as energy consumption and implementation payback time of the sensors arise. Zheng et al. (2022) present in their innovative study a self-powered smart transportation infrastructure skin. The sensor is installed under the road surface and gets mechanically excited of the by-passing vehicle. The electric signal which the vehicle causes is then sent to the central processor where deep learning terminal analyses the type of the vehicle. The research state that the critical benefit in addition for the energy self-sufficiency, is that other sensors usually are planted in the upper level of the road surface which causes deformation and abrasion inconsistency between the sensor and road material. This shortens the infrastructures lifetime and makes the sensor more plausible to fail.

Triprathy et al. (2020) in their study present an IoT based ridesharing platform for more sustainable transportation in smart cities. Regarding to the study these kinds of ridesharing pilots have failed in many smart cities. The ridesharing focuses most on decreasing single occupied vehicles (SOV) and this way for instance aim to diminish congestions. Tripathy and others list reasons for failure in previous ridesharing pilots and those related to lack of coordination between platform users, trust and security worries, unwillingness for direct dealing of rides in the platform, sustainability point of view was subsidiary for the users, user engagement challenges, and social status viewpoint. They state that especially one of the key challenges related to engagement to the platform which requires for operating continuous involvement of citizens. The platform also aims to improve the awareness of more sustainable transportation solutions achieve behavioural change achieved among citizens. One of the IoT based platform benefits of the real-time sensing is able to offer statistics of sustainability contribution relating to fuel savings and carbon dioxide emissions and this way encourage citizens to choose more sustainable mobility methods. And as mentioned before, Alter (2019) states in his research essay that socio-technical aspect through intensive involvement of users is a major principle of smartness.

So, to develop citizens awareness on sustainable transportation methods, ability to offer data from chosen methods is beneficial (Liu et al, 2023). Liu et al. (2023) developed a

CO_2 calculation platform for urban passenger transportation for estimating and analysing emissions. The platform could provide real-time information of the carbon emissions and they highlight that individual perspective helps to create incentives and nudges for citizens to consider transportation choices. This could also help the fact than individuals more easily could perceive their influence for the common good (Tripathy et al, 2020). Liu et al. (2023) state that this kind of carbon emission related mobility management through a platform should offer variety of transportation choices. Mobility as a Service (MaaS) has been a suggestion for a while to gather different mobility options under a single platform and influence citizens' travel choices.

Smart vehicle is capable of sensing and monitoring the surrounding environment and automotive industry is constantly developing application of this technology (Shokravi et al, 2020). In smart city, goal of smart vehicle is that it is connected to a mutual network and is creating, sharing, acquiring information for the surrounding environment, and to be automated (Javed et al, 2022). Smart vehicle is connected to the Internet of Vehicles (IoV) which consists of different communication technologies such as vehicle to sensor, vehicle to vehicle, vehicle to road and vehicle to human (Balasubramiam et al, 2017; Sahand & Bina, 2022).

Automated vehicles (AV) are confronting from a very wide range of new challenges in implementation to a public road transportation system. Whereas driverless trains work in a very strict and closed laboratory setting for instance in a manufacturing site, AVs in a public road need to adapt into a so-called natural setting. (Sitinjak et al, 2023) Concerns have been risen regarding to the speed of automated vehicles, controlling them, integration with other transportation options, and general security. Sitinjak and others (2023) list a couple challenges relating to the optimization on transportation utilizing AVs. One challenge is the allocation precision meaning that transportation resources need to be able to meet changing mobility demand effectively. To this challenge AVs can be considered as a flexible solution. Another challenge relates to the traffic sensor placement which are in the key point of improving transportation systems and to control AVs.

The development of IoT and automated driving have created the idea of platooning vehicles. This platooning means that connected automated vehicles are cooperatively moving in a train-like manner where new vehicles can also join from intersections (Chen et al, 2023). Chen et al. (2021) developed an algorithm for this kind of platooning smart vehicles. Testing and simulation found several possibilities to develop efficiency and sustainability of the traffic. They keep optimal distance to each other which optimizes for instance fuel consumption with less air resistance and platooning could significantly increase traffic safety (Chen et al, 2021; Musa et al, 2023). Based on research of Chen and others (2021), the opportunities of and benefits of the autonomised driving and platooning vehicles groups are for example: decreased fuel consumption meaning cost savings and less emissions, less air pollution with optimized braking and less traffic accidents. Autonomised vehicles obliterates abnormal driving behaviours by humans which usually occurs inefficiency in big picture in the traffic flow and jeopardizes road safety.

Platooning vehicles require constant network coverage and, on some occasions, using UAVs (unmanned aerial vehicles) can be helpful as they are able to share and exchange information with other IoT objects. (Aloqaily et al, 2022). Aloqaily and others highlights the flexibility that these drones have, and they can be a good addition for ITS. For instance, UAVs could offer modifiable visibility on roads and parking lots, patch up vehicular networks and offer information of hazardous situations in the traffic. However, the drones have operating challenges such as changing weather conditions and power adequacy relating to computing tasks, communication, and movement. Still, Aloqaily et al. (2022) state that optimal use of UAV's is becoming a reality when providing sustainable smart transportation services.

Regarding to Lu et al. (2022) many smart transportation programs have been implemented even though the technology used has not been yet enough mature level which has for one's part led to failure. In addition to the incomplete technological aspects, they state that also citizens expectations and needs have not been fully understood. To dig into the later problem, they used the Kano model in their study for understanding

citizens priorities through online questionnaire in Taiwan. Citizens were able to compare different smart transportation items relating to public transportation support system, private mobility system, vehicle sharing service and energy-saving vehicle service. From the items the study participants considered as a “attractive need” the smart streetlights, free charging stations for electronic devices, online interactive traffic map, smart parking service, renewable energy-powered vehicles, and solar charging roads. When skimming the item list of the study, the most attractive items were more positioned on the private methods of transportation than the public and share-based transportation options which were mostly categorized as indifferent in this study.

Wallsten et al. (2022) researched governing strategies in Stockholm metropolitan area for achieving sustainable smart transportation. They highlighted the role of public authorities’ responsibility to steer new applications to sustainable direction because commercial interests sometimes might not be optimal in the sustainable development point of view. Regarding to their findings, developing the knowledge in these governmental departments is one of the key factors for fulfilment of long-term sustainability goals. However, the appropriate level of proactive measures of the government in these new smart transportation innovations is hard to perceive. This is why Wallsten and others (2022) remark that this kind of new dynamic concept to develop smart transportation solutions requires skilled staff to execute, for instance understanding of private companies’ interests and business models together with supporting public sectors long-term goals.

Wallsten and others in their study present three different strategies for governments for developing sustainable smart transportation. First relates to *leadership* which means that policymakers need to consider from the available options for the best actions to steer the transportation system towards sustainable choices. This is a proactive role includes for example objective setting, monitoring, and anticipating impacts. The second was called as *enablement* which aims to offer platform for public-private partnerships and pilot projects. This strategy consists of proactive barrier removal and supporting

market actors with incentives. The third was the *Laissez-faire,* often described as “wait and see”, strategy where public actors stay more in the background and do not get involved in new innovations proactively. Especially if public actors are not enough convinced of which direction the evolving technology is going, they desire to give the responsibility of innovations for private actors. Wallsten and others mention that usually the course of action in real life is somewhere between these strategies.

Oladimeji et al. (2023) summarises the concurrent and most usual smart transportation systems applications in their review of smart transportation technologies and applications. In the Figure 6 these seven most usual applications are gathered.

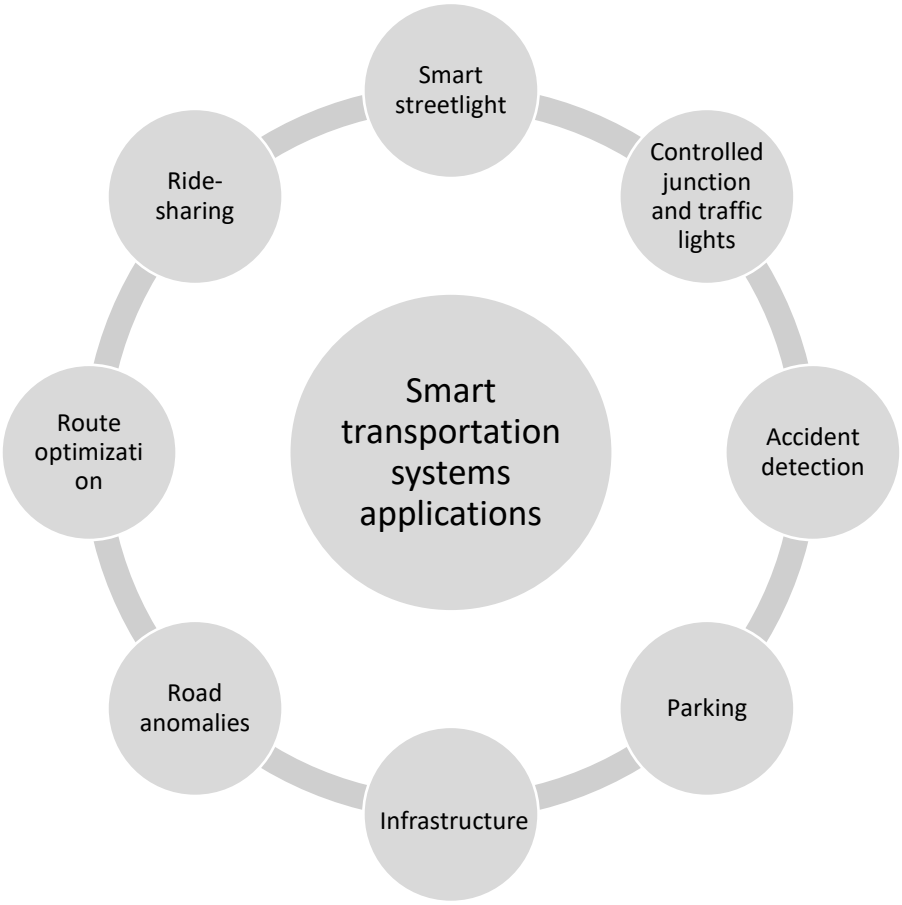


Figure 6. Smart transportation systems applications (Modified from: Oladimeji et al, 2023)

When considering the technologies mentioned in this review, they are well aligned with Oladimeji and others summarization even though this review included also other aspects of smart transportation than just applications. However, from the basis of this review, IoT based ridesharing systems could be a well-founded addition into the Figure 6 summarization which has been added to the figure.

Sustainability in smart transportation

As stated in the introduction, most scholars take account on economic and social dimensions in addition for environmental in sustainability (Wang and Zhou, 2022). This compilation of economic, social and environmental sustainability dimensions has been called as a triple bottom line construct or as a three-sphere model as presented before (Reyes-Rubiano et al, 2021; Zak, 2015). Reyes-Rubiano and others presented the general objectives of these three sustainability dimensions in smart transportation. Economic dimension includes for instance congestion reduction and profitability aims, social dimension focuses on health and safety concerns, and the environmental dimension whereas considers nuisance reductions, resource optimizations, emission reductions and infrastructure protection. The common stakeholders of smart transportation, which are government, companies, and citizens, have their own objectives in these sustainability dimensions.

Based on this review, the sustainability challenges related to these three dimensions relatively even although it is hard to draw exact line between them in terms of what challenge relate to which. In the Table 5 there is gathered the selected journals and the sustainability challenges of them. Also, the solution proposition for the challenge has been presented. Because the sustainability of smart transportation has many different key points, it was justified to compare how the different research considered the sustainability point of view in the journals.

Table 5. Sustainability challenges and solution suggestions of the journals

Reference	Sustainability challenge	Solution suggestion
Aloqaily et al. (2022).	Traffic inefficiency	Rendering better IoT network operation with UAVs.
Zheng et al. (2022).	Sustainability of the monitoring network in energy supply wise.	Independent mechanical energy supply through sensor innovation assembled under the road surface.
Liu et al. (2023)	Urban transportation pollution and emissions.	Offering multiple traveling options and connect them with incentives and personal CO_2 emission data to promote low carbon mobility.
Vicuna et al. (2019).	Traffic conditions and safety	Monitoring and operation development through transportation performance metrics.
Wallsten et al. (2022).	Productivity and efficiency problems, lost hours in the traffic	Highlighted the knowledge of public authorities to support for instance infrastructure development.
Musa et al. (2023).	Congestions, economical inefficiency, and negative environmental aspects	IoT and ITS for better traffic management and development.
Sitinjak et al. (2023).	Congestion, safety, and emissions	Shared mobility for decongestion and emission lowering.
Lu et al. (2022).	Congestions, economical inefficiency, and negative environmental aspects	Citizen's perceptions need to be taken better in to account through evaluation model when debating new ST projects for better engagement.
Reyes-Rubiano et al. (2021).	To be aware how decisions affect each other in different dimensions of sustainability.	To access optimal balance between economic, social, and environmental dimensions of sustainability.

Reference	Sustainability challenge	Solution suggestion
Chen et al. (2021).	Fuel consumption and traffic inefficiency	ITS based vehicle platooning opportunities.
Tripathy et al. (2020).	Congestions occurred by single occupied vehicles	Efficient IoT based vehicle sharing platform.
Balasubramariam (2017).	Pollution and traffic accidents	IoV based sustainability through pollution-free vehicular and traffic safety.

In the journals major sustainability development factor was traffic safety. To this factor, automated vehicles and their utilization in different ways were suggested to achieve social sustainability. Another major sustainability challenge was congestions which occur to variety of negative impacts. To this challenge efficient intelligent transportation system together with shared mobility was most suggested.

To get these innovations to succeed, engagement of the users and hearing the citizens opinions was highlighted in many journals. To encourage citizens to use new smart transportation technologies, different incentives was considered. Also offering knowledge and results of the behaviour change was suggested.

Based on the review the research and implementations have been somewhat technology focused on previous years which had led to diminishing the citizens real needs. This might be one reason for engagement challenges which was mentioned in several journals. However, whilst the technology matures and the systems are operating reliably, the implementations can be shifted towards to a problem solving than just piloting new technologies.

3.3 Internet of Things in smart transportation

As introduced in the definitions of this thesis, Internet of things consists of devices and machines which are connected to mutual network to create and share data for yielding

analytical knowledge (Nord et al, 2019). Internet of Things has revolutionized the communication among devices and the idea of gathering information from the physical environment (Bellini et al, 2021). Due to fourth industrial revolution, hardware costs of information systems have had a significant cost reduction which has rendered implementation of IoT systems commonly affordable for societies (Javed et al, 2022, p. 2; Azgomi & Jamshidi, 2018).

Internet of Things applications have also revolutionized human computer interaction and have brought new kind of applications into smart cities (Javed et al, 2022; Liu, 2018). Regarding to Liu (2018, p. 101), human computer interaction has shifted from computer centric to human centric approach in recent decade. The shift from computer centric to human centric approach in IoT applications supports the journey for sustainable smart transportation as the system in holds variety of different human computer interactions such as human to vehicle (Zhang et al, 2023). As stated in the research by Ahvenniemi and others (2017, p. 235), understanding the connections between humans and environments is in key position when developing sustainable smart cities.

Most common IoT architectures consists of three layers which are sensing layer, communication layer and service layer (Bellini et al, 2021; Nord et al, 2019). The sensing layer observes the surrounding physical environment and creates raw data. The communication layer then transfers the perceived data to the service layer which processes the data and works as a platform for users and offers analytical insight from the data. The more developed five stage IoT architectures differ from the three stage architectures as they include in addition the application layer and the infrastructure layer. The application layer is about the monitored objects and human social life and the infrastructure layer, on some occasions called as business layer, is about more advanced analytics for instance to develop the system or execute predictive what if analytics (Bellini et al, 2022; Nord et al, 2019). In the Figure 5 there this kind of general five stage IoT architecture of smart transportation system presented.

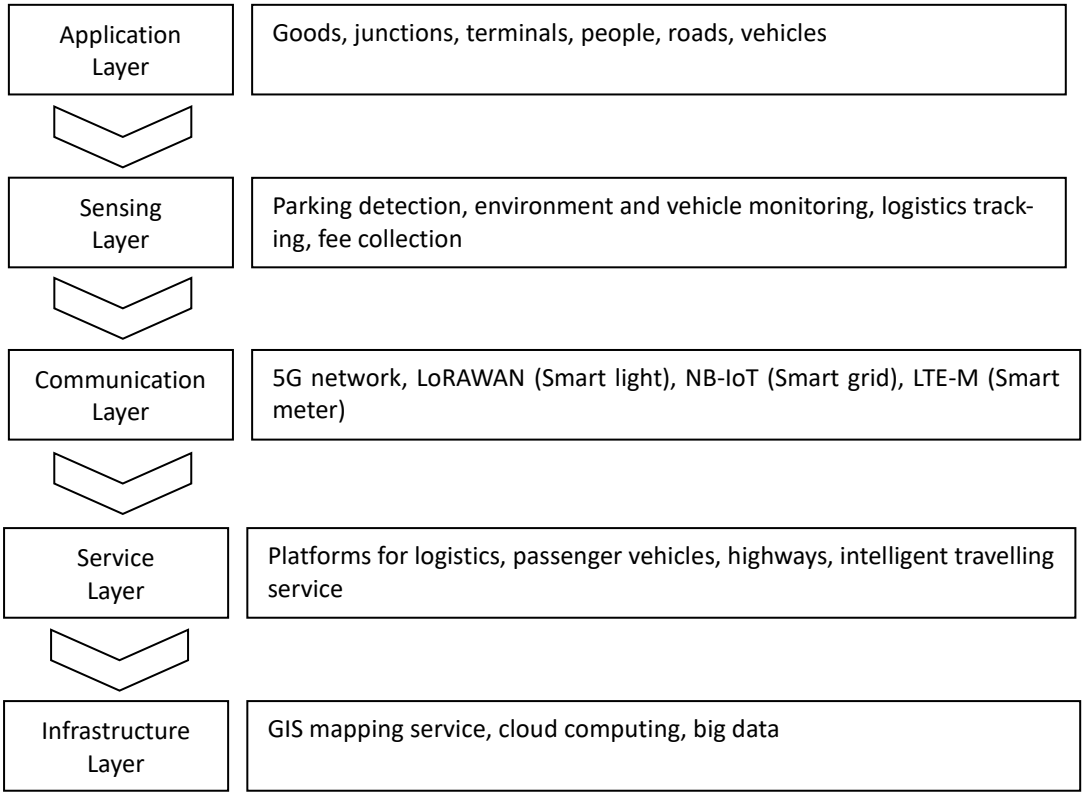


Figure 7. IoT system architecture in smart transportation (Kumar & Dash, 2017)

These IoT architectures have a few key factors that need to be considered in technical and operative dimensions. Technical infrastructure must be sufficient for high-speed data transfer. Smart city communication network should have high bandwidth, low latency and of course excellent reliability (Yu, 2020, p. 685). Bandwidth relates to the networks capacity to transfer data and latency relates to the delay of executing the instruction of transferred data. With new generation 5G and 6G networks huge masses of data created by IoT systems can be transferred. Especially, with 6G network, future requirements for bandwidth are secured for a while (Javed et al, 2022, p. 8).

Also, the connected devices in the IoT network have different kind of capabilities. Porter and Heppelman (2014) presents in their article that these IoT device capabilities can be categorized in to four areas which are monitoring, control, optimization, and autonomy. The functions create a foundation for the following stage but also create value as an

independent application. Monitoring stage includes the simplest form of operation of the IoT device. The device monitors for instance product condition, external environment, and operational usage. On top of monitoring, control stage is based on software embedded on the device which renders controlling device functions and personalization of user experience. The monitoring and controlling capabilities can be enhanced further with inbuild algorithms which makes it possible to optimize device performance and possibly make predictive diagnosis of the device. The last stage, which is autonomy of the device, is capable of autonomous operation, self-coordination in the systems and make self-diagnosis of the operation. In the Figure 7. these stages have been presented.

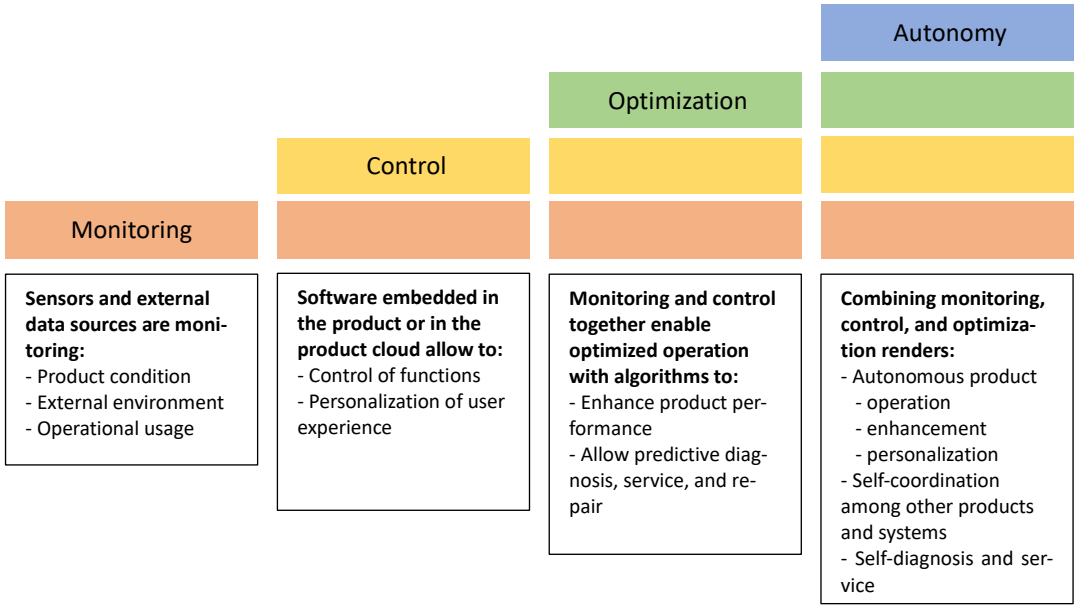


Figure 8. Capabilities of smart connected products (Modified from: Porter & Heppelmann, 2014)

When considering the previous subchapter, the use of Internet of Things was mentioned in every technology considering journal. And in the smart transportation application summary, every application was based on internet of things. So, the statement of Internet of things being as the backbone of smart transportation solutions seems to be valid. Based on the journals, internet of things technology is used on smart transportation

solutions for data creation, traffic monitoring, vehicle controlling and real-time data sharing for instance.

3.4 Framework of the study

The literature review started with reviewing concept of smart city and sustainability of it. The smart city concept consisted of main themes, attributes, and infrastructure parts. After these, there were presented the common components of smart city which were smart transportation, smart management, smart energy, smart health, smart infrastructure, and smart citizen. The components had various points of contacts with smart transportation in the operation. The literature highlighted the interaction between the different components which renders the improvement of collective intelligence in a smart city.

The sustainability of smart city was divided into three dimensions which were economic, social, and environmental. To achieve different sustainability goals in a smart city, it requires procedures such as citizen participation in the process, focus on continuity and balancing between the three dimensions of sustainability.

After the smart city review, the review directed to smart transportation and sustainability. The subchapter was executed with imitating traditional scoping review method. The systematic journal selection process offered 12 relevant journals for a closer review. The review offered a versatile list of different applications of sustainable smart transportation and other aspects such as governing strategies for smart transportation development. The sustainability challenges of urban transportation among these journals related often to the traffic inefficiency, pollution, and unsafeness. The use of Internet of Things was widely exploited in every technology-based solution and considered as a tool for solving these challenges or at least diminishing them.

The Internet of Things subchapter presented the general architectures of the IoT systems and capabilities of individual IoT devices. The IoT systems have created the foundation

for the smart cities to create data for intelligent use. Due to the fourth industrial revolution, hardware costs have decreased, and this way the cities have had better possibilities to create wide IoT networks more cost-effectively.

In the Figure 9. below there has proposed a smart transportation architecture based on the journals in this review. The layout of the architecture has been influenced by a national guideline of Canada for smart transportation in the early 2000s (McGregor & McIver, 2003). The layout has been modified to respond to the common smart transportation architectures in today's smart cities.

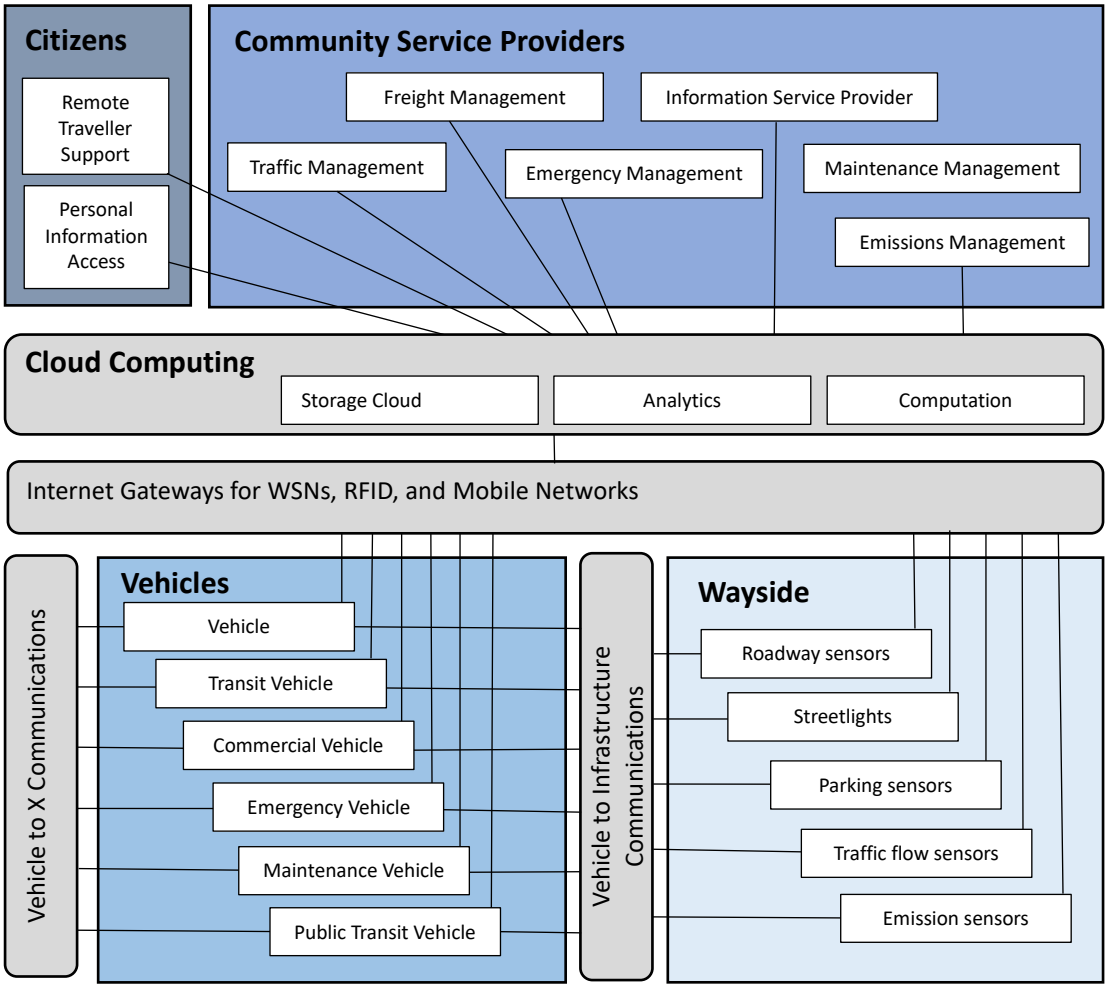


Figure 9. Smart transportation architecture (Modified from: McGregor & MacIver, 2003; Moazzami et al, 2021)

In addition, for presenting the smart transportation architecture, the Figure 9. in holds the usual deviation of three layers IoT infrastructure which were sensing, communication and service. The upper section which includes travellers, centres, and cloud computing, is the service and control layer of the IoT system. Then the internet gateways section belongs to the communication layer. And the bottom section is the sensing layer which in holds the vehicle to x communications and all the wayside sensors.

Several journals which consider the infrastructure of smart transportation are displaying it in a figure where a city is shown and there are different communication lines between objects. In the Figure 9. these same communication lines are presented but the value comes from the IoT structure which can be integrated with simplified manner to this architecture layout. Also, in the Figure 9. there are the two main parts of smart transportation presented, the smart traffic control and smart vehicles as stated in definition subchapter in this thesis.

4 Methodology

In this chapter at first there will be presented the research process and research design. Then there will be data collection explained. And after that the gathered data will be analysed. Finally, there will be the methodology reliability and validity evaluation.

4.1 Research process

In research the researcher aims to find out things in a systematic way. In addition, for finding out things in a systematic way, research needs to include explanations of the methods used of how the data is collected and what issues and limitations influence the results.

The research process aims to answer the research question and fulfil the research objectives. It includes the research gap identification and research question statement at first. Then the conceptual framework of the topic will be assembled based on the literature review. The research design then aims to gather precise primary data to investigate the research question. The primary data will be gathered with the chosen appropriate methodology and analysed. Then research process needs to have a validity and reliability evaluation and finally research results will be presented. (Saunders et al, 2006) In the Figure 10. the steps of the research process of this thesis can be seen.

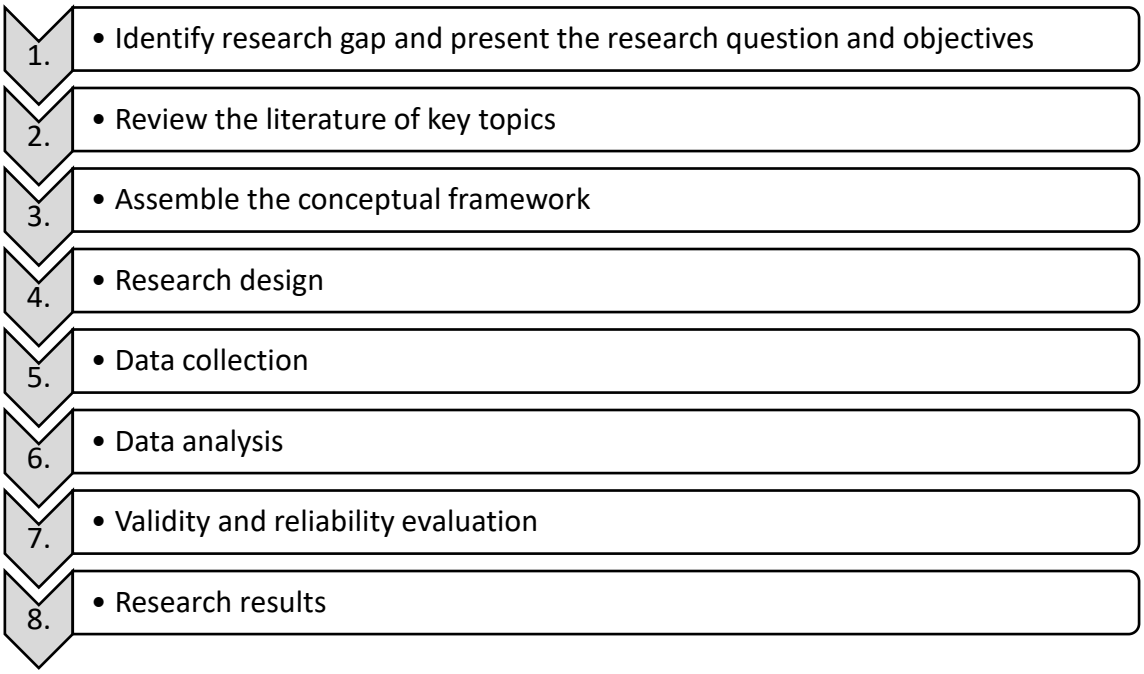


Figure 10. Research process

To revise, the research question of the thesis was *"What are the main opportunities and challenges for Finnish municipalities when implementing smart city solutions for sustainable transportation?".* The main limitation was that the research focuses on road transporting in urban areas.

4.2 Research design

In this thesis the research design has been built utilising the theoretical concept of "*research onion*" created by Saunders et al. (2019) to answer the research question. The research onion is constructed of different layers and with the help of them, the researcher can formulate an effective methodology for use. The layers are philosophy delineation, research approach, strategy for collecting data, methodological choice of using quantitative, qualitative or mixtures of both, choosing appropriate time horizon, and choosing technique and procedure for data collection.

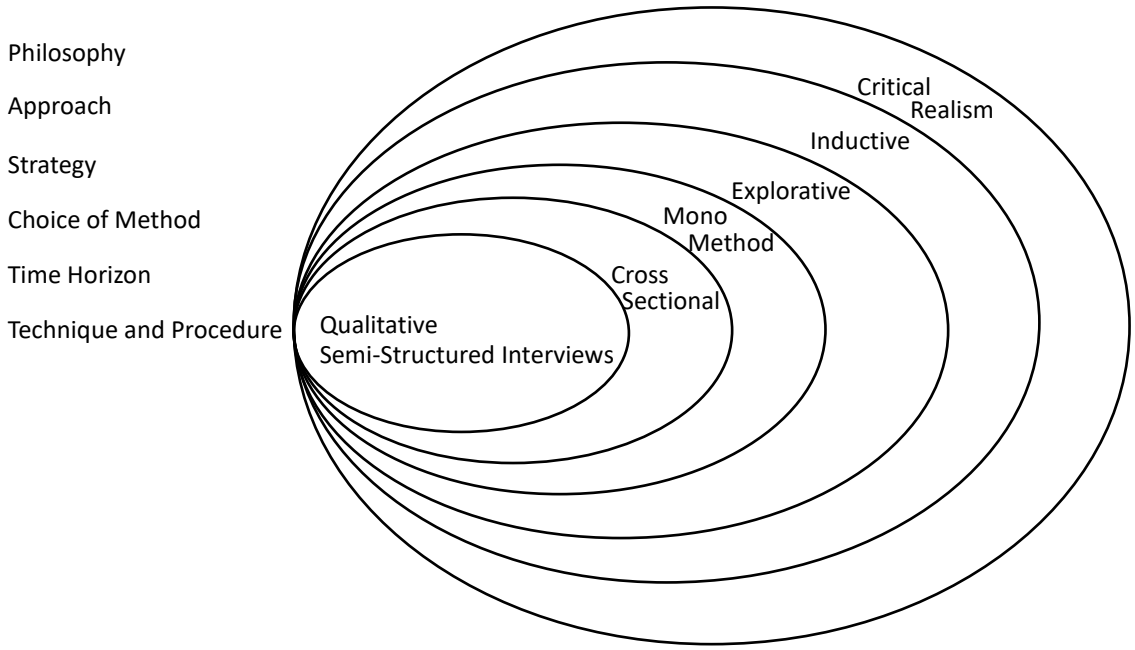


Figure 11. Research onion (Modified from Saunders et al. 2019).

In the research onion shown in the Figure 10, there have been presented the chosen options for this methodology. In the first layer, for the philosophy there have been chosen the critical realism which assumes that future has capability to be flexible and it consists of multiple possibilities of transformative events, and it can be influenced by involved participants (Melnikovas, 2018). Saunders et al. (2007, p. 128) represent that *"the term research philosophy relates to the development of knowledge and the nature of that knowledge".* The context of smart transportation has this kind of flexibility of the future events as the critical realism philosophy allows because its development depends on human choices and actions. The critical realism also focuses more on on-going and future actions rather than historical events.

In the second layer of the research onion there has been chosen inductive theory development approach. Inductive approach can be seen as bottom-up approach where first the data will be gathered, and then on basis of the data possible theories, concepts, and hypotheses will be developed. The inductive approach emphasizes for instance a

thorough knowledge of the research knowledge, a flexible structure in the research progress and less concern with the necessity of generalisation. (Saunders et al, 2007)

In the third layer, there has been chosen explorative for the research strategy. Melnikovas (2018) presents in her journal that explorative strategy focuses on exploration of possible future developments or what is happening contemporary. Regarding to Saunders and others, main principals of an explorative strategy are a literature review and interviews with experts or focus groups. In this thesis the experts of the smart transportation sector will be interviewed.

In the fourth layer, there has been chosen mono-method for methodological choice which means that there will be used either only qualitative or quantitative research method, and in this thesis, there will be used only qualitative method for data gathering.

Qualitative research consists of previous studies and theories, empiric data, which is most commonly in a textual from, and researcher's own thinking and reasoning. Qualitative investigation tries to achieve its goals thorough three different stages which are exploration, description, and interpretation. Exploration aims to identify patterns and themes which offer the initial understanding of the phenomenon. Description stage conveys the information so that it can be more accurately considered. With the interpretation's researcher tries to create meaningful statements and make sense of the subject. After completing these three stages researcher should have overall understanding of the phenomenon. Data of qualitative method can be gathered for example from interviews, documents, focus groups and observations. (Office of Research & Doctoral Services, 2015).

The fifth layer is about the chosen time horizon, and because this thesis focuses on contemporary observations of the environment, cross-sectional time horizon has been chosen. The cross-sectional time horizon considers data at a particular time (Saunders et al, 2006). When considering the research question of thesis, the focus is on the present

moment and on the contemporary opportunities and challenges of smart transportation in Finnish municipalities.

The final layer's technique and procedure layer need to fit to the previous choices. In this thesis the most suitable technique and procedure for data gathering is semi-structured interviews which is respecting the previous choices of the research onion. These semi-structured interviews are used in exploratory studies. The semi-structured interview consists of pre-determined questions but allows the interviewer to steer the interview flexibly (Barribal & While, 1994).

4.3 Data collection

The questions were made to be open questions so that the risk of leading the answers in any way was minimized. The interviews' first part consisted broader questions, the middle section then aimed to steer the conversation more in depth. Finally, clarification questions were asked if necessary. (Mannan, 2020) The interview questions included the key topics of the thesis and aimed to get comprehensive answers to the research question.

In semi-structured interviews, the prepared questions are guiding the conversation, and it is acceptable to probe subjects that come up during the interview with unstructured following questions. This renders the possibility to find new insights and applies the best the features of structured and unstructured methods. (Barribal & White, 1994) However, the probing questions need to be in some extent similar so that the different interviews are comparable.

For the interview, the objective was to have five interviews with the most suitable experts of from most centric organizations and municipalities in smart transportation development in Finland. Altogether six requests for participations were requested through phone calls and five of those were accepted. The most suitable interviewees were aimed

to find from the websites of the organizations and municipalities. In two requests there were directed the request to a more suitable expert of the organization based on the thesis' topic. The participants were very cooperative and willing to participate into the interviews which helped to achieve the planned sample for the study. Interviewees were from a municipal innovation company, a smart mobility forum, a private company, and from two different municipalities. As in the literature review there were mentioned, different sectors have close co-operation in this branch, so it is justified to interview experts from different sectors. In addition, this could probably provide more comprehensive view of topic and possibly give new insights than just interviewing experts only from singular sector such as only from municipalities. Below there are listed the type of expertise and experience in years of the interviewed participants.

- *Smart Mobility Senior Specialist, experience 25 years*
- *Smart Transportation Expert, experience 20 years*
- *ITS Senior Specialist, experience 10 years*
- *Smart Mobility Developer, experience 4 years*
- *City Infrastructure Development Project Manager, experience 20 years*

The interviews were held as individual Microsoft Teams meetings, and the questions were translated into Finnish. The list of question can be seen in the Appendices both in Finnish and English. The interview questions were not sent in forehand for the participants. All meetings were allowed to record which helped the transcription phase. In the beginning of the interview there were the subject of the thesis presented and the structure of the literature review and limitations explained. This way the participant could get the general idea of the subject and what are the main key points which are guiding this thesis. Also, the anonymity of the answers was told, and the background information of the participants was gathered.

4.4 Data analysis

In this subchapter the analysis of the interviews will be presented. The interview questions will be covered one by one. The common thread is aimed to find from the different responses without forgetting individual key points across the interviews.

The first question of the interview asked to characterize the contemporary state of smart city development in Finnish municipalities. Repeated response for this question across the interviews was that the smart city development mostly focuses only on a few biggest cities in Finland and especially in the capital region and in the city of Tampere. In those cities there are a certain determination associated with the development of smart city projects, but as one interviewee pointed out, in the other cities the development is somewhat tentative and a clear strategy across the different projects may be missing. However, in Finland the overall attitude towards smart city development is affirmative and there is consciousness of the opportunities which might be achievable with these kinds of new smart city technologies. Also, it was considered that in Finnish municipalities there are a reasonably good understanding of the possibilities of data and digitalization utilization and a genuine effort to implement new solutions which can be seen already in practise in the transport sector. The overall know-how regarding to the smart city development is generally in a good level and the atmosphere is sympathetic to advancing smart city solutions and cities dare to do them.

Unifying opinion among the interviewees was that the smart city related projects have been smaller undertakings rather than large singular investments for certain technologies to this point. The projects have mostly depended on external founding by EU or Business Finland kind of organizations and not specially included into the budgets of the municipalities. Reasons for this were listed as that the smart city related projects have been rather experimental, and the payback time of possible investments have been hard to forecast and anticipate.

When it came to smaller municipalities, the need and demand for the smart city solutions have been considered as unnecessities and the financial resources are not considered as sufficient for investing new technologies, especially when the vast majority of small municipalities have pressure to achieve considerable cost savings in the coming years. The lack of reasonable finance was seen as challenge in smart city development in Finnish municipalities which for one's part influences negatively to the ability to develop the smart solutions.

The importance of citizens needs also came up during the interviews. As in the literature review, where it was highlighted that the smart solutions need to serve the citizen's needs, also regarding to one interviewee this same kind of mindset is applied in smart city development in Finland. A few years ago, there were thought internationally that the more you gather data and use the modern technology, the smarter the city is. Instead, today the thinking is more shifted to that a smart city is smarter when it supports the citizens needs and streamlines the everyday life. In other words, there are considered precisely what is the achievable output of the new solution and how citizens could benefit from it. This same kind of transition from technology focusing to actual problem solving in smart city development was detectable in the literature. In smart transportation this citizens' life quality improvement relates strongly to the time saving and productivity development. The interviewee pointed out that from little time savings daily from different things, an individual can save significant amount of time cumulatively already in one day. And, when this is considered among all habitants of the city, the overall productivity and efficiency achieves major development through time saving.

The second question considered that how important the interviewees considered the smart transportation as a part of smart city development. All the experts kept the smart transportation as a significant and focal part of smart city structure which has been centrally included in the smart city definitions already ten years ago. It was also considered that the transportation sector is one of the most natural parts to utilize and implement new smart technologies.

In addition, the transportation has an influence on every citizen in everyday life which makes it is relevant factor. One expert pointed out that it is critical to not focus only on for instance transportation related matters even though the main focus in your department is on the transportation when developing new smart solutions. Instead, the mindset for supporting smart solution development should be applied in all sectors and departments of municipal in terms of data creation and anticipation of where the future developments are conjectured to go. So, it can be thought that the different service domains can have significant importance for offering data from a such a thing that is not considered as a meaningful or does not seem to offer any important knowledge as a singular data set for themselves. Hence, from these minor but integrated data sets the overall smartness of the city develops and the different service domains can uplift their importance in the smart city development.

The third question aimed to survey the already implemented smart transportation solutions in municipalities. The real-time public transportation information system was mentioned repeatedly as far developed smart solution. These real-time public transportation information systems have been established firmly into the practice for years already and was considered as an inevitable factor of an efficient and fluent public transportation system. Beside to this real-time public transportation system, there has been applied intelligent traffic light management which promotes especially the fluency of using public transportation because the traffic lights can be used in their favour if needed. For example, in the city of Tampere this kind privileged traffic light control for the benefit of public transport has been utilized. As a side comment, in the city of Tampere, there was recently investigated the needs of smaller surrounding municipalities relating to the smart transportation solutions. The aim was to see if there are some minor transportation development concerns which could be implemented cost effectively or promoted easily.

The fourth question of interview asked from the participants how they consider that Finnish municipalities could benefit smart transportation solutions in the future. One of

the participants stated that there exists an old saying that one-third of the cities' traffic is caused by parking searching drivers. In other interview was told that in connection with the development of parking services it turned out that citizens were willing to look ten minutes for a free parking space instead of driving directly to a paid parking lot. This leads to that developing smart parking solutions and efficient information systems to guide free parking spaces or to the paid parking lots is a critical development area. It makes the city transportation in many ways more efficient as in terms of time sparing and decreasing waste of resources.

One interviewee pointed out one critical point on developing smart transportation solutions is to consider why these things are done and what are the goals. Repetitively there were presented in the interviews that the biggest forward pushing factor is the internationally agreed emission reduction goals which forces countries and cities to make changes because it is not possible to continue as before if municipalities want to achieve these settled goals. But in the other hand there were mentioned that the economical perspective weighs heavily on decision making.

As continuation for the emission reduction goals, among the experts the smart transportation systems were expected to have significant value as the vehicles turn towards of using electricity as source of energy. It is relevant to know exactly where are for instance free charging points, what is the type of charging station and what is the pricing.

When it comes to these experiments of smart transportation solutions it was mentioned that it is desirable that the new solutions are taken as a part of the city transportation ecosystem so that citizens have better possibilities to utilize and test them. One example can be the robot busses in the city of Tampere which are included in the public transportation information system even though they are still in the test phase. The pickup and drop of traffic systems and their automatization was also expected to have significant value on smart transportation systems and in travel chain thinking in Finnish municipalities in the near future.

The Cooperative Intelligent Transport Systems (C-ITS) was also expected to get more general use. When the city transportation infrastructure achieves sufficient technological abilities, for instance the C-ITS messages can be delivered for instance citizens' smart phones. Regarding to an interviewee these kinds of C-ITS mobile phone applications have been taken into use already in Holland. These C-ITS solutions can have good capabilities to make traffic flow more efficient for instance with guiding to drive optimal speed when approaching traffic. Also, the messages that relate to safety can be customized so that they are more valid for the individuals.

In one interview a participant considered that previously it was a general way to solve traffic jams and bottle necks of the traffic with increasing the capacity of traffic flow such as with new driving lanes. With smart transportation solutions there are now new tools to solve these kinds of problems such as with intelligent rerouting and driving speed guiding. One interviewee considered these kind of old traffic problems requires new kind of thinking because the problems cannot be solved in cities with the continuous capacity increase method as before. It has been also seen that increasing driving lanes does not solve the original problem of over-represented use of private cars. Nowadays these traffic jams can be solved and diminished for example by developing infrastructure of other transport methods and public transport and this way decrease the number of private vehicles in city centres.

The fifth question considered what kind on challenges there have been encountered when smart transportation solutions have been implemented so far. The challenge of acquiring electricity for new sensors was mentioned a couple times. One expert explained that it has been for some extent also a surprise that in a city where you would assume that electricity would be easy to obtain all around but in fact it has been a real challenge. Also, the electricity provided from street lightning is problematic because the electricity is offered only in the hours the streetlights are on. Another challenge relates to older cities which have culturally significant and listed buildings. It is prohibited to

attach any sensors on their surfaces, or it needs accurate investigation before installing which can be time and resource consuming.

A couple times was mentioned that a challenge has been the lack of raw data and where new data can be gathered cost effectively to measure traffic. The costs of assembling completely new sensors were also considered as too high and a working IoT network requires several sensors to work properly of course depending on the use case. Privacy related challenges has been also encountered and it would be beneficial to have possibility to acquire more personalized data of the travellers which municipalities have much less in use than for instance operators such as Google.

One expert presented that even though the technological solution would be finished and working as it should, the business model is required and sometimes it might also take a couple attempts before the business model meets the customers' needs or is priced appropriately. The business model of smart transportation solutions is quite broad challenge because it can be sometimes hard to define is the innovation municipal driven or should it be market driven. This challenge repeated in every interview. There have been different kind of models how municipalities have been encouraging private companies to innovate these new smart transportation solutions which are rather in the initial stages without forgetting the business models. Forum Virium has this kind of pre-commercial tenders where there has been created challenges regarding to some new smart solutions and private companies can apply to solve it and get funding for the development project. This way the buyer parties get acknowledged important information what can be expected of a certain technology and get indications what are the costs if it goes for later procurement. In addition, these kind of pre-commercial smart solution projects help with the procurement planning as it is much more complicated than a basic infrastructure procurement process as one interviewee pointed out. To mention, one interviewee also noted that the marketing must be acknowledged so that the end-users find these new transportation services.

One major challenge which was mentioned was lack of space when new modes of transportation in cities have been invented in the recent years. It has been a challenge to offer the infrastructure for e-scooters, e-city bikes, and other new electrical gadgets. Before there were roughly three main ways to move in cities: walking, cycling and with car. In addition, for lack of space, the new modes of urban transportation have very different speed of moving. To fit and adjust these new transporting methods is a real challenge which hopefully can be helped with smart transportation solutions. Such as informing of correct parking spaces for e-scooters or give intelligent route suggestions based on mobility method.

The sixth question was concerning what kind of challenges might be expected in the future when implementing smart transportation solutions. Regrading to the experts, the largest Finnish municipalities have this same kind of tricky situation as other growing cities in Europe, while the cities should decrease carbon emissions caused by the traffic, the need of movement and number of vehicles is constantly growing.

Regarding to the interviewees one rather larger challenge relates to the standards. It is not wise to make any city-specific implementations, whereas there should be always possibility to scale and connect new technologies to other cities with suitable work manners that have been appointed through standards. This way the same smart transportation solutions could be implemented and duplicated very similarly into another city which in holds big opportunities in turn.

In one interview a challenge came up that there can possibly appear vandalism towards the new sensors. It is easier to give reasons for video surveillance in safety matters for citizens, but this kind of data gathering can be harder to validate. However, it requires a lot of information and transparency in the processes so that citizens can trust that their privacy will not be compromised in any ways.

The seventh question asked from the interviewees that how well the IoT technology have been utilized in smart transportation solutions in Finnish municipalities for now. One interview pointed out that only a few municipalities have a connecting platform where the IoT generated data could be gathered in one place. But pedestrian and bicycle volumes have been already measured in several Finnish municipalities which offers valuable information of the volumes of non-motorized mobility which can be then used for multiple use cases. In smart transportation development close collaboration with car manufacturers to exchange data between vehicles and infrastructure was seen to in hold big opportunities. Vehicles have variety of different sensors assembled already for sensing the traffic and transportation infrastructure and to get all this data for collaborative use would help in the IoT system building.

This kind of connecting master platform for data gathering was considered as a good development step for IoT utilization in municipalities. One interviewee considered that when capital region and city of Tampere possibly get some positive experiences gleaned of these IoT platforms it encourages also other municipalities to develop similar kind on IoT solutions. In one interview there was consideration that there could be a marketplace for open data so that the data maintenance and offering could be arranged in that way also.

The eighth question considered how the interviewees saw the smart transportation solutions as a part of sustainable development. The common consideration of the interviews was that the smart transportation solutions offer critical tools for measuring different operations and evaluate the impacts of changes made in the transportation system. In the other way, sustainable development as a part of smart transportation solutions was considered as integral part. There was a probing question asked in every interview about how the interviewees consider that the three key dimensions on sustainability have taken account when new smart transportation solutions have been implemented. Mutual opinion was that all three dimensions are always considered even though the emphasis can vary between them. For instance, regional segregation in a city

concerning these new solutions must be noticed so that different city areas are treated equally even though some areas are easier and more attractive for deploying smart solutions.

The ninth question aimed to cover what the interviewees expected that smart transportation solutions would progress in short term time scale in Finnish municipalities. The general opinion based on the interviewees was that intelligent transportation systems are in critical position to support the upcoming changes to the city transportation and mobility. To achieve decreases on carbon emissions and to offer more comfortable city infrastructure, it was highlighted that every action which one way or another takes forward towards more sustainable transportation in cities is needed. It was clear that relying only on smart solutions is not going to get municipalities to achieve the emission decrease goals but is an important tool. However, it was expected that municipalities increasingly want to measure different mobility factors, collect data, and utilise it in the development of transport operations.

To achieve the emission reduction goals, there will need changes in modal split which means that citizens are willing to change more sustainable transportation modes. One interviewee highlighted that is important to develop different platforms that support sustainable mobility methods, because these service platforms are used by a relatively small number of people and targets certain type of citizens at the moment. With these platforms the modal split can be influenced without doing major changes in the transportation infrastructure. In addition, for modal split changing, the change in power source of vehicles is needed such as using electricity as power source. Electrical vehicles have the advantage that the cause very minimal number of emissions in the operation even though the production of the electric vehicles is still another subject to discuss.

As Finnish municipalities want to decrease costs and still meanwhile offer platform for even better public transportation services for citizens, in one interview came up the idea of using these automatic vehicles especially at night times. At night hours, the demand

for moving is only small-scale and roads are much more unhurried. The significant cost saving comes from labour cost of human which is high in night hours. This thinking also pointed out that automatic vehicles are not exclusionary for conventional public transport which operates with human driving. This kind of utilizing the best practices of different smart transportation solutions leads to the more efficient transportation system in cities. In other interviews the cost savings relating to automized driving was mentioned from the point of view of optimising driving shift arrangements.

The tenth and the last question considered how the interviewees perceived the roles of different stakeholders as enablers of smart transportation development in Finnish municipalities. Legal aspects have significant influence in the smart transportation development which is based on the political decision making. Till this point smart transportation solutions have been developed with help of municipalities and their partly owned innovation companies. This has for one's part also ignited the municipalities interest to hire expertise of data and digitalization point of view because there a lot of things to do and quite few working for those things as one interviewee expressed.

One interviewee highlighted that the smart transportation technologies develop in fast phase, which requires close cooperation among the municipalities', private companies' and research institutes' representatives with long term scope so that knowledge of upcoming technologies is up to date. In other interviews also, the cooperation of different operators was emphasized in every phase of developing new smart solutions.

From the private companies' point of view the municipalities are good testing platforms and they in hold good scalability possibilities. However, private companies can have troubles to anticipate the municipalities' willingness to buy services especially if the procurement relies on third party financing. This is why private companies should focus on creating business models around the new smart transportation solutions and find ways to offer services for citizens or other companies. One interviewee also pointed out that especially smaller companies can have difficulties to work as partner with a municipal

because municipalities are rather large operators and work with different time cycle for instance, whereas smaller companies wish to move forward at a faster pace on many occasions.

As an addition, in one interview this kind of new thinking came up that the services should be closer where citizens live so that the need for moving longer distances is decreased. This can be seen for instance in the current trend of building arenas and large grocery stores into the city centres instead of building them to the outskirts of the cities as before. Another factor as addition that came up in the interviews was that it helps the city traffic stress when very many things can be done remotely nowadays. One interviewee expressed this as *a virtual transportation*.

4.5 Reliability and validity evaluation

Regarding to Saaranen-Kauppinen and Puusniekka (2009) evaluation of reliability and validity of the research process in academic research is a centric issue. Validity in qualitative study considers that is the research executed with decent manners so that construct of research supports what is estimated to measure and does the research results seem convincing and credible. Noble and Smith (2015) state that validity evaluation considers also that does the findings reflect from the data with adequate precision. Validity of a research is good when the research method is chosen correctly, target group is suitable, and in this thesis does the interview questions serve the research aim. Reliability evaluation whereas focuses on the consistency of analytical procedures and what possible participant biases might influence to the findings. Schell (2009) highlights is his publication that to improve reliability documentation during the research process is important so that the research protocol is repeatable.

The literature review of this thesis was executed with transparency and the journals were chosen systematically from multiple academic data bases. From the presented research string in the literature review, evaluation of the chosen journals can be made. In

addition, the goal was to use as recent journals as possible to guarantee that information is up to date. The research method was designed to support the research aim and it produced widely desired information on the subject.

To improve the methodology's validity and reliability, the data was aimed to collect from most knowledgeable experts. The interviewees were thoughtfully chosen, and the backgrounds were investigated through internet. The interviewed experts were all from different relevant organizations in the smart transportation branch. Because the nature research aim was to survey general opportunities and challenges, and the interviewees represented variety of different organizations, it supports that results can be considered as valid and reliable beyond this chosen sample of experts. Critical point when considering the results of this thesis is that it is a summary of encountered and expected opportunities and challenges presented by interviewees, in other words the interviewees were not knowledgeable of the answers of each other and might not agree in every issue. However, as the interviews were recorded, the transcription and analysis of results were able to do reliably. The challenge was still to find the key aspects concerning the thesis research aim because the interviewees had from a very wide scale different perspectives and comments.

The confidentiality and anonymity have been respected and kept so that the different answers cannot be connected to an individual interviewee. Also, direct citations were not used because the translation affects to the layout and nature of the wording. The interviews had enough time reserved so that there was not a sense of rush, and the interviewees were allowed freely to choose a suitable interview time.

5 Discussion and conclusions

In this chapter, first there will be summarized the key points of each chapter of thesis and then concluded the findings for research question and objectives in the discussion subchapter. Then the research results and key findings of the research will be presented and finally recommendations for Finnish municipalities suggested.

5.1 Discussion

The thesis started with introduction chapter which presented the background of the study, expressed the research gap, and stated the research question and objectives. Global trend of accelerated urbanization has caused challenges for cities to maintain and develop functioning transportation systems (Chen et al, 2021). Number of vehicles have been increased in cities which have caused severe congestions and created various defects such as pollution and reduced safety (Rodrigue, 2020, p. 192). To solve these challenges and improve the overall efficiency of operations, cities have begun to utilize smart transportation solutions which rely on modern technology (Chen et al, 2021). The utilization of Internet of things technologies have rendered the recent rapid development and have been considered as an inevitable factor in smart city solutions (Perera et al, 2020). In addition, sustainability and its development has been integrated into smart solutions. Many challenges of cities relate to sustainable development and new solutions need to support it. These smart transportation solutions have already been implemented in a few Finnish municipalities and there is strong focus to decrease emissions and pollutions caused by traffic and to develop the overall transportation system efficiency in municipalities.

The research gap analysis showed that internationally smart transportation component was significantly less studied topic than for instance smart energy. There has been some research made in Finland of these smart city solutions relating to transportation, but the concept is rather new in its present form. Now when there has been already

implemented some smart transportation solutions in Finnish municipalities, it was interesting to survey how these have been succeed and what kind of challenges might have been faced.

The first part of the literature review studied the background of smart city development in Finland and offered a quick glance to the smart transportation programs and projects implemented in Finnish municipalities. Regarding to the review public organizations have had a leading role on igniting new smart city related projects and in creating cooperation platforms for different stakeholders to develop the new solutions together. From these programs and projects there have been found new working methods and involvement in these projects have had positive impact on citizens image of the city which has been noticed later as enhanced vitality and attractiveness.

There were also considered what kind of governmental matters have an influence in smart city development in Finland. Regarding to the review are different norms, legal regulations, acts, and EU directives which have an influence for instance. There were highlighted that in terms of smart city solutions development, the credible data security legislation is in key point so that citizens can trust that the data is processed and managed with respect to individuals' privacy protection. In addition, there are sustainability norms that affect to the smart solution development and different emission reduction targets. One major point on smart solution development regarding to the review was the knowledge of critical standards and involvement in their development processes. A significant motivator for smart solutions development is the scalability between different municipalities in Finland and on abroad. To guarantee compatibility and integration with other systems, the standardisation plays a key role.

Then the literature reviewed the smart city concept and what sustainability dimensions it includes. The components of smart city were presented and some examples how they are linked to smart transportation. In the review, the collective intelligence which builds on integrated exchange of data across the different components of smart city was

emphasized. This highlights the importance of the internet of things in the development of a smart city which was considered as a backbone of a functioning smart city. In addition, when developing a smart city, the main goal is to improve quality of life of its citizens which is based on efficient operations and services whilst respecting the sustainable development aspects.

The smart transportation and sustainability review were executed with traditional scoping literature review method. This subchapter consisted mainly of the journals selected for the closer review. This method was excellent to get comprehensive outlook of the recently published international journals and the current sustainable smart transportation research topics. In this review the timeline was from 2017 till 2023 and there were 12 journals selected after the eligibility evaluation. The main topics these journals were relating to decreasing of single occupied vehicles, information offering for citizens of the transporting, automated driving, and smart traffic management. Even though these journals were considering on many occasions much larger cities than Finnish municipalities are, still the solution proposals were noteworthy especially in the larger cities in Finland.

The methodology chapter aimed to find insights to contemporary state of smart transportation solutions and the main opportunities and challenges in the implementation of those in Finnish municipalities. The chosen research method was the semi-structured interview and there were interviewed five experts of the smart transportation sector from different organizations. The interviews offered comprehensive overall view of the smart transportation development in Finnish municipalities and covered various opportunities and challenges relating to the implementation.

Recently, in September 2023, Ministry of Finnish Transportation and Communications organized a meeting with significant operators of smart transportation sector in Finland. The future ambition among the participants of the meeting is to create a city infrastructure which renders the utilization of transportation automation and this way enhance the sustainable traffic system. In these meetings, there has been considered for instance

the mutual view of automation in urban transportation, challenges in the implementation of these innovations, and responsibilities and roles of different operators. (Liikenne- ja viestintäministeriö, 2023) So, there are similar kinds of considerations of smart transportation and its implementation on going as in this thesis has been covered.

5.2 Research results

Regarding to the interviews the contemporary state of smart transportation development in Finnish municipalities is mainly focused on Tampere and capital region. However, there are also implemented different solutions in other cities but not with same kind of determination. The overall atmosphere towards the smart transporation development was considered as affirmative and municipalities are predominantly conscious of the possibilities which can be achieved with these new solutions.

The main opportunities of implementing smart transportation solutions based in the interviews were to promote a change in modal split, to promote a change of the power source of vehicles, and to make the city transportation more efficient and safer for citizens.

Implementing smart transportation solutions to promote of modal split change was considered in the interviews as one of the main opportunities. The modal split change means that citizens are willing to use other mobility methods instead of private cars. This has several positive effects such as emission and pollution reduction, traffic efficiency improvement, and for citizens' health. Based on the literature and interviews the smart transportation solutions can advance this change by improving public transportation systems to make them easy and flowing, support infrastructure development with data offering, give valuable information of road conditions, offer data from behaviour change in terms of CO2 emissions for example. The pickup and drop off traffic and clarification of travel chains were also considered as advocating factor for citizens to choose preferably public transportation which can be developed with smart transportation solutions.

The promotion of power source change of vehicles was also considered as one of the main opportunities which means that different vehicles stop using fossil fuels and switch to renewable energy sources for example to using electricity. To advance this development the smart transportation solutions are needed for instance to create an efficient real-time information system for charging locations. This opportunity is at the same time a major challenge for Finnish municipalities because the emission reduction goals cannot be achieved without significant change to more sustainable power sources regarding to the interviews. The modal split development also supports this challenge as citizen transport with public transportation methods or with other options such e-bikes. However, the smart transportation solutions were expected to have significant value in the promotion of the power source change of vehicles.

The third main opportunity was the general idea which repeated in every interview that all solutions nudge the overall transportation system forward as more efficient and safer for citizens. All solutions are needed to support the sustainable development and diminish defects caused by traffic. These solutions can relate for instance parking, ITS and C-ITS, automated vehicles, real-time data gathering and so on. The comprehensive development and utilization of these new solutions supports achieving the goals of Finnish municipalities. And as in the literature the common goal was to decrease the number of the cars in city by offering other mobility options for citizens, this same kind of thinking is applicable in Finnish municipalities.

As the opportunities were concerning to support larger entities, the challenges were concerning more details. The main challenges of implementing smart transportation were that the solutions need to be rather far developed before they are capable of functioning in the ecosystem properly, to get these solutions fitted in to the budgets of municipalities, when assembling new sensors there can be difficulties to acquire power source, and business models for new solutions also need to be developed.

The challenge of that smart transportation solutions must be developed to a certain state is multidimensional. The technology must be working so that it is possible to charge of the usage for example, the standardization must be at a good level so that municipalities and private companies are willing to invest to new solutions, and the legal aspects must be considered and compliant. This can be acknowledged for instance in the development of automated vehicles, sensor assembling, and in the data gathering.

Another main challenge for implementing smart transportation solutions was that it is challenging to get these new development projects fitted in to the budgets of the municipalities. In many interviews the financing of these projects was relying on third party financing which affects certain types of challenges. However, as mentioned in the beginning of this thesis, the municipalities responsible for providing basic services mainly and therefore, deployments are shifting to the private sector and municipalities continue as platform providers and support the development.

The acquiring power source for different smart transportation solutions' sensors came up repeatedly in the interviews and that is why it is considered as a main challenge. In the literature this same kind of problem was considered in the journal of Zheng and others (2022). In the journal there were studied a self-powered bionic sensor which get mechanically excited of the by-passing vehicle. In one interview came up that there had been tested batteries as power source for sensors in some projects if there was not easy to acquire electricity, but this had also problems.

The last main challenge of implementing smart transportation solutions related to the business models of the new solutions. This relates in some extent to the issue that municipalities are mainly offering basic services and therefore even though the private companies are developing the solutions together with public organizations there need to be the business model developed meanwhile. In the interviews came up that even though the solution is implementable, the business logic is not mature enough and may take a few tries before the citizens find these new solutions in to use. Similar kind of concerns

were considered in the journal of Tripathy and others (2020) where ride-sharing systems' pitfalls were analysed. When it came to the data processing, one interviewee highlighted that even though the process would be organised by different operators, municipalities are in one or another way involved in the data gathering process in every stage.

5.3 Key findings of the research

Key findings of the opportunities of implementing smart transportation solutions in Finnish municipalities related to promoting the change of modal split and the change in used power source in vehicles. In addition, implementing smart transportation solutions have significant value to support different kinds of development dimensions in the city transportation. From the little development steps forms the more efficient and safer transportation system and every solution is needed so that municipalities can achieve for instance settled emission reduction goals.

One of the key findings in the challenges concerned that the new smart transportation solutions must be developed rather far so that they can be implemented into the transportation ecosystem of the city. These issues often relate to legal and standardization aspects which postpones the development projects for instance. Other key findings of the challenges were to get these new solutions fitted in to the budgets of municipalities, when assembling new sensors there can be difficulties to acquire power source, and business models for new solutions can be challenging to develop.

5.4 Recommendations for municipalities based on results

Based on this study, Finnish municipalities should keep considering how smart transportation solutions can be utilised to support modal split change so that different mobility methods will become more diverse and attracting to use. In addition, to support electrifying vehicles with smart solutions especially in the infrastructure planning. As the

development platform providing for smart transportation solutions continues, the importance of business model development should be highlighted to the private companies.

5.5 Future research suggestions

As this thesis considered the implementation of smart transportation solutions, the security issues of the functioning systems were not studied. The security of data or privacy of individuals in these smart city solutions could be a well-founded to topic to study. Also, in the interviews of this thesis, there were considerations that the security issues will come up again especially when the artificial intelligence utilization comes more in general.

Another suggestion is to survey suitable IoT platforms for smaller municipalities for data gathering which also came up during the interviews. Especially now when there has been recently published EU directive which revises the ITS directive to advance smart mobility in European cities which may also obligate Finnish municipalities to develop these kinds of services (European Commission, 2023).

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Appendices

Appendix 1. Interview questions in Finnish

1. Miten luonnehtisit älykaupunkikehitystä Suomen kunnissa tällä hetkellä?
2. Miten tärkeänä koet älykkään liikenteen osana älykästä kaupunkikehitystä?
3. Miten kunnat hyötyvät älykkään liikenteen jo käyttöönotetuista ratkaisuista tällä hetkellä?
4. Miten kunnat voisivat hyötyä älykkään liikenteen ratkaisuista tulevaisuudessa?
5. Mitä haasteita on mahdollisesti kohdattu tähän mennessä liittyen älykkään liikenteen ratkaisujen käyttöönottoon?
6. Mitä haasteita on mahdollisesti odotettavissa tulevaisuudessa älykkään liikenteeseen liittyvien uusien ratkaisujen osalta?
7. Kuinka hyvin mielestäsi IoT-teknologiaa on hyödynnetty älykkääseen liikenteeseen liittyvissä ratkaisuissa?
8. Miten näet älykkään liikenteen ratkaisut osana kestävää kehitystä?
9. Miten odotat älykkään liikenteen kehityksen etenevän Suomen kunnissa?
10. Miten koet eri toimijoiden roolit älykkään liikenteen kehityksen mahdollistajina?

Appendix 2. Interview questions in English

1. How would you characterize the smart city developed in Finnish municipalities at the moment?
2. How important do you consider smart transportation as a part of smart city development?
3. How are municipalities benefitting from already implemented smart transportation solutions currently?
4. How could municipalities benefit from smart transportation solutions in the future?
5. What kind of challenges have been encountered when smart transportation solutions have been implemented so far?
6. What kind challenges might be expected in the future?

7. How well do you think IoT technology has been utilized in smart transportation solutions?

8. How do you see smart transportation solutions as part of sustainable development?

9. How do you expect smart transportation development to progress in Finnish municipalities in the future?

10. How do you perceive the roles of different stakeholders as enablers of development?