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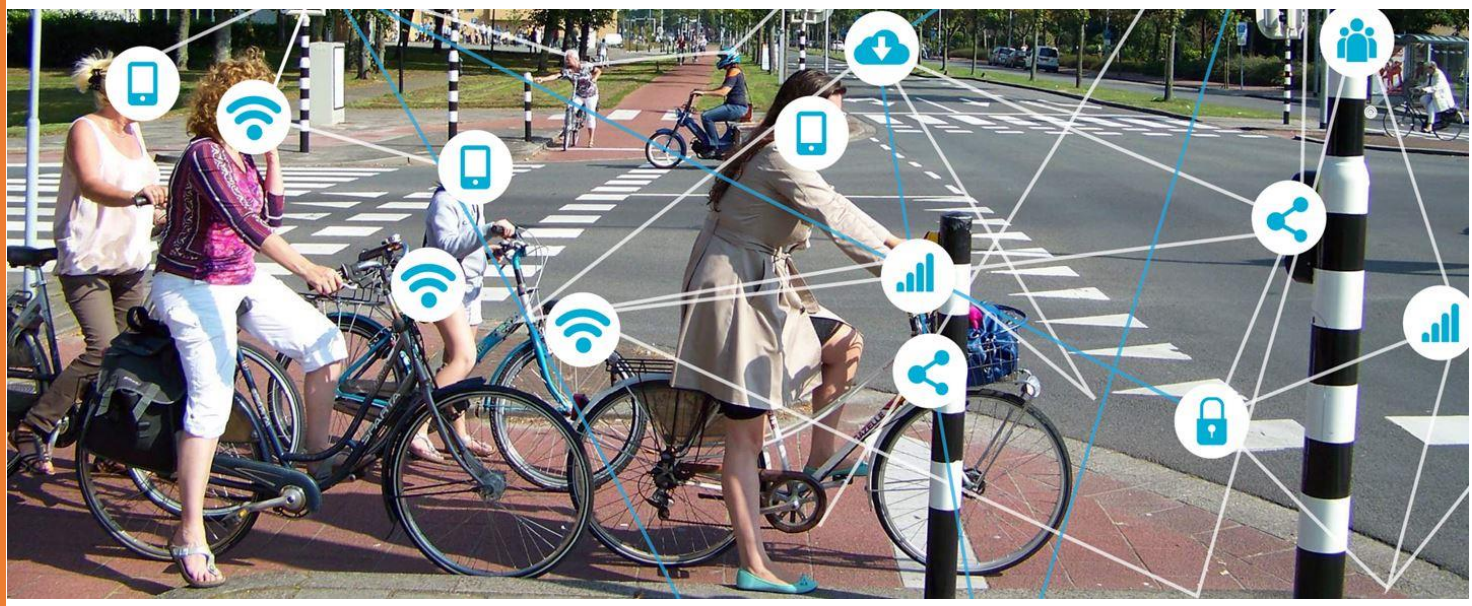
BITS
Bicycles and Intelligent Transport Systems



SMART CYCLING INNOVATIONS

AMPLIFYING THE INTEGRATION OF CYCLING AS ACTIVE MODE IN SMART URBAN MOBILITY SYSTEMS

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Colophon

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Abstract

The smartification of cities is redefining space in urban environments. Traveling is no longer a simple matter of physical infrastructure, but of smart objects and smart infrastructure. Despite the growing interest of policy makers around cycling as a catalyst for sustainable urban mobility, the majority of policies focuses on cycling as an offline activity, whereas smartification potentials of cycling are often overlooked. Despite its benefits for health and the urban sustainability, cycling is not featured prominently in the European Commission's Work Programme, which aim to develop smart, green and integrated mobility systems. Therefore, this research aims to explore the role of smart cycling innovations in amplifying the integration of cycling as active mode into the smart urban mobility system. A smart cycling innovations catalogue is developed to provide an overview of current smart cycling innovations. The Interreg project BITS (Bicycles & ITS) is used to recruit mobility experts who are at the forefront of smart cycling futures for in-depth interviews. Results of this research highlight the potential of smart cycling innovations in (1) demonstrating the ITS potential of cycling (2) increasing the modes visibility in the physical as well as virtual environment (3) improving cyclists safety, comfort, speed and integration with other modes as well as efficiency of traffic flow (4) showing the potentials of the smart bicycle as data collection device in the urban environment and (5) identifying the newly emerging opportunities in regards to the interactive landscape and its potential to initiate a process of empowering communities and creating a shared meaning by fostering the narrative of citizens collectively reclaiming the public space through cycling.

Keywords: Smart mobility, smart cycling innovations, ITS, urban sustainability, mobility system

Content

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List of Abbreviations

BITS	Bicycle and Intelligent Transport Systems
CIE	Cycling Industries Europe
EU	European Union
GIS	Geographic Information Systems
ICT	Information and Communication Technology
ITS	Intelligent Transport System
IoT	Internet of Things
KPI	Key Performance Indicator

1. Introduction

Urbanization challenges: sustainability & urban mobility

Throughout the 20th century, most authorities followed the 'predict and provide' approach, to predict traffic increases and build road capacity to accommodate that. Even today many projects are the result of this procedure. However, not only did this fail to bring the expected social and economic benefits, but it also had vast impacts on our environment and livelihood. Nowadays most cities suffer from heavy congestion, significantly degrading quality of life in our urban settlements (Finck et al., 2020).

Rapid urbanization increases the magnitude of this challenge. The United Nations predict that the world population will reach 8.6 billion by 2030 and 9.8 billion by 2050. 55% of the world population lives in urban areas today, a proportion which is expected to grow to 68% by 2050 (UN, 2020). Cities do not only host more than half of the world population, they also are a key driver for the global economy, contributing around 85% to the European GDP (EU, 2013). Cities are facing the challenge to respond to these developments by expanding their urban infrastructure and adapting their mobility networks, making urban planning more complex than ever (Mullen, 2020).

Urban mobility accounts for roughly 40% of cities carbon dioxide (CO2) emissions (Finck et al, 2020). A major reason for this is the dominance of cars in urban environments. The presence of cars in our cities is a symptom of the adoption of mass car ownership in the second half of the 20th century, and the planning decisions taken to facilitate and encourage their use. As a result, the current mobility systems rely heavily on fossil-fuelled private car ownership. This results in several consequences such as: Local air pollution, land, and water pollution due to transport run-off, congestion from overburdened road networks, as well as urban space deficiency (Steffen, 2015). Despite most of these concerns being of environmental nature, it is crucial to not see environmental sustainability distinct from social- or economic sustainability. These environmental impacts of our current mobility systems have great impact on our environment and thus also on the people affected by this environmental damage (Steffen, 2015).

European sustainability agenda – what about cycling?

It has become a well-established aim of planning authorities across Europe to work to reduce car dominance, ensuring sustainable mobility and liveability in urban areas. Approaches have broadly taken the shape of providing attractive alternative modes of transport for journeys otherwise taken by cars, while simultaneously reclaiming streets from car dominance, be this through pedestrianization, the provision of cycle infrastructure, the removal of parking infrastructure etc. (Geurs & Van Wee, 2006; Ewing & Cervero, 2010).

For roughly two decades now, a general understanding of mobility as a matter of sustainability has made it into the mainstream (Mullen, 2020). The European Commission has acknowledged the importance and potential of urban mobility to reduce greenhouse gas emissions to combat climate change and has therefore formulated its commitment towards the establishment of a 'European Strategy for Low-Emission Mobility' in order to respond to current environmental and societal challenges (European Commission, 2016).

In 2020 the European Commission updated its Work Programme taking the results of the Interim evaluation of Horizon 2020, the biggest EU research and innovation programme, into account (European Commission, 2020). This lead to the publishment of the Horizon 2020 – Work Programme which follows the general present conception that there is a need for 'smart, green and integrated' transport solutions to contribute to the global climate targets set by the COP 21 Paris Agreement (European Commission, 2020). The target is defined and operationalized within the Work Programme through four lines of activities: (1) resource efficient transport that respects the environment (2) better mobility, less congestion, more safety and security through innovations and ICT technologies (3) global leadership for the European transport industry (4) socio-economic and behavioural research and forward-looking activities for policy making (European Commission, 2020)

Despite the ambitions of the European Union to develop smart, green and integrated transport solutions, the role of active modes such as cycling is heavily underrepresented in the commission's Work Program. Especially when it comes to digital mobility solutions and ITS potentials. Cycling futures however are in the midst of change, due to the current multitude of innovations, new digital and smart technologies as well as consultants and policy makers increasingly transforming cycling experiences, infrastructures, and gadgets (Nikolavea et al., 2019).

Throughout the past five years, a scholarly debate about potential cycling futures arose, reflecting on current innovation and potential pathways of cycling as a mode of transport. Whereas these innovations have the potential to change how cycling is experienced, understood and governed as mode of transport (Larsen, 2014; Vivanco, 2013; Brömmelstroet et al., 2017). With the upcoming of these cycling innovations a whole new field of mobility research arises, bringing up many questions regarding impacts of these innovations on cyclists and their surrounding infrastructure as well as how cycling is governed in the urban environment.

Research problem

The aim of this study is to gain insights into the current status quo of smart cycling innovations in mature cycling environments throughout Europe, as well as explore how these potentially amplify the integration of cycling as active mode into the urban mobility system of medium-sized cities whilst contributing to the European ambition of developing smart, green and integrated transport solutions. The central aim of this research leads to the following main research question:

What is the role of smart cycling innovations in amplifying the integration of cycling into the smart urban mobility system of medium sized cities in Europe?

The subsequent secondary research questions have been formulated to explore and answer the main research question:

1. What is the current status-quo of smart cycling innovations in Europe?

An analysis of existing literature on smart cycling innovations combined with a content analysis of the smart cycling innovations catalogue developed by the Cycling Industries Europe in light of the European Interreg project BITS has resulted in the development of a new catalogue displaying the current status quo of cycling innovations (see Appendix i).

2. What is the influence of mobilizing cycling data on cycling as active mode in urban mobility systems?

The categorization of smart cycling innovations according to data types, as well as specific use-cases per innovations and data types combined with interviews with mobility experts, researchers and policy makers recruited in the vicinity of the BITS project has produced learnings which are discussed in *chapter 4., 4.* Results.

3. What is the influence of cycling innovations on how cycling is organized and governed as mobility mode?

Information for this secondary question will be derived from documents and interviews with mobility experts, researchers and policymakers in the vicinity of the BITS project. Providing information regarding the influences of smart cycling innovations on cycling governance (*see chapter 4. Results*)

4. How can smart cycling innovations contribute to the development of future smart mobility systems?

Information will be derived from documents and reports published throughout the BITS project and interviews with mobility experts, researchers and policymakers. This will provide information regarding the contribution of smart cycling innovations towards the development of smart, green and integrated transport solutions with four lines of activities proposed by the European Commission.

Research design

This explorative research takes a qualitative approach, combining desk research and semi-structured interviews. The European Interreg project BITS (Bicycles and Intelligent Transport Systems) is of particular interest as it is the frontrunner regarding best practices of current smart cycling pilots and implementations in Europe.

Primary data has been collected via semi-structured interviews with mobility experts, researchers and policymakers from all BITS member countries: NL, DK, BE, DE, UK. All interviewees have been recruited in close vicinity of the BITS project. The municipalities involved in the project are medium-sized, meaning have a total population between 100.000 and 500.000.

Secondary data has been gathered by analysing papers, articles and websites of commercial smart cycling innovation providers as well as reports and the smart cycling catalogue published via Cycling Industries Europe (CIE) through the BITS project.

Societal & academic relevance

The results of this research are valuable for both theory (e.g., how smart cycling innovations influence/amplify the role and integration of cycling as mode in smart urban mobility systems) and practice (e.g., better integration of cycling as active mode in the future urban mobility systems).

In terms of planning practice, the results of this study can be used by medium-sized cities to obtain an overview of current smart cycling innovations, their data types and use cases to design/plan more sustainable urban mobility systems, whilst prioritizing active mobility and improving integration of modes. There is no scientific knowledge on the influence of cycling data collection processes, how this data is used, its impact on cycling infrastructure development and governance of cycling as a mode (Nikolaeva, 2019). This specific gap in the academic literature is addressed by this research.

In general, the results of this research can facilitate the transition of medium-sized cities to more sustainable and liveable urban environments with a focus on active modes of transport. Moreover, this research amplifies the awareness and visibility of cycling potentials for future mobility systems.

Structure of thesis

Pursuant to the introductory chapter 1, chapter 2, the theoretical framework provides a synthesis of the literature relevant to this research. Existing research, theories, and crucial concepts are explored and presented, leading to a visualized conceptual model. Chapter 3, the methodology outlines the research approach, providing information regarding data collection and methods/software used for the purpose of analysis. Chapter 4 presents the research findings, which are further interpreted in sub-sections. Chapter 5 will provide a discussion of the results as well as specific learnings and action steps regarding smart cycling innovations and cycling governance in future mobility systems. Lastly, chapter 6 will draw a conclusion and summarise reflections and recommendations for future research.

2. Theoretical framework

The following chapter provides an overview of theories and the operationalization of relevant concepts. Firstly, the nature of the emphasis of urban mobility planning on motorized traffic is explored and the theoretical approach to bicycle planning is introduced. Secondly, the processes of smartification of cities and urban mobility are explained. Thirdly, mobility data is defined and operationalized, including emerging challenges of data protection. Fourthly, smart cycling innovations are explored and operationalized per theme, category and data type. Lastly, a conceptual framework displays the relation of smart cycling innovations to cycling governance and future mobility systems.

Mobility planning: motorized transport vs cycling

In alignment with a broader idea of sustainable transport, cities across Europe aim to decrease motorized traffic in urban areas, whilst formulating policy goals to shift car trips to public transport and active modes such as walking and cycling (Banister, 2008). However, in reality these goals often remain theoretical (Koglin, 2013).

Increased car use was seen as essential for economic and social progress throughout the 20th century, leading to a one-sided professionalization of models and theories in the domain of motorized traffic (Iacono et al.,2008; Knoflacher,2009). This in turn lead to a more sophisticated analysis of motorized traffic over active modes such as cycling, providing theoretical ground to accommodate more cars and invest in respective infrastructure, a self-reinforcing loop. Traffic flow theory enabled policymakers and transport planners to calculate and forecast motorized traffic flows, providing legitimization for urban highway construction and almost exclusively applied to motorized transport (Nuhn & Hesse, 2006; Treiber & Kesting, 2013). People believed that motorized traffic would need to flow through the urban environment with the least amount of interruptions possible, aiming to develop better traffic flows, less congestion and faster travel times (Hall, 2002; Holston, 2002). This modernist notion of urban transport planning are reflected in arguments of urban power relation and knowledge by Flyvbjerg (1998), stating that *'through measurable knowledge that builds on positivistic theories, motorized traffic has been prioritized in transport planning'* (Koglin & Rye, 2014, p.217).

The reasons for the marginalization of active modes of transport in urban transport planning have been explained through poor data quality of the alternative modes (Iacono et al, 2010). Even up until today there are limited amount of books about the theory of bicycle planning. In his book, *Planning for Cycling – Principles, Practice and Solutions for Urban Planners* McClintock (2002) provides suggestions for policymakers to emphasize road safety, health and sustainable transport in bicycle planning (McClinton, 2002). More cycling mature countries such as the Netherlands and Denmark have been applying these fundamentals to their urban transport planning for decades, significantly boosting their urban bicycle shares.

The exclusion or marginalization of cycling in urban transport planning led scholars like Creswell (2010) to develop theories into planning for bicycles within the urban politics of mobility, emphasizing the practice of movement to visualize the power relations of modes in the urban environment (Creswell, 2010). Koglin & Rye (2014) built upon this theoretical ground with the overall aim to develop a safer and more useful environment for cyclists. The theoretical approach for bicycle

planning developed by Koglin & Rye emphasizes four focus areas for policymakers when planning cycling in the urban environment:

(1) Physical movement from A to B – cyclists should be able to travel through the urban environment without obstacles in safety and with flow.

(2) Power relations in urban traffic space – policymakers should be aware and consider the power relations of different modes in the urban mobility system, whilst providing spaces where cyclists are not excluded.

(3) Positive representations of bicycling – referring to the creation of positive shared meanings attached to cycling as a mode which goes beyond class, gender, ethnic or other boundaries.

(4) Experience of cycling – the mode of cycling should benefit people in their everyday lives and, make it easier and more comfortable. Therefore, cycling infrastructure should involve these everyday aspects of life to make the urban bicycle journey more pleasant overall (Koglin & Rye, 2014).

These theories aim to inform policymakers and transport planners and offer new angles of governing cycling in the urban environment. The urban environment however is changing as cities and smartification processes might influence and bare new challenges regarding the division of space among modes.

Towards smart cities: mobility & data

The smartification of cities and upcoming technologies are redefining space in our urban environments. Striving towards the 'smart city' has become one of the top priorities of many cities around the globe (Finck et al, 2020). The European Commission defined the smart city as - 'a *place where traditional networks and services are made more efficient with the use of digital and telecommunication technologies for the benefit of its inhabitants and business'* (Publications Office of the European Union, 2014)

Sensors and IoT (Internet of Things) technologies enable monitoring of all kinds of events and activities, such as road congestion, movement of humans and vehicles, air quality, availability of parking etc. (Finck et al, 2020). IoT technologies enable physical objects to store, send, and receive information, potentially transforming planning in our cities (Dutton, 2014). Thus, traveling from one point to another is no longer a simple matter of physical infrastructure, but of smart and intelligent infrastructure (Behrendt, 2016). Additionally, the smartphone does not only affect people's mobility through physical space but is further augmenting and facilitating our physical mobility, enabling tracking of movement of individuals, objects and vehicles (Bratton, 2009; Schwanen, 2015). Some academics go even further, stating that smart applications would become the key means through which transport systems will be governed and regulated (Schwanen, 2015). Naturally, these new developments bring up concerns about the sharing and ownership of data. There is, however, a number of scholars who believe that these smart innovations might have the potential to reshape physical mobility systems for greater urban sustainability, by increasing efficiency of current systems and making alternative modes such as cycling, walking, public transport as well as sharing-schemes more attractive and convenient (Geels 2012; Lyons, 2015).

Data, surveillance & privacy

If smart mobility implies the production, sharing and collaboratively analysis of data, concerns related to surveillance and data ownership emerge (Büscher et al, 2012). Smart technologies around urban mobility can collect and process personal data in different spaces and forms including location-related data (Andrew, 2020). In a potential future scenario of a smart city, there might be no movement without digital tracing or tracking (Elliot & Urry, 2010). This is especially true in an urban environment which is increasingly made up of intelligent transportation and mobility infrastructure (Andrew, 2020). IoT devices are becoming more precise when it comes to augmenting and diversifying location services, operating under the premise that information directly linked to the individual is more valuable if connected to their location. Mobility and location data is increasingly laying the foundation for authorities to monitor and predict peoples movement and behaviour in the urban environment (Andrew, 2020). Finck et al. (2020) point out that the transformation of urban mobility will lead to a *'more widespread sensing of people's movement, coupled with advancements in analytical capabilities rendered by enhanced data mining of large datasets, presage significant challenges for society´* (Finck et al, 2020; p. 327). Thus, ownership and management of personal data specially are to be regarded as a major issue in discussions around smart cities and smart mobility systems (Koglin & Rye, 2014).

Cycling in smart cities: cycling & mobility data

The ongoing sustainable urban mobility transition in many cities across Europe further increases the attention to cycling and due to rising globalization as well as increasing challenges of global warming, the bicycle is more and more seen as a transformative agent of urban change (Nikolavea, 2020). Potentially contributing to public health, urban sustainability as well as liveability agendas.

Despite the growing attention in smart cities and IoT on a European level, cycling does not feature prominently within the European Commission's working documents on IoT (European Commission, 2016). According to Koglin cycling is still widely marginalised in transport planning, not only in terms of physical infrastructure but also in the digital environments of modern ICT developments around mobility (Koglin, 2015). This is interesting, as cycling resembles a sustainable and active mode of transport and the European Commission itself acknowledged its benefits for health and environment (European Commission, 2016). Despite the growing interest of scholars and policy makers around cycling as catalyst for sustainable urban mobility, the majority focuses on cycling as an offline activity, whereas intelligent transport networks as well as smartification and IoT potentials of cycling get overlooked (Berendt, 2016). A growing number of academics is calling for the inclusion of cycling as active mode in smart city processes and urban transport planning (Koglin & Rye, 2014; Koglin, 2015; Behrendt, 2016). Therefore, it is crucial to explore and understand how present cycling innovations can potentially contribute to amplifying the integration of cycling into smart urban mobility systems.

In the prior section the process towards smartification of our cities and mobility systems has been laid out. What does this mean for cycling and what role does mobility data play within smart cycling futures?

Smart cycling relates to networked practices, systems, and technologies around cycling (Behrendt, 2016). Smart cycling manifests itself if mobility data is produced, shared, and analysed (Büscher et al., 2012). To explore the potentials of cycling in smart cities it is crucial to identify and categorize the

nature of data the mode can produce. This research will classify cycling data into three groups according to the nature of data they are based on: (1) Live point data (2) Journey data (3) GPS data.

(2) Live point data, refers to data gathered at a specific location such as a fixed counter or a traffic camera. The data represents less volume in comparison to GPS data but enables the derivation of specific insights due to consistency of inputs. Opening up opportunities for immediate response and spatial interventions (Rogers & Papanikolopulos, 2000).

(3) Journey data, provides information regarding the origin, destination as well as travel time of an individual journey. This type of data often requires a serious amount of time to collect a significant number of journeys to be able to derive findings. Thus, the data is often published several months after the first journey was recorded, making it a more suitable data type for long-term trend analysis. (Romanillos et al, 2015).

(1) GPS data is usually gathered via a smartphone or similar device. This type of data is often connected to a specific individual but can also be anonymized. The application of GPS data for transport planning has often resulted in complications in the past due to its inaccuracy and volume (Romanillos et al, 2015).

Smart cycling innovations

The current multitude of innovations, new digital and smart technologies as well as consultants and policy makers are increasingly transforming cycling experiences, infrastructures, and gadgets (Nikolavea et al., 2019). Some academics even go further, saying the bicycle would be the single most important tool in the urban toolbox for improving our cities (Colville-Anderson, 2018). Throughout recent years, a scholarly debate about potential cycling futures arose, reflecting on current innovation and potential pathways of cycling as a mode of transport. Bringing up the question of how these innovations have the potential to change how cycling is experienced, understood, and governed as mode of transport (Larsen, 2014; Vivanco, 2013; Brömmelstroet et al., 2017)

These promises have been amplified by the latest cycling innovations and smart cycling technology, increasing the potential to integrate this active mode of transport into the wider smart mobility system of the future (Nikolaeva et al. 2019; European Cyclists Federation, n.d.). Hence, smartification of cycling has the potential to create new alliances as well as create narratives around smart technology, liveability, and environmentalism (Nikolaeva, 2019).

A distinction is made between three themes of smart cycling innovations. (1) Smart innovations related to the bicycle (2) Smart innovations related to the relationship of cyclists & the spatial environment (3) Smart innovations related to governing cycling. In this research governing cycling refers to the organization and planning of cycling as mode in the urban mobility system. Within each theme, categories of innovations as well as the specific data type which served as input have been identified and grouped.

Nikolaeva et al. (2019) developed an extensive review on smart cycling futures, providing a systematic overview of smart cycling innovations, which has been used as starting point for this research. Throughout the BITS project, many new smart cycling innovations emerged, all in very different stages of development. Table 1 displays the current status quo of cycling innovations based on the review by Nikolaeva et al (2019) in combination with the state-of-the-art report published by Cycling Industries Europe in light of the BITS project. More detailed descriptions of each innovation can be found in the smart innovations catalogue (*see Appendix i*).

Theme	Categories	Data type	Innovations
Smart Bicycle	Simplicity & connectedness Gamification Tracking/Tracing/Counting	GPS data Journey data	Linka, Mobilock, Smart Halo, VanMoof Electrified S, Hexagon, Linkalock, Brightspark, Blubel, Sherlock, Student Bike **BITS**: Mytripper, MaxS, SMART, Ring-Ring, Naviki, BikeCitizen, Komoot, Strava, COBI.Bike, fride, See.sense, Smart Grips, GSM-tracker, Human, CrossCycle/Give me Green, Bicycle tracker Tailit, Liberty Bell
Cyclists & Spatial environment	Interactive landscape • Information provision • Facilitate parking Adaptation of cyclists to their environment • Increase safety • Increase cyclists comfort	Live point data GPS data Journey data	Warmtesensor, Groenvoorspeller, Schwung, Spinning Wheels, Flo, Evergreen, Volg Groen, Electronic information boards, P-Route, Bikescout **BITS**: Traffic light with countdown timer, Hybrid Cycle Data Radar, Fairytrail, Poliscan Redlight, ThermoPath (heated bike lanes), IceAlert, Bikescout, Crossover, DayBright PLUS, Digital information panels, glowing bike lanes, Intersection conflict warning system, Mobimaestro (intelligent streetlights), The Smart Crossing, Xfire bike lane laser lights, TheSmartCone, TMP, Vierkant groen, Cycle specific green waves, Brighton Cycle Hub, Bike Counter, Solar Path, Green wave, LaneLight in-road BikeSafe system, Cyclemeter, Solar road, Intelligent road studs, Bike Box, Blue-lockers, Dynamic traffic sign, Omniflow, Rain sensitive traffic lights with thermal camera, Schwung, Bicycle Presence
Governing cycling	Data-driven governance • Tacking/Tracing/Counting • Rewarding cyclists Automobilization of cycling • Improve Speed • Facilitate Routing	Live point data GPS data Journey data	Sitraffic SiBike, Volg Groen, GoLight Avenue, Green waves for cyclists, electronic information boards, P-Route, Cloudfiestenstalling, Mobilock, Blinkers, Brightspark, Livall, Hövding, Hexagon, Lumos **BITS**: Hybrid Cycle Data Radar, Digital panels with information, Mobimaestro, TheSmartCone, TMP, Bike counter, Cyclemeter, Intelligent Road studs, Omniflow, Smart traffic lights with thermal camera, Flexradar, See.sense, Smart Road stickers, Mytripper, Radar, Actime bicycle counter, SESAMO, Schwung, Strava Metro, Thermal imaging camera for traffic monitoring, Sniff bicycle, Bicycle Presence, FlowCube, Thermal traffic camera, TrafficCam 3D

Table 1: Bicycle innovations per theme/category

Smart Bicycle

Smart innovations related to the bicycle broadly promise four key features: (1) simplicity, (2) connectedness (Nikolaeva, 2019), (3) gamification and (4) tracking/tracing/counting (BITS, 2020).

The 'smartified' bicycle will offer the *simplicity* of a regular bicycle combined with the promised convenience of ICT enhancements. The *connectedness* of the bicycle to a smartphone is a key feature, opening many opportunities for the smart mobility system of the future. Companies such as VanMoof, Linkalock, Brightspark, Blubel, and Sherlock aim for 'seamless' integration of smart accessories into the simple bicycle structure, while promising 'multiplication of functions and possibilities' (Nikolaeva, 2019).

Büscher et al (2012) claim that smart mobility would entail *'producing, sharing and collaboratively analysing mobile data, utilizing computation that non-experts can make palpable'* and '*where technologies augment human reasoning about, and control of, the mobile society people enact every day'* (Büscher et al., 2012: 146). Producing and sharing mobile data provides the means for *tracking/tracing/counting*. This data can contribute to a better understanding of cycling research while simultaneously increasing interest of participants as their movements become recorded and classified (Elliot & Urry, 2010). On the other hand, this phenomenon has to be seen very critically - some academics claim it to be the key concern of smart mobility futures, as if everything will be producing and sharing data, there will be no movement without tracking or tracing (Elliot & Urry, 2010).

Closely linked to the notions of *connectedness* and *tracking/tracing/counting* is the concept of *gamification*, which relates to the practice of using existing game elements in situations which do not have game-like characteristics. In this process elements from games such as scores, leader boards, avatars, levels, difficulties, virtual awards etc. are applied to encourage engagement with a product or service (Deterding et al, 2011).

An example combining all the four key features of smart innovations related to the bicycle is the Ring-Ring smartphone application. 'Cyclists are automatically tracked regarding what distances and routes they cycle, how much carbon dioxide they have been saving, in what weather conditions they have cycled and how much time they have been active. The cycle kilometres are the source of rewards based on geographical area or in a specific private group or at shops and stores. These credits can be used to buy goods in local stores'. As an addition, cyclists can give feedback on their cycling experiences and road safety (BITS, 2020).

Relationship between cyclist and spatial environment

Smart innovations related to the relationship between cyclists and their spatial environment are particularly prevalent in mature cycling contexts. They relate to the interaction and relationship between the cyclist and their spatial environment. These can be divided into two main categories: (1) interactive landscape and (2) adaptation of cyclists to their environment (Nikolaeva, 2019), as well as four sub-categories: (1) information provision, (2) facilitate parking, (3) increase safety and (4) increase comfort (BITS, 2020)

The interactive landscape refers to innovations such as the '*Warmth Sensor*', '*Green Predictor*' and '*Dash*', which are supposed to monitor the presence and number of cyclists at a particular crossing and provide longer and more frequent green light periods when needed. Innovations such as *Flo*, *Evergreen*, and *Volg Green* also entail the interaction of cyclists with their spatial environment by displaying the speed in real-time. If the cyclists adjust their speed accordingly it will enable them to catch the green light for one or several traffic lights. Additionally, information boards can be used to share information about the traffic situation and availability of bike parking. Thus, a new interactive landscape emerges between cyclists and their spatial environment enabling *information provision*, and *parking facilitation*, thus aiming to increase *comfort* as well as *safety*.

The adaptation of cyclists to their environment refers to innovations such as the *WAIR scarf* developed in France, aiming to protect cyclists from air pollution and monitor data regarding air pollution while cycling through the city. Cyclists can look at their data and take a 'healthier' route. A similar innovation is the *Ring a bell*, which changes colour according to the level of air pollution. These innovations enable cyclists to adapt to their environment and aim to *provide information, increase safety* & *comfort* (BITS, 2020).

Governing cycling

Smart innovations related to governing cycling include categories which have the potential to change how cycling is governed and organized as a mode of transport. This paper will focus on (1) data-driven governance and (2) automobilization of cycling.

Data-driven governance is based on data-collection and thus on the concept of tracking/tracing/counting. Cycling has largely been seen as an offline mobility mode, which might change in the future due to systematic data collection processes (Nikolaeva et al, 2019). Innovations such as the Hybrid Cycle Data Radar enable 24/7 monitoring of bicycle traffic flows on specific locations, enabling spatial- and policy interventions specifically directed at the actual needs of cyclists (BITS, 2020). Data-driven governance can be combined with the concepts of *gamification* and *rewarding cyclists* as described in the example of the Ring-Ring application.

The automobilization of cycling relates to the promise of smart technology of granting cyclists with similar privileges as car drivers (Nikolaeva, 2019). Dutch innovations such as Follow Green, GoLight Avenue offer green waves to cyclists, a concept which was only applied to motorized traffic before. Policymakers aim to *facilitate routing* and thus *improve speed* for cyclists to make the mode more attractive. Such developments have the potential to influence the hierarchy of modes within the urban realm and change how cycling is perceived as mode within future mobility systems.

Conceptual framework

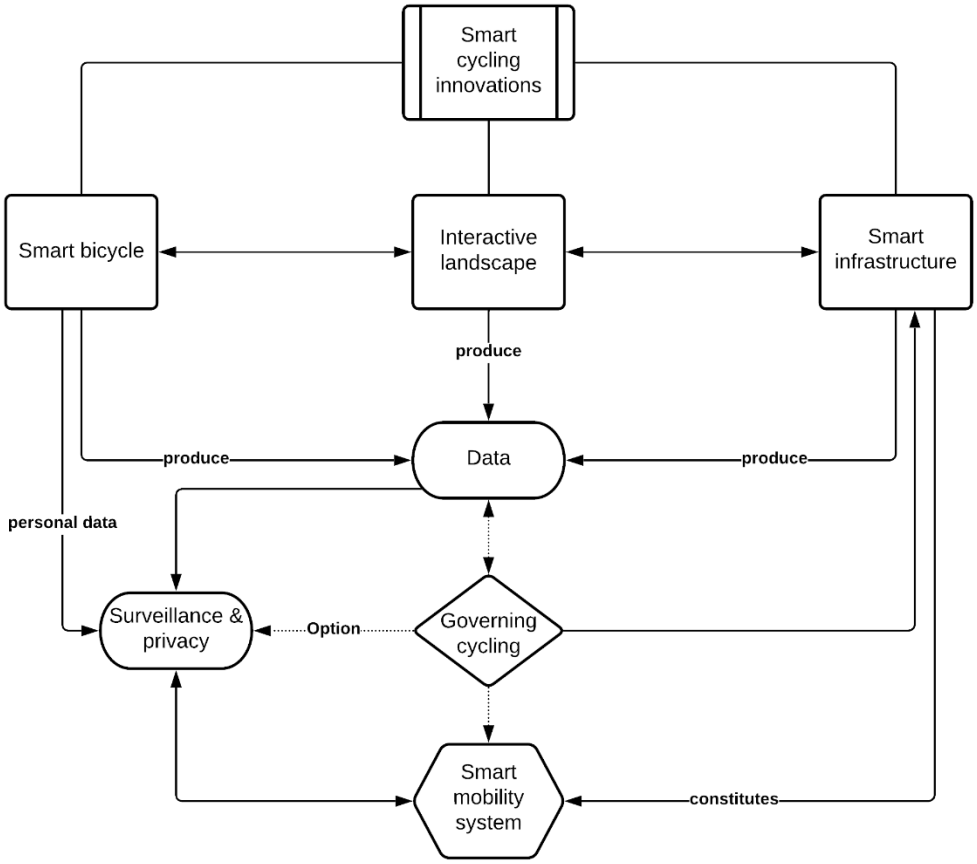


Figure 1: Conceptual framework

The conceptual model demonstrates the three main themes of smart cycling innovations, namely (1) smart bicycle, (2) smart infrastructure and (3) relationship between cyclists and their environment, thus the emerging interactive landscape. Innovations within each of these themes produce data, potentially influencing the way cycling is organized and governed as mode. Through the continuous production of data, opportunities for governing cycling emerge, however also lead to challenges regarding data anonymization, privacy & protection. The specific relationship between cycling data and cycling governance as well its potential in amplifying the integration of cycling into the smart mobility system, which is constituted by smart infrastructure and data, will be explored in this research.

Hypothesis

H1. Mobilizing cycling data can amplify the integration of cycling as active mode into the smart urban mobility system.

H2. Through mobilizing cycling data new challenges of data privacy arise.

H3. Smart cycling innovations influence the way cycling is organized and governed as a mobility mode.

H4. Smart cycling innovations contribute to urban sustainability agendas by improving the efficiency of the urban mobility system and making cycling as a mode more attractive.

3. Methodology

The following chapter comprises the methodological approach of this research. To produce convincing and meaningful results a structured research design and methods are crucial (Clifford et al., 2016). First, the research approach will be presented. Secondly, the BITS project will be introduced. Thirdly, the data collection process is elaborated on, including general characteristics of interviewees. Fourthly, data analysis is explained. Lastly, the ethical considerations of this research are explored.

Research approach

The research strategy of this paper is a combination of secondary- and primary data collection. An intensive research design is applied, as the focus lies on the description of a small number of cases in detail (Clifford et al., 2016).

Secondary data has been gathered by collecting information from academic journals, reports, government websites and published policy papers to provide a theoretical foundation. Of specific interest were the reports and published data related to the BITS project and commercial websites of innovation providers. The state-of-the-art report as well as the BITS applications catalogue have been analysed and synthesized with secondary literature to formulate the current academic state of knowledge regarding smart cycling innovations.

Before conducting fieldwork, various research methods have been ruled out due to limited applicability. For example, the observing method, representing the process of looking at a certain situation and evaluating it afterwards (Veal, 2006). A quantitative approach was considered. A comprehensive amount of data would be collected, meaning results would have been numerical and statistical. Quantitative methods are useful to describe trends, attitudes, opinions by studying a sample of a population and generalizing the result. However, as the BITS related projects are not all completed yet, this quantitative approach was not suitable.

To explore influence of smart cycling innovations in amplifying the role of cycling in future urban mobility systems a qualitative approach in form of semi-structured interviews has been chosen. All participants of the BITS project will be interviewed with the aim to gather a great amount of 'rich' information about limited cases (Veal, 2006). Therefore, this qualitative approach has been combined with a content analysis of the BITS reports and websites of commercial innovation providers.

All participants share a common characteristic, which is their vicinity to the European BITS project. The BITS project comprises 10 project partners, thus purposive sampling has been applied to select interviewees. Individuals have been specifically approached through the Communication manager of the BITS project. Additionally, mobility experts and researchers specifically related to mobility and cycling have been interviewed.

11 semi-structured interviews have been conducted. Interviews have been conducted via Teams due to the current global Covid-19 pandemic. Each interviewee has been provided with an information sheet (*see Appendix xxxiii*) and a letter of consent (*see Appendix xxxii*) entailing general information about the research as well as legal formalities regarding data collection and privacy concerns.

For the analysis interviews have been transcribed and coded. A deductive code tree has been developed based upon the relevant themes of smart cycling innovations and future mobility systems (*see Appendix xxi*). Inductive codes have been developed on the basis of the transcripts within Atlas. The development of code networks enabled structural analysis and visualization of relevant code groups.

The BITS project

The BITS is a European Interreg project on Bicycle and ITS (Intelligent Transport Systems), with the main aim to reduce urban CO2 emissions by 9% and increase bicycle use by 10% within target groups. The BITS encompasses 10 European partners from 5 countries within the North Sea Region, involving regions which already can be considered mature cycling environments such as (1) the Netherlands (2) Belgium and (3) Denmark, as well as regions which have the ambition to become mature cycling environments such as (4) the United Kingdom and (5) Germany. All specific participants are listed in *table 2*.

The aim of this European Interreg project is to raise awareness towards best practices of 'smart cycling'. The result of this project have been a series of publications, projects, pilots, labs, interdisciplinary studies within the realm of smart cycling futures and the development of the European Cycle Data Hub. The BITS project and its members have entered a new terrain and thus opened the way for a new research agenda within sustainable urban mobility and cycling in particular, thus are of major interest to this research.

Part. No	Participant name	Short name	Country code	Type of beneficiary	Role in project
1	Province of Overijssel	OVE	NL	Regional public authority	Lead beneficiary
2	City of Zwolle	ZWO	NL	Local public authority	Project beneficiary
3	City of Bruges	BRUGES	BE	Local public authority	Project beneficiary
4	East Riding Council of Yorkshire	ERYC	GB	Local public authority	Project beneficiary
5	City of Aarhus	ARH	DK	Local public authority	Project beneficiary
6	Baron Mobility	BAR	DE	SME	Project beneficiary
7	Cycling Industries Europe	CIE	BE	Interest groups including NGOs	Project beneficiary
8	VIVES	VIVES	BE	Higher education and research	Project beneficiary
9	Province of Antwerp	PA	BE	Regional public authority	Project beneficiary
10	University of Oldenburg	UoO	DE	Higher education and research	Project beneficiary

Table 2: BITS project participants

Data collection

This research applies primary and secondary data collection as a mixed method approach can widen the validity of results (Tyrrell, 2016). In general, a mixed method approach refers to a combination of qualitative and quantitative methods, however, can also be defined more broadly, encompassing the combination of several qualitative data collection methods (Hennink et al. 2016).

Interviews

Primary data has been collected through semi-structured interviews, as they have some form of predetermined order but leave room for addressing other issues (Longhurst, 2016). The interviews have been prepared and structured with an interview guide in order to translate the operationalization of concepts from the theoretical framework into questions (*see Appendix xxx*). The key topics of the interview where smart cycling innovations, cycling data and its influences and implications, smart mobility systems and cycling governance.

The interview guide has been adjusted slightly following the first interviews, thus went through an iterative process. The overarching themes of discussion remained identical. Interviewees have been recruited in close vicinity to the BITS project. The communication manager of the BITS was contacted with a request to reach out to all participating countries and their involved representatives. The BITS communication manager was briefed in a vis-à-vis meeting about research content, objectives and process. The profound knowledge of the Communication manager about all related projects and processes enabled identification of relevant potential interviewees. The identified individuals were contacted through the Communication manager with an information sheet shared by the researcher (*see Appendix xxxiii*). This can also be seen as form of snowball effect (Bailey et al., 2011). Due to the ongoing pandemic, all interviews have been conducted and recorded with Microsoft Teams. The table below shows individual characteristics of each interviewee.

Interviewees - General Characteristics

General Characteristics n=11		**Count**	
Gender ▪ Male ▪ Female		8 3	
	Professional background		**Country**
Interviewee 1	Mobility expert	1	BE
Interviewee 2	Mobility & GIS expert	1	BE
Interviewee 3	Senior mobility consultant	1	NL
Interviewee 4	Mobility manager	1	NL
Interviewee 5	Bicycles and Intelligent Transport Systems Project Coordinator	1	UK
Interviewee 6	Local Growth coordinator	1	UK
Interviewee 7	Mobility advisor	1	NL
Interviewee 8	Mobility expert	1	NL
Interviewee 9	Research assistant, Data scientist	1	DE
Interviewee 10	Mobility planner	1	DK
Interviewee 11	Mobility advisor	1	NL

Table 3: General characteristics of interviewees

Content analysis

Secondary data gathered for this research consisted of documents, articles, books and papers to provide a theoretical basis for the framework. Additionally, a content analysis was conducted of existing literature about smart cycling innovations, the smart cycling innovations catalogue published by Cycling Industries Europe (CIE) and the reports published in light of the BITS project. A combination of existing literature of smart cycling and the smart cycling innovations catalogue resulted in the creation of a new updated catalogue including a categorization of the three data types relevant to this research (*see Appendix i*).

Data analysis & interpretation

The semi-structured interviews have been recorded within Microsoft Teams and transcribed using the Otter.ai software. The produced transcripts have been coded and analysed within Atlas.ti. Coding refers to the process of assigning values and meanings to specific elements within the collected data. The creation of code groups enabled the researcher to further organize and structure the data. A deductive code tree was developed prior to the data collection, based on operationalized concepts relevant to this research (*see Appendix xxi*). Next to deductive coding, inductive coding was applied to the interview transcripts. Inductive codes resemble values and elements within the data which have not been considered before conducting the interviews. The organization of deductive and inductive codes into code groups as well as networks enabled detailed analysis of the collected data and guided the structure of analysis and discussion (*see Code Book, Appendix xxii*).

Ethics

The awareness towards potentially arising ethical issues is fundamental to research design (Clifford et al. 2016). Specifically, when conducting interviews ethical considerations are crucial. To maintain the participants privacy when presenting in-depth information gathered through interviews represents a challenge (Kaiser, 2009).

Privacy of each participant has to be guaranteed. To avoid privacy concerns of respondents, the interviews have been anonymised. Respondents were informed about the research background and objectives through an information sheet prior to the interview. A letter of consent entailing methods of data storage and data privacy was signed by both the interviewee and the researcher (*see Appendix xxxii*). Furthermore, a verbal consent has been recorded prior to the interview.

The Data collected is stored on a password-secured offline device, which only the researcher has access to and will be stored for 3 months after conducting each interview, to be deleted indefinitely.

4. Results

The following section presents the combined results of the smart cycling innovations catalogue content analysis and in-depth interviews with mobility experts. Firstly, innovations and use cases per data type will be presented. It should be clarified that many innovations apply several data types and will therefore appear in multiple sections. Secondly, the central and newly emerging topic of data in smart cycling futures will be explored. Thirdly, the influence of innovations and data on how cycling is organized and governed as mode is analysed. Lastly, the contribution of smart cycling innovations to the development of 'smart, green and integrated' mobility systems is presented.

Data types: innovations & use cases

Live point data

Live point data is data collected a specific location at a specific point in time (Rogers & Papanikolopulos, 2000). The categories of innovations which make use of point data offer opportunities for (1) tracking/ tracing /counting (2) increasing safety, comfort & facilitate parking of cyclists and (3) reward cyclists as well as facilitate routing to improve speed.

The most common use case for point data is counting cyclists through fixed or mobile counters to establish baseline data (Interviewees: all). This is because it is crucial for planning to know the amount of cyclists on the road (Interviewees: Ronald, Angela, Anabel, Hans, all). Innovations applying live point data for the purpose of counting cyclists have been divided into three categories according to their sophistication of use cases and classified from tier one to tier three for the purpose of this research.

Tier 1 innovations such as the 'Actime bicycle counter', 'Eco display compact' and 'Poliscan redlight´ enable counting of cyclists with a 98% accuracy (Actime traffic count services, 2021).

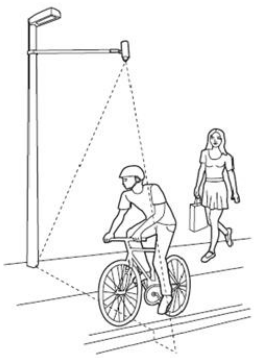


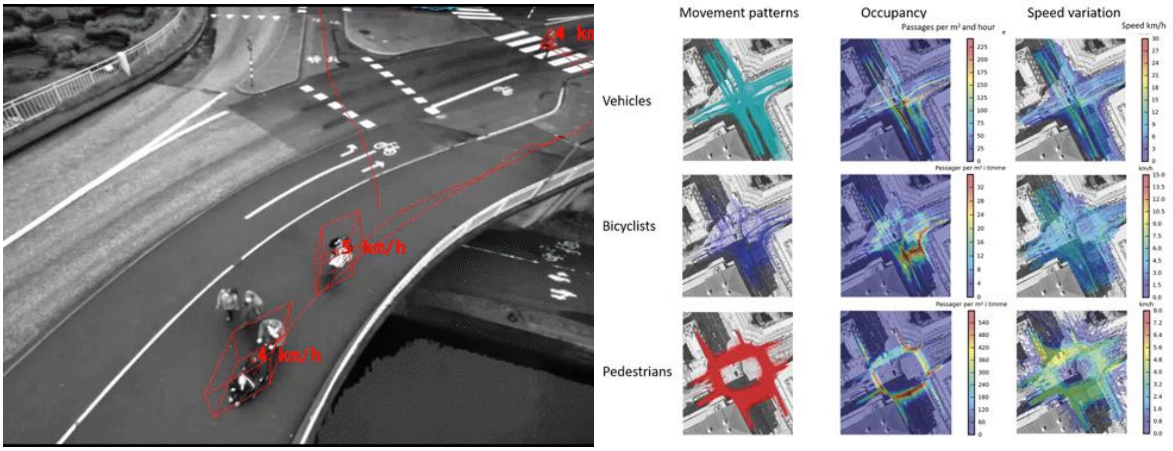
Figure 2: Actime bicycle counter (Actime traffic count services, 2021)

Figure 3: Eco display (Ecocounter, 2021)

Tier two tracking and counting innovations such as the 'Intelligent Road studs', 'Fietstelpunt', 'Radar' and 'Hybrid Cycle Data Radar' offer counting of cyclists as well as collection of more specific KPI's such as speed, peak times, night use, averages as well as classification of mobilists. These innovations already offer real-time dashboards for data analysis (*see Appendix i*).

Figure 4: Hybrid Cycle Data Radar (BITS, 2020)

Tier three, the most sophisticated live point data innovations like cameras, 3D cameras and thermal vision cameras (e.g., Viscando) offer new use cases next to counting, classification of modes and speed measurements such as conflict analysis through tracking of near incidents at specific intersections, monitoring of traffic flow and comprehensive congestion analysis in real-time. The tracking of near incidents at specific intersections enabled policymakers to understand traffic flow, behaviour of individual modes and lay the ground for better integration of modes (Interviewees; 1,2,3). Hence, allowing quick evaluation of the traffic environment and implement suitable changes (Viscando Traffic Systems, 2021). To prevent identification of the individual, the image resolution is



deliberately not high enough.

Figure 5: Viscando Camera (Viscando Traffic Systems, 2021)

Innovations with tracking/tracing/counting characteristics at a specific location can also function to reward cyclists by improved routing and improved speed. Innovations such as 'CrossCycle', 'Schwung', 'Smart traffic lights with thermal camera' and 'Cycle specific Green Waves' enable tracking of cyclists at intersections to give them priority. If cyclist approach a signalled intersection carrying a smartphone with an installed application (e.g., 'Vialis'), the system will recognize and the traffic light will turn green as quick as possible (*see Appendix i*). Commercial providers aim to reduce

waiting times for cyclists, thereby improving safety and making cycling more attractive through improved routing (Volker Wessels, 2021).

Point data can also be applied to improve information provision and facilitate parking for cyclists. 'P-Route Cycle' collects data from different stands/bike parking facilities across the city and provides detailed information of parking capacities as well as dynamic routing opportunities within an app and on information boards which can be distributed around the urban environment (*see Appendix i*).

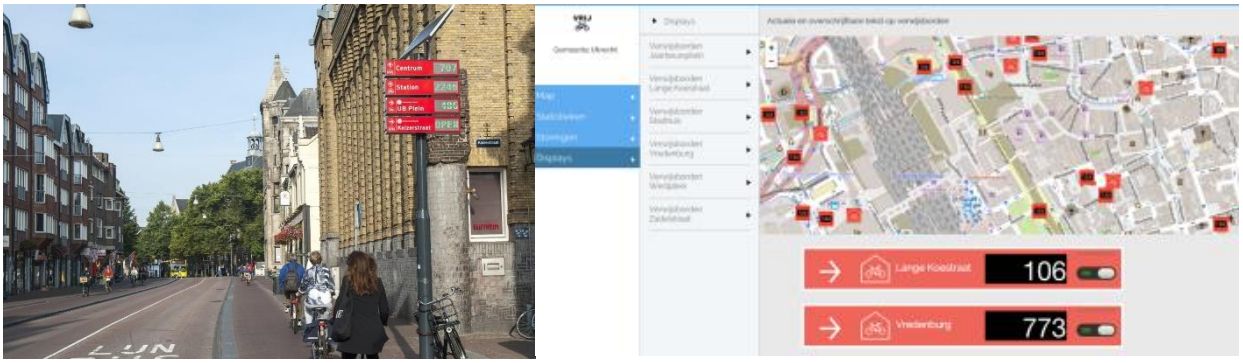


Figure 6: Information Boards (Lumiguide, 2021)

To conclude this section, *table 4* provides an overview of all cycling innovations making use of point data. Point data is specifically useful for public authorities to establish baseline data regarding cycling numbers and other cycling related KPI´s such as speed, volume, peaks etc. in the urban environment. Furthermore, producers promise detailed conflict analysis at intersections and traffic monitoring to obtain real-time insights into urban traffic flow.

Overview

Live point data		
Categories	**Innovations**	**Use cases**
Tracking/ Tracing/ Counting	• Camera (video) • Radar • Hybrid Cycle Data Radar • Actime bicycle counter • CrossCycle/ Give me Green • Schwung • Thermal imaging camera for traffic monitoring (FC T2 series) • Traffic management of bicycle flow by camera-based speed and volume measurement adjusted by Bikesim simulation • Flexradar • P-Route Cycle • Cycle Specific Green Waves • Poliscan Redlight • Bike counter (Eco-Display Compact) • Green Wave • Cyclemeter • IceAlert • Intelligent road studs • Bicycle Presence • Digital panels with information • Fietstelpunt • FlowCube • Omniflow (smart lighting) • Smart traffic lights with thermal camera's • Thermal traffic camera • TheSmartCone • TrafficCam 3D	• Speed measurements • Counting cyclists (accuracy 98%) • Classification of mobilists • Real-time insights into bicycle traffic flow • Traffic monitoring • Traffic management • Integration of modes at specific intersections • Conflict analysis (e.g., near accidents) • Identification of traffic flow issues • Information provision • Security & traffic control • Prioritizing cyclists in traffic flow • Shorten urban bicycle trips • React to weather and traffic flow conditions in real-time • Improve traffic flow
Increase safety, comfort & facilitate parking	• Hybrid Cycle Data Radar • CrossCycle/ Give me Green • Schwung • Traffic management of bicycle flow by camera-based speed and volume measurement adjusted by Bikesim simulation • Flexradar • P-Route Cycle • Cycle Specific Green Waves • Green Wave • Bicycle Presence • Omniflow (smart lighting)	

	• Smart traffic lights with thermal camera's • Digital panels with information	
Rewarding cyclists, facilitate routing & improve speed	• Hybrid Cycle Data Radar • Traffic management of bicycle flow by camera-based speed and volume measurement adjusted by Bikesim simulation • Cycle Specific Green Waves • Smart traffic lights with thermal camera's • Green Wave • Schwung	

Table 4: Point data & use cases

Journey data

Journey data, provides information regarding the origin, destination as well as travel time of an individual journey (Romanillos et al, 2015). The categories of innovations making use of journey data offer: (1) tracking/tracing/counting (2) increasing safety, comfort & facilitating parking, (3) rewarding cyclists, facilitate routing to improve speed, (4) gamification and (5) interactive landscape. Nearly all innovations providing journey data require a tracking device, such as an application or gadget to mount onto the bicycle in order to enable monitoring of a journey from A to B.

Innovations such as `Mytripper' enable monitoring of travel behaviour (e.g., employees, commuters) by placing an RFID-tag on the wheel of the bicycle. Gadgets and applications like Mytripper can be combined with incentivising employees to cycle to work. 'Smart' for example is used by the municipality of Enschede, Netherlands to launch a cycling challenge for citizens every two month. Their mobility patterns are collected via smartphone and aimed at stimulating active travel and cycling (*see Appendix i*).

Similar applications like 'Human', 'SESAMO', 'Fahrrad Tracker', 'Mapmyride' and, 'Fride' offer cyclists the possibility to map their journey through the urban environment, whilst providing community functions and gamification. Via 'SESAMO' public authorities can reach out to users through surveys, thus enabling qualitative data collection next to journey data (*see Appendix i*).

Innovations such as `See.sense', 'Snuffelfiets' and, 'Meetfiets' enable a more detailed cycling data collection by collecting ride insights into: Movement patterns, speed & dwell times, road & pavement quality, near-incidents as well as air quality and temperature measurements (*see Appendix i*). The collected insights are visualised in dashboards to provide information on 'understanding how cyclists move in our cities´ (See.Sense, 2021)

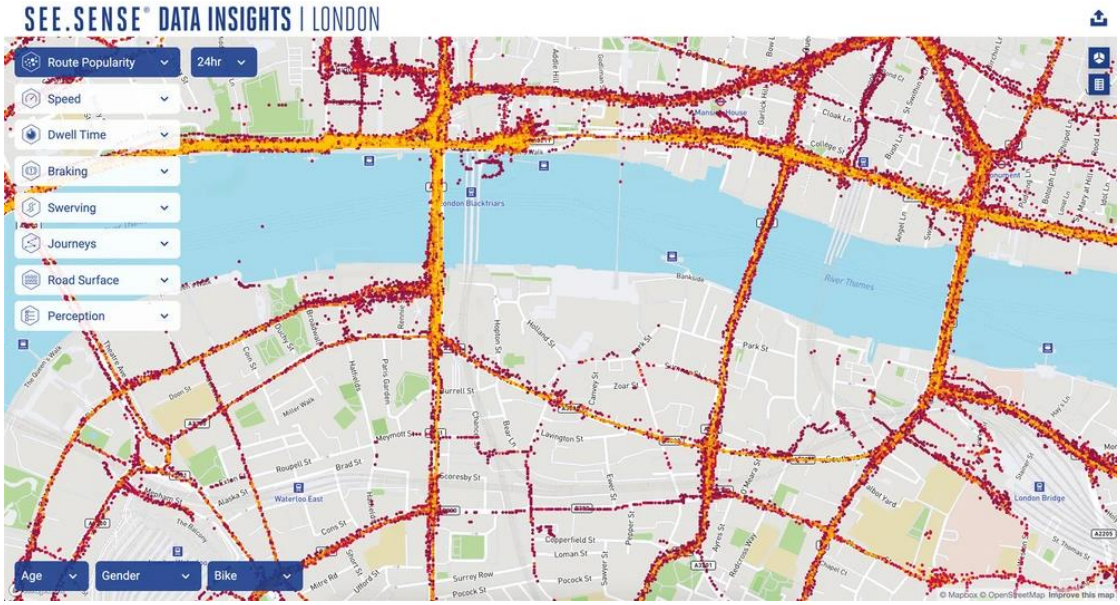


Figure 7: See.Sense Data insights (See.Sense, 2021)

To conclude this section, table 5 shows innovations and use cases using journey data. Journey data is specifically useful for public authorities to collect a variety of cycling related insights to improve the urban mobility system. *'This data provides us with evidence, it picks up all information, shows us*

where there might be problems at a particular junction or tells us if the road surface is not very good', explains interviewee 10, a mobility expert from Denmark (Interviewee, 10).

Overview

Journey data		
Categories	**Innovations**	**Use cases**
Tracking/ Tracing/ Counting	• Mytripper • Diverese appps, e.g., MaxS, or 'Ritje van de zaak' • SESAMO - SEnsing and SAmling for MObility • Human • Mezuro • See.sense • Sniff bicycle (Snuffelfiets) • BikeCitizen • bikemap • Radfahren - Fahrrad Tracker • mapmyride	**For authorities:** • Monitoring travel behaviour (e.g., commuters) • Comparing movement data of individuals • Collect insights: movements patterns, speed & dwell times, road roughness & pavement quality, near-miss events, air quality & temperature • Collecting qualitative data through applications • Provide cycling challenge → register mobility patterns **For cyclists:** • Discover new routes as cyclist • Tracking bicycle progress & share rides with community (speed, distance, calories etc.) • Mapping, routing & statistics
Increase safety, comfort & facilitate parking	• Diverese appps, e.g., MaxS, or 'Ritje van de zaak' • Smart • See.sense • Data collection bicycle (meetfiets) • BikeCitizen	
Facilitate routing & improve speed	• Mywindsock • BikeCitizen • Bikemap • Mapmyride • fride. - Mountainbike Tracker	
Gamification	• Mytripper • Diverese appps, e.g., MaxS, or 'Ritje van de zaak' • Smart • BikeCitizen • fride. - Mountainbike Tracker	
Interactive landscape	• See.sense • Data collection bicycle (meetfiets) • Sniff bicycle (Snuffelfiets) • BikeCitizen • bikemap	

Table 5: Journey data & use cases

GPS data

GPS data is usually gathered via a smartphone or similar device. This type of data is often connected to a specific individual can however also be anonymized (Romanillos et al, 2015). The categories of innovations applying GPS data are: (1) tracking/tracing/counting, (2) interactive landscape, (3) increase safety, comfort & facilitate parking and (4) facilitate routing.

There are little particular use cases for GPS data which have not been mentioned in one of the sections about live point data or Journey data above. There are, however, a few innovations which offer GPS-specific information. The innovations 'Liberty bell' and 'Ping if you care' offer cyclists the opportunity to log, map and describe their experiences while traveling through the urban environment. Cyclists can ping a specific spot on their route which they would like to comment on (e.g., feeling of unsafety, lacking cycling infrastructure, aggressive behaviour of other road users, potholes etc.). The developers aim for improved walkability and cyclability through citizen engagement (Liberty Bell, 2021). These innovations offer involvement in city planning as incentive and provide public authorities with the potential to mobilize communities and collect feedback on the public space. 'We obtain the chance to integrate the people's perspective into the planning process, I think that is something that's new', claims interviewee 9 (Interviewee, 9).

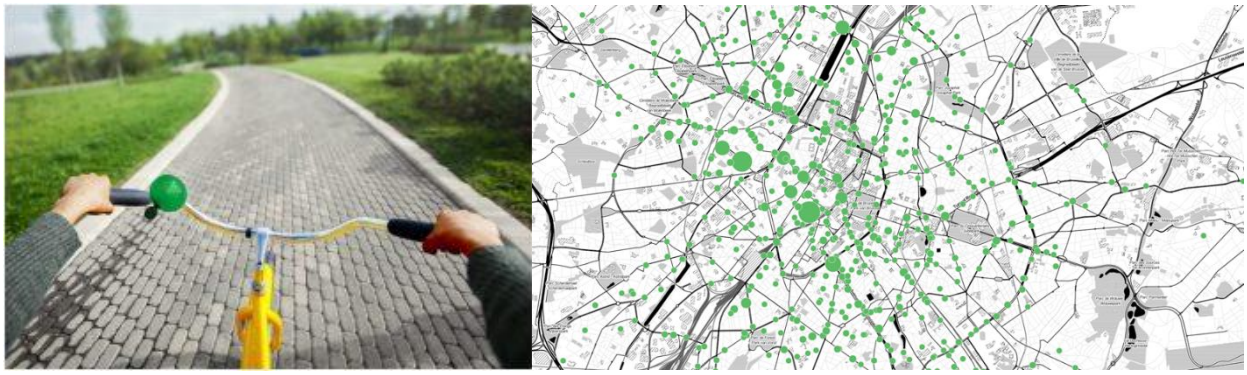


Figure 8: Liberty Bell & Ping-Cities (Liberty Bell, 2021; Ping-cities, 2021)

Other innovations such as 'Smart grips', 'Naviki', 'Locus map' and 'Komoot' aim to improve navigation of cyclists. The 'Smart grips' are specifically interesting, as they introduce tactile feedback via the handlebars through vibration to help the cyclist navigate through the urban environment, making the smartphone as navigation device obsolete.

To conclude this section, *table 6* presents an overview of innovations applying GPS data. GPS data for cycling is specifically useful to collect feedback of cyclists about specific issues around cycling in the public space as well as better navigation of the individual through the urban environment.

Overview

GPS data		
Categories	**Innovations**	**Use cases**
Tracking/Tracing/ Counting	• Mytripper • GSM-tracker • Human • CrossCycle/ Give me Green • Bikesharing: Swapfiets • Mezuro • Data collection bicycle (meetfiets) • Sniff bicycle (Snuffelfiets) • Liberty Bell • Smart Grips • Ping if you care • Naviki • Komoot • Locus map • Bikemap • Radfahren - Fahrrad Tracker • mapmyride	**For authorities:** • Monitoring travel behaviour (e.g., commuters) • Prioritizing cyclists at intersections with certain application • Collect feedback of road users • Road improvements • Mobilizing communities • Involvement in city planning as incentive **For cyclists:** • Locate bicycle via GPS • Comparing physical activity with the community • Provide feedback regarding infrastructure or issues • Navigation • Mapping & routing
Interactive landscape	• Data collection bicycle (meetfiets) • Sniff bicycle (Snuffelfiets) • Ping if you care • Naviki • Komoot • Bikemap	
Increase safety, comfort & facilitate parking	• CrossCycle/ Give me Green • Bikesharing: Swapfiets • Data collection bicycle (meetfiets) • Sniff bicycle (Snuffelfiets) • Liberty Bell • Smart Grips • Ping if you care • Naviki • Komoot • Locus map	
Facilitate routing	• Komoot • Locus map • Bikemap • Radfahren - Fahrrad Tracker • mapmyride	

Table 6: GPS data & use cases

Key findings: Interviews

The following chapter comprises the results of all interviews conducted with the mobility experts from NL, DK, BEL, GER and UK. Each subsequent section is based on code networks created within Atlas. First, the newly emerging theme of data and cycling is explored. Secondly, the influence of smart cycling innovations of cycling governance is presented, including a sub-chapter on empowering and mobilizing communities which emerged during the inductive coding process. Thirdly, the relation of cycling and smart urban mobility systems is analysed including challenges for municipalities engaging with smart cycling innovations.

Data and cycling

Mobility data is a central topic within smart city futures. This research aimed to explore how smart cycling innovations amplify the potential to integrate cycling as an active mode into the wider smart mobility system of the future. The interviews with mobility experts of mature cycling environments within Europe highlight the importance as well as potential of data for cycling as a mode. It has been shown that smart cycling innovations provide the means for public authorities to collect GPS data, point data as well as journey data related to cycling. However, these new opportunities of cycling data result in new challenges for public authorities regarding collection, ownership, privacy, and harmonization of data.

Several mobility experts agree that it is crucial to gather baseline data, e.g., in the form of mobile or fixed counters to identify the number of cyclists in specific locations in the urban environment (Interviewees, 1; 5; 6). *'For us that was the beginning, the start of our cycling data collection'* (Interviewee, 11). However, it would not only be about counting cyclists but also about efficiency in the data collection process, as one interviewee points out (Interviewee, 8). Therefore, it would be crucial to identify the most efficient ways of measuring specifically relevant locations. Public authorities thus need to balance efficiency and representativeness when establishing their baseline cycling data. As '*sometimes you have too much data, too much information, and you simply do not know where to begin or what to analyse'* (Interviewee, 1). Especially smaller municipalities do usually not have designated data teams to work with all the available data.

When public authorities engage in cycling data collection, they work together with third parties due to lack of technical knowledge and institutional capacity, which ultimately leads to issue and challenges related to the ownership of data. Smart cycling innovations are often developed with commercial intents. Several mobility experts mention the danger of relying on third hand data, as this would make the public authority dependent on their commercial partners (Interviewees, 10; 11). *'We want to own the data we collect'*, says interviewee 1. Resembling a problem specifically for smaller municipalities as they lack the institutional capacity as well as technical knowledge to develop these innovations themselves. As a solution for public authorities engaging with commercial parties for cycling data collection purposes, experts highlight the importance of contractual agreements regarding data ownership (Interviewees, 8; 11). '*You have to make sure to have the rights of the data, when making contracts with these companies, you have to be very aware of that*', emphasized interviewee 10 a mobility planner from Denmark.

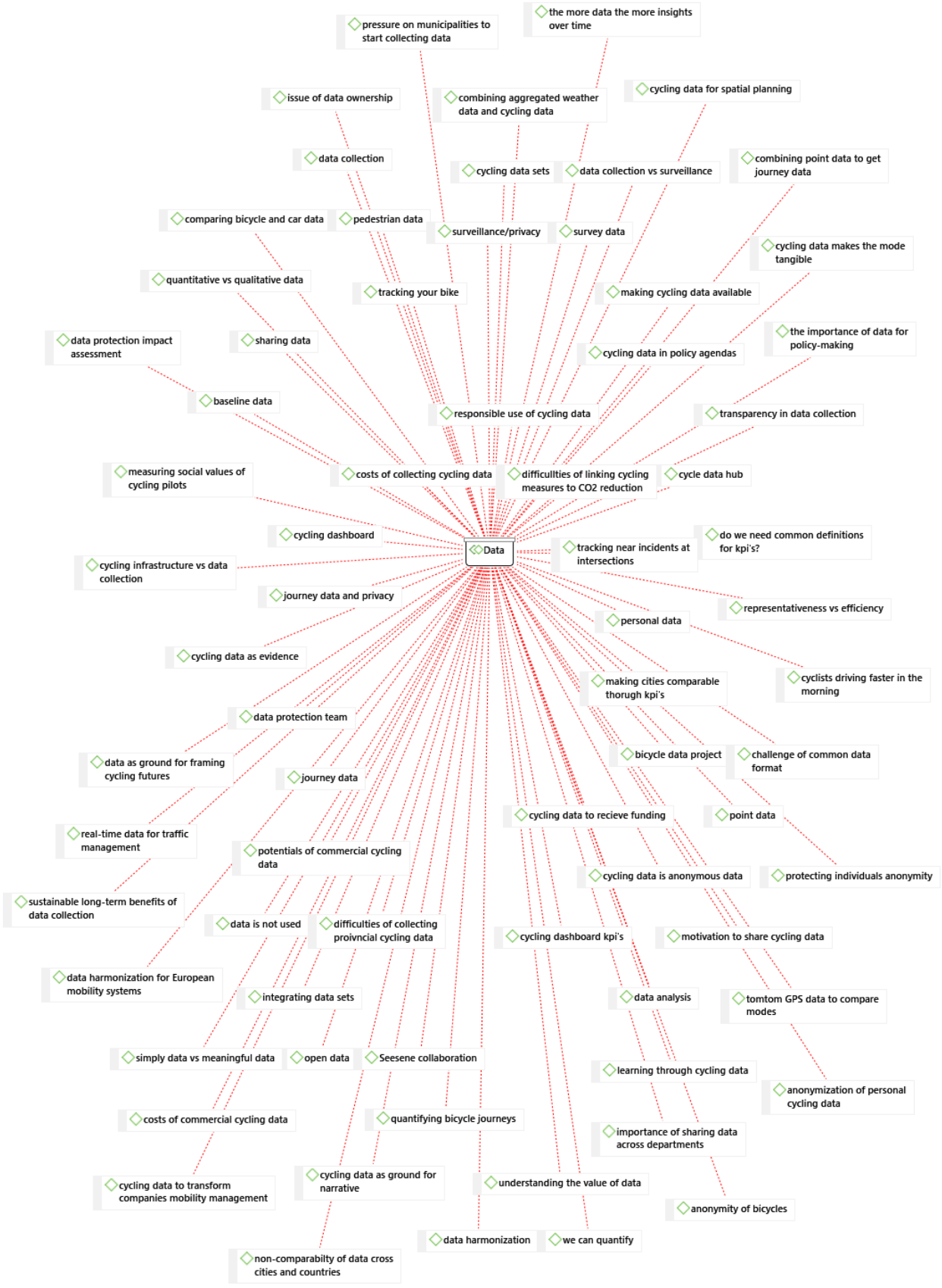
The issue of data ownership is closely linked to one of the central topics of smart mobility futures, surveillance, and privacy. In a future smart mobility scenario, there might be no movement without digital tracing or tracking (Elliot & Urry, 2010). Smart cycling innovations enable the integration of cycling into this future mobility scenario. What are the challenges for public authorities in terms of personal data and privacy of cyclists? All interviewed mobility experts claimed that cycling data

would mostly be anonymous data (Interviewees, 1; 2; 8; 10; 11). Most infrastructure-based innovations used for counting and traffic monitoring purposes simply count the number of bicycles passing by. *'It does not say who's bike it is, it is simply a bike, so privacy wise we do not have any issues'*, emphasized interviewee 1 a mobility expert from Belgium. If traffic cameras or 3D-camera technology is implemented, such as the 'Viscando' camera the image quality is deliberately blurry to not allow identification of individuals. The purpose of these innovations is the differentiation of modes on a specific intersection and not the identification of any individual moving around the city. *'You can see it's a pedestrian or a bicycle, but the image because it is high up and low quality, you cannot identify someone'* claims interviewee 1. Nonetheless, policy makers are aware of the fact that some of these innovations will create resistance among residents if communicated poorly and non-transparently. In some cases when working with journey or GPS data municipalities need to anonymize datasets before the analysis. Additionally, when collecting journey data, via an application or connected bicycle, the tracking can be programmed in such a way, that it will not show the first and last few hundred metres of each journey. There is consensus among interviewees that data privacy shall be central when collecting cycling data. Interviewee 8, a mobility expert from the Netherlands called this a *'hot topic among policy makers and experts'* in its municipality. Public authorities make use of privacy checklists or even have a data protection team to ensure all measures taken comply with the GDPR of the European Union (Interviewees, 5; 8; 11).

The continuously growing amount of cycling data which will be collected through current and upcoming smart innovations will result in the public authorities having access to a variety of datasets. Opening opportunities of integrating and combining datasets, depending on the specific KPI`s relevant to the public authority. Or as interviewee 10 states, *'data is a good thing, but combining of data is what makes it powerful'* (Interviewee, 10). A potential use-case is the integration of cycling data and aggregated weather data to evaluate how cycling changes in different weather and seasonal conditions (Interviewees, 2; 9). The newly arising possibilities for integration with other modes will be dealt with in the following chapter. The integration of datasets however does not come without problems. The development of the Cycle data hub during the BITS project has shed light on the opportunities of open data as well as challenges of data harmonization. The Cycle Data Hub was developed throughout the BITS project to collect data links on bicycle use, infrastructure, safety, climate impact and bicycle business performance from all participating countries (BITS, 2020). The Cycle Data Hub is an open data base and free to access for everyone, aiming to increase cyclists visibility in statistics, analysis and policy. However, the integration of datasets from municipalities around Europe represented a major technical challenge. Master students from the university of Oldenburg have been developing a script to integrate all datasets on the platform. Interviews with GIS and data experts revealed that harmonization of European mobility data will be one the next big challenges in European collaborations around mobility. Interviewee 9 researcher and data scientist from Germany claims, *'I think there will be more cooperation in the future not really about data collection, but more about the data itself, how it can be harmonized'* (Interviewee, 9).

It can be concluded that newly emerging possibilities of cycling data collection through smart innovations leads to a new range of challenges for policy makers and urban transport planners. The main focus areas deducted from the interviews with mobility experts are: (1) efficiency versus representativeness when engaging in cycling data collection, (2) issues around data ownership, (3) rising privacy concerns in an urban environment where every journey is tracked and traced and (4) newly arising challenges of data harmonization.

Code Network: Data



Governing cycling

So far in this paper, the newly emerging challenges of cycling data collection through smart cycling innovations has been explored. How do smart cycling innovations and data influence how cycling is governed and organized as a mode?

Interviews with mobility experts revealed that a primary and central influence of smart cycling innovations on cycling governance is that they increase the visibility of cycling as a mode. Especially the ITS components in smart cycling innovations would *'potentially increase integration with other modes because data makes planning more tangible'* (Interviewee, 3). Policy makers highlighted the difficulty of linking bicycle related measures directly to CO2 emission reduction, thus urban sustainability agendas. Smart cycling innovations and ITS technology enable policy makers to quantify cycling in the urban environment. *`It's a new way of showing, we can put a number on our goals, make our goals visible'* (Interviewee, 10).

A relatively new and crucial component in increasing the visibility of cycling as a mode are real-time dashboards. Described by a GIS expert and provincial mobility advisor as '*spatial and dynamic maps'* which display relevant cycling KPI's in real-time (Interviewee, 2). A prime example of a cycling dashboard is the 'Bicycle Barometer' from the province of Antwerp, - an open data-based dashboard displaying all cycling related KPI's such as cycle counters, speed measurements, traffic flow, infrastructure/road quality, road ownership, near accidents etc., in an integrated online tool. The platform is free to access and enables policy makers and citizens to download reports about specific cycling related KPI´s.

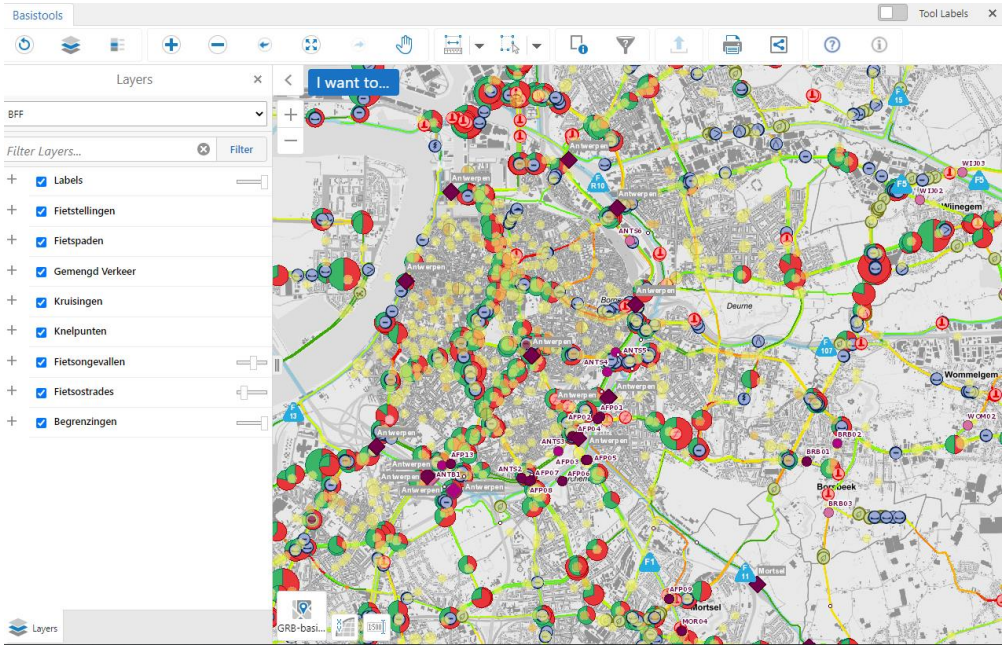


Figure 9: Fietsbarometer (Provincie Antwerpen, 2021)

The development of dashboards enable the display of cycling data in a tangible manner, giving policy makers *'A new ground for legitimization to organize cycling'* (Interviewee, 3). A mobility consultant working with cities on their mobility strategies claims that municipalities should invest into the development of these dashboards to *'see everything at one glimpse and enable integrated transport planning*' (Interviewee, 3). Smart cycling innovations grant policy makers access to real time cycling data, opening new pathways for data-driven governance and informed decision-making.

The evidence produced through these innovations and their display in dashboards does not only enable data-driven spatial planning and traffic management but helps to justify funding for cycling infrastructure in urban environments.

'It's a way, and a very important one, to justify the use of money for cycling towards politicians, to show the benefits as well' (Interviewee, 10).

Mobilizing cycling data enables policy makers to make informed decisions about cycling futures in the urban mobility system, understand cycling patterns and make the mode more attractive to increase bicycle share. '*Data can help us to get more people on the bike'*, states a Dutch mobility advisor (Interviewee, 4). Interviewee 11, mobility advisor from the Netherlands adds '*We are trying to get more data and a variety of data, that we can use in the coming years towards our new plans and directions'* (Interviewee, 11). Thus, clearly indicating the relevance of cycling data for urban policy agendas. The smart innovations catalogue (*see Appendix i*) and use cases show the potential for municipalities to increase their bicycle share by making the mode more attractive through improved routing, increased comfort, and safety as well as information and parking provision. Ultimately, making cycling more attractive through ITS.

Empowering & mobilizing communities

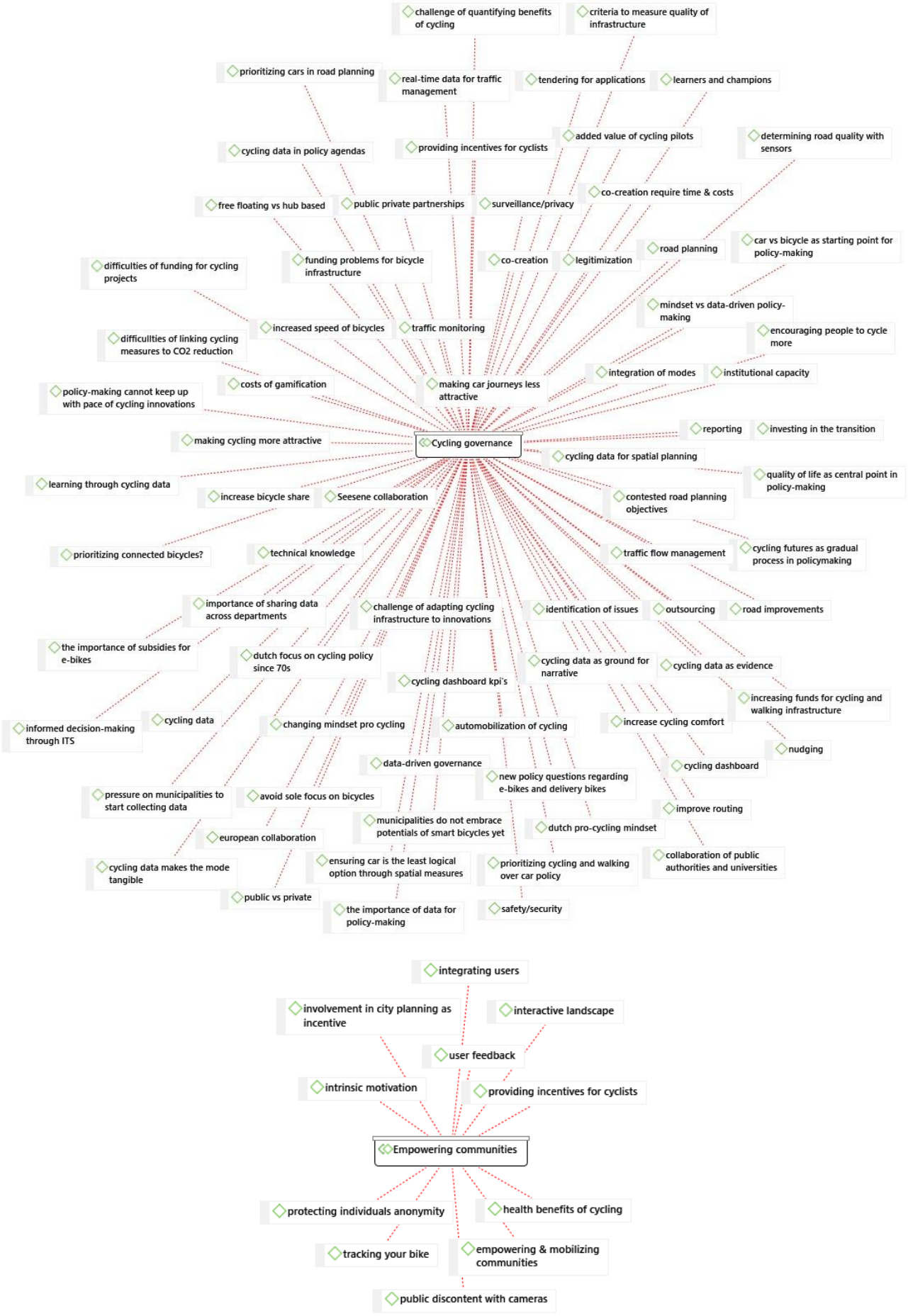
The emerging interactive landscape between cyclists and their spatial environment opens up new opportunities for public authorities to empower and mobilize communities. Therefore, provide a chance to *'involve people earlier into traffic planning'* (Interviewee, 9). Numerous smart cycling innovations enable cyclists to provide feedback or share their observations regarding topics such as road quality, quality of cycling infrastructure or perceived safety at intersections. According to several interviewees this interactive landscape can have benefits for planning of urban mobility systems.

'If people are involved in data collection and feedback provision regarding the infrastructure, their perspective can be part of the planning and construction process', states interviewee 8.

The integration of the user perspective into planning can help public authorities to create cycling infrastructure in accordance with cyclists needs, thus make cycling more attractive, helping authorities to achieve increased bicycle shares and ultimately a more sustainable mobility system. *'This really opens up a new space of interaction between cyclists and policymakers',* claims Interviewee 3, a mobility consultant from the Netherlands (Interviewee, 3). Additionally, the involvement in planning processes can be used by public authorities as an incentive for cyclists. If cyclists obtained the opportunity influence the planning process with their feedback, they could potentially feel empowered and more likely to accept spatial interventions through increased transparency in the process. Future research could investigate the potential of this interactive landscape to increase bicycle share as well as perceived levels of empowerment of citizens in urban mobility planning processes.

The interviews with mobility experts that smart cycling innovations and the integrated opportunities of cycling data collection influence cycling governance in several ways: (1) increase visibility of cycling as a mode, making it tangible, (2) the development/availability of real-time dashboards provide legitimization and informed decision-making when organizing cycling in the urban mobility system, (3) increased potential of funding for cycling infrastructure and pilots due to legitimization through data, (4) potential of making the mode more attractive through ITS and (5) empowering and mobilizing communities by offering the involvement in city planning as incentive for cyclists.

Code Network: cycling governance & empowering communities



Cycling & future smart mobility systems

It has become a well-established aim across Europe to reduce car dominance, whilst ensuring sustainable mobility and liveability. Therefore, this research explores the potential of smart cycling innovations in amplifying the role of cycling as active mode in future smart urban mobility systems. The European Commission claimed the need for the development of smart, green, and integrated transport solutions through four lines of activities: (1) resource efficient transport that respects the environment, (2) better mobility, less congestion, safety & security through ITS, (3) global leadership of EU transport industry and (4) research & forward-looking activities for policy making (European Commission, 2020).

How can smart cycling innovations contribute to these four lines of activities, and thereby contribute to the development of smart, green and integrated transport solutions?

(1) Cycling as active mode of transport is a healthy and resource efficient way of traveling from A to B, it is however difficult to link cycling measures directly to CO2 emission reduction, an indicator which is often used in urban sustainability agendas. *'Cycling is healthy, is not energy consuming, is not polluting, it's got a lot of benefits to it. But those benefits are far more difficult to calculate and graph'*, states interviewee 8 (Interviewee, 8). Therefore, municipalities link their ambitions of lowering CO2 emissions with increasing the urban bicycle share. Following the logic of decreasing urban car trips whilst increasing the number of trips taken by bike in the urban environment.

'If you look at CO2 reduction in mobility, you want to reduce the amount of cars on the road, so what we're trying to do is to make cycling easier and more attractive' (Interviewee, 11).

Smart cycling innovations aim to make cycling more attractive through reductions in travel time, improved routing, gamification, increased safety/comfort and facilitated parking, as shown in the smart cycling innovations catalogue (*see Appendix i*) and data types & use cases. '*We want to make it more accessible to cycle, we want the travel time to go down'*, claims interviewee 10, mobility planner from Denmark (Interviewee, 10). Interviewee 8, a mobility advisor in a Dutch municipality goes even further stating that '*We are doing everything, so that no one has a reason not to cycle'* (Interviewee, 8). Hence, clearly prioritizing cycling over car in transport policy, whereas smart cycling innovations provide the legitimization. '*We have to use data, to put the car in second place'*, emphasizes interviewee 10 (Interviewee, 10). Thus, by making cycling more attractive through smart innovations, as well as increasing visibility of cycling as a mode through data and dashboards, public authorities have a powerful tool towards the development of a more resource efficient and environmentally friendly urban mobility system. Whilst actively working towards the objective of the European Union to reduce dependence on fossil fuels (European Commission, 2020).

(2) Less congestion and improved safety & comfort are perhaps the most prominent contributions of smart cycling innovations to future urban mobility. Especially road safety hinders many people from cycling regularly. Interviewed experts agree that smart solutions that help to improve road safety will have the biggest impact in amplifying the integration of cycling into the urban mobility system. Interviewee 3 a mobility consultant expects smart cycling innovations and ITS technologies to make cycling *'safer and increase efficiency of traffic flow'* (Interviewee, 3). Additionally, innovations like intelligent green waves for cyclists would very much make traffic more efficient, and safer whilst decreasing congestion, he adds (Interviewee, 3). Innovations within the category *facilitate routing* & *Improve speed*, show the ITS potentials of cycling as a mode.

The Antwerp BITS-pilot on 3D-camera technology shows the potential of smart cycling infrastructure for road safety, integrated traffic management and spatial planning. The camera monitors traffic at a specific intersection, dividing up road users according to modes. Every individual trajectory is registered with speed and time. The technology is able to track near incidents among road users as well as provide insights into the effective use in comparison with the desired use as intended in the

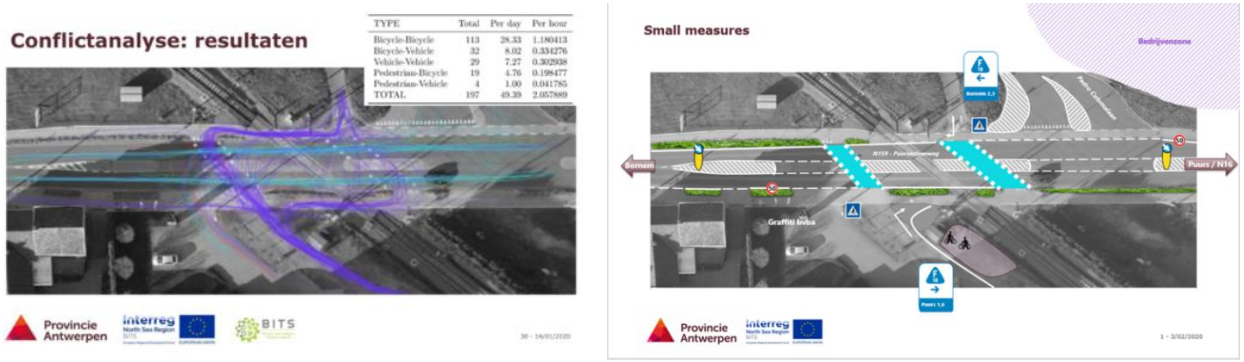


Figure 10: Antwerp BITS-pilot (BITS, 2020, published by CIE)

design of a specific intersection. Interviewee 2, a GIS expert involved in the project, realized that '*cyclists didn't use the markings that were on the road because it would actually force them to cross the railway track at an awkward angle'* (Interviewee, 2). Hence, cyclists would deviate from the intended route, increasing risk of accidents with other modes. The displayed data was used to implement measures aiming to improve safety, traffic flow and integration of modes. *'We will do re-measurements and see how behaviour has changed'* (Interviewee, 2). Thus, enabling traffic planning and integration of modes become an iterative process helping authorities to improve the urban mobility system bit by bit.

(3) The aim of the European Commission to reinforce the competitiveness and performance of European transport industry and a mobility system is supported by interregional collaboration within the BITS project. Especially the fact that the project is constituted of regions which already show a high bicycle use (NL, DK, BE) or have ambition to increase bicycle use (UK, DE), highlights the collaborative nature and supports the objective of collective learning within the European transport industry. *'The fact that there is an EU project on this topic is promising, it is something in the correct direction*', says interviewee 2 (Interviewee, 2). Authorities engaging in co-creation activities with commercial partners and innovators push the boundaries for new smart innovations developed within Europe, reinforcing the EU's competitiveness. Co-creation activities are especially relevant for smaller municipalities with less institutional capacity and technical knowledge. *'You don't buy it, but you make it together. And I think that is going to be a good solution'*, states interviewee 1, a mobility expert from Belgium (Interviewee, 1).

(4) Moreover, the BITS contributes to the fourth line of activities, research and forward-looking activities for policymaking, through the development of a European Cycle Data Hub. Described by interviewee 2 who is involved in building the platform as *'European crossroad for cycling data'* (Interviewee, 2). It is aimed to combine over 100 cycling related datasets on the platform so that European policymakers, commercial partners and research institutes can find them on the hub. It is hoped that the Cycle Data Hub will further increase visibility of cyclists in statistics and ITS related future mobility systems.

'We need to be present as pedestrians or cyclists in this broader mobility context because they will not take us into account, so our data should be there as well' (Interviewee, 2).

The collaboration between public authorities and knowledge and research institutions is a prime example on how smart cycling innovations, cycling and ITS can foster the objective of the EU to support improved policymaking and promote innovations (European Commission, 2020).

Challenges for municipalities

Despite the apparent benefits of smart cycling innovations in amplifying the role of cycling in future urban mobility systems, the interviews revealed many challenges connected with these innovations. The development and implementation of smart cycling innovation require a significant amount of institutional capacity and technical knowledge which can be a challenge, especially for smaller municipalities. '*We do not have the personnel, nor the money to develop our own'*, says interviewee 1 a mobility expert from the municipality of Brugge (Interviewee, 1). *'It starts with the private sector, companies who come up with ideas who supply municipalities which want to collect data, but don't have the knowledge or the money to create their own apps or other systems'*, adds interviewee 11 from the municipality of Zwolle (Interviewee, 11). Therefore, public authorities need to outsource these activities or engage in co-creation with commercial parties. *'It is going to be one of the key things we want, the co-creation'*, states interviewee 1 (Interviewee, 1). However, co-creation processes require a significant amount of time and costs, as public authorities need to engage in public tendering processes, meet and communicate back and forth with commercial parties, until a satisfactory product can be achieved. '*You need a lot of time and it can be quite costly'*, says interviewee 1 (interviewee, 1). It could however be a very interesting solution or potential for smaller municipalities to *`get a grip on some innovations´*, adds interviewee 1 (Interviewee, 1). As mentioned above in the data and cycling section, public authorities need to be very careful engaging with companies that offer data collection with commercial intents, as compliance with open data formats and European General Data Protection Regulation should be of utmost importance.

Data & Infra: chicken & the egg

For municipalities in countries which are just on the brink to become mature cycling environments such as UK and DE the challenge can be that the cycling infrastructure network is poorly developed. This means, that people are less likely to cycle and if these municipalities want to start engaging in data collection the low numbers of cyclists might not provide strong legitimization to argue for more investments in cycling infrastructure. '*We need the cyclists to prove that we need the infrastructure. But cyclists won't cycle because they want the infrastructure'*, pinpoints interviewee 5 (Interviewee, 5). Investing in this transition also requires public authorities to adapt a pro cycling mindset. Mature cycling environments such as NL, DK and BE are in a privileged position, as they have been focusing in their urban mobility policy on walking and cycling since the 70s & 80s. Thus, are miles ahead in terms of infrastructure provision and the cultural embeddedness of cycling. Smart cycling innovations and data will however produce crucial insights into a more efficient cycling infrastructure development and there is a certain pressure on municipalities across Europe to start collecting cycling data to accelerate the transition towards sustainable mobility and liveability in urban areas (Geurs & Van Wee, 2006; Ewing & Cervero, 2010).

Keeping up with pace of innovations

The growing number of smart cycling innovations and changing speed limits of bicycles as well as number of cyclists on the streets have municipalities struggling to keep up with the pace of innovations.

'A drawback of attracting more bicycles, is providing more space for those bicycles and making it safe for different types of bicycles like e-bikes, speed pedelecs, cargo bikes etc.', (Interviewee, 2).

These innovations will require public authorities to proactively prevent conflict among road users in the urban environment to guarantee safety and efficiency of traffic flow. '*A drawback is doing this fast enough, and having the money to do that*', adds interviewee 2 (Interviewee, 2). There is consensus among participants that it will be a challenge for mature as well as non-mature cycling environments to anticipate the growing numbers of cyclists and increased speed limits. Several mobility experts highlight the importance of avoiding a sole focus on the bicycle in urban policy agendas and instead focus on all active forms of mobility.

'We have to be careful not to make the same mistake as we did with the cars in the past,' warns interviewee 1, mobility expert from Belgium (Interviewee, 1). '*We should not forget pedestrians, as the first and last part of our trips is almost always by foot'*, adds interviewee 11 (Interviewee, 11)

It can be concluded that engaging with smart cycling innovations can offer potential benefits in contributing to the European Union's objective of developing smart, green and integrated mobility systems. (1) making cycling more attractive and accessible through smart cycling innovations and ITS municipalities can increase the urban bicycle share, (2) improve the efficiency of traffic flow and management whilst increasing road safety and improving integration of modes, (3) data and innovations accelerate co-creation processes and collaborative learning across regions, hence foster the competitiveness of the European transport industry and (4) enable research and data-driven policymaking to produce knowledge and more efficient urban mobility systems.

These contributions do however bring up various challenges: (1) lacking institutional capacity and technical knowledge of public authorities to seriously engage with smart cycling innovations and all the related implications of infrastructure development and data collection and analysis, (2) the difficulties for non-mature cycling environments to implement smart cycling innovations without existing fundamental cycling infrastructure, and (3) the challenge for municipalities to keep up with the pace of innovations in terms of policymaking, road planning and division of space among different road users.

Code Network: Smart mobility system

5. Discussion

The following chapter provides a synthesis of the results and academic literature explored in the theoretical framework. First, sub-questions and the resulting hypothesis are discussed. Secondly, the main question of this research is answered. Lastly, recommendations for non-mature cycling environments aiming to amplify the integration of cycling as active mode into their smart urban mobility system are formulated.

This research contributes to the only recently emerged scholarly debate about smart cycling futures and potential new pathways in cycling governance and urban sustainability agendas (Brömmelstroet et al., 2020; Nikolaeva, 2019). It was identified that the smart bicycle is heavily underrepresented in working papers regarding smart urban mobility programmes of the European Commission (European Commission, 2020). Therefore, this research aimed to obtain a better understanding of how emerging smart cycling innovations potentially amplify the integration of cycling as active mode into smart urban mobility systems. Due to the short-lived nature of smart cycling innovations in general there is a limited amount of research and theories exploring their influences and implications. Which further stresses the apparent knowledge gap as well as urgency to conduct this research. The central question this research aimed to answer was:

What is the role of smart cycling innovations in amplifying the integration of cycling into the smart urban mobility system of medium sized cities in Europe?

To answer this question four sub-questions were formulated:

1. What is the current status-quo of smart cycling innovations in Europe?
2. What is the influence of mobilizing cycling data on cycling as active mode in urban mobility systems?
3. What is the influence of smart cycling innovations on how cycling is organized and governed as mobility mode?
4. How can smart cycling innovations contribute to the development of future smart mobility systems?

Several assumptions, based on existing literature where made prior to the data collection process, leading to the formulation of four main hypotheses:

1. Mobilizing cycling data can amplify the integration of cycling as active mode into the smart urban mobility system. (H1)
2. Through mobilizing cycling data new challenges of data privacy arise. (H2)
3. Smart cycling innovations influence the way cycling is organized and governed as a mobility mode. (H3)
4. Smart cycling innovations contribute to the development of smart, green and integrated mobility systems. (H4)

The following section will discuss each of these hypotheses in turn by providing a synthesis of existing academic literature and combined results of the smart cycling innovations catalogue and in-depth interviews with mobility experts.

H1. Mobilizing cycling data can amplify the integration of cycling as active mode into the smart urban mobility system

The underrepresentation of cycling in urban transport planning has been justified with poor quality of data in the past (Koglin & Rye, 2014). An increasing amount of scholars have tried to come up with modelling theories to measure bicycle traffic, mostly trying to increase visibility of cycling as a mode by collecting qualitative data on travel behaviour through surveys (Iacono, 2010).

The development of the smart innovations catalogue, content analysis of reports and commercial websites of innovations as well as data collection through interviews with mobility experts revealed data as a central topic to smart cycling futures. Supporting the premise that smart cycling innovations amplify the integration of cycling into the wider smart mobility system (Nikolaeva et al., 2019). Smart cycling innovations enable the collection of cycling data, increasing the visibility of cyclists in statistics and dashboards, thus proactively working against what Koglin (2015) coined as the marginalization of cycling in transport planning, not only in terms of physical infrastructure but also in the digital environment of modern ICT developments around mobility (Koglin, 2015).

The categorization of innovations by data types highlighted several use cases specific to each data type. According to Rogers & Papanikolopulos (2000) live point data would be enable immediate response and spatial interventions. Findings of this research support and build upon this claim. The smart innovations catalogue revealed that live point data is and can be used to obtain real-time insights into urban traffic flow, as shown in the example of a conflict analysis done at a specific intersection through a 3D-thermocamera. However, its primary use-case was the establishment of baseline data by collecting cycling data, helping municipalities to build dashboards with cycling related KPI`s. Hence, live point cycling data is increasingly laying the foundation for authorities to monitor and predict movement and behaviour in the urban environment (Andrew, 2020). Monitoring of cyclists through life point data enabled authorities to increase their safety & comfort whilst facilitating routing, speed and parking.

Journey data produces information regarding the origin, destination and travel time of an individual journey (Romanillos et al., 2015). Similar to GPS data, which is usually collected through a smartphone or similar device. Smart cycling innovations studied in this research reveal more potentials of journey cycling data for the urban mobility system. Innovations enable authorities to collect very specific ride insights while documenting an individual cycling journey, including data on movement patterns, speed & dwell times, road & pavement quality and air quality and temperature measurements. By enhancing the bicycle with smart innovations or gadgets which enable these new forms of journey data collection, these gadgets increase the relevance of bicycles as tools to improve the urban mobility system through data-driven governance. The potential for public authorities, if hundreds or thousands of bicycles become data collection devices and provide real-time insights into the condition of infrastructure and the public space are ground-breaking. Gamification opportunities and the newly emerging interactive landscape between cyclists and their spatial environment (smart infrastructure), combined with tracking & tracing functions of innovations make the integration of cyclists perspective into urban mobility planning possible. Thus, contribute to a better understanding of cycling research while simultaneously increasing the interest of participants as their movements become recorded and classified (Elliot & Urry, 2010). Therefore, improve the iterative nature of adapting the urban environment and its mobility system. Creating new narratives around smart cycling technology, liveability and environmentalism (Nikolaeva, 2019).

H2. Through smart cycling innovations and mobilizing cycling data new challenges of data privacy arise

The process of mobilizing cycling data has to be seen critically as in a city where every movement and journey is tracked, issues around surveillance and data privacy arise (Büscher, 2019). In the prior section it has been highlighted that smart cycling innovations, applying journey or GPS data can collect and process the individual journey, including location-related data. The potentials and benefits for gaining real-time insights into cycling specific KPI`s in the urban realm have been worked out. But what if journey or GPS data can be linked to a specific, identifiable individual? Are we not trading the individual's right for data privacy under the umbrella of enhanced data-driven mobility planning?

Following the claim of Schwanen (2015) that smart applications will become the key means through which transport systems will be governed and regulated, these questions become more relevant than ever. This research revealed that smart cycling infrastructure used to monitor and count cyclists in the urban realm, simply gather data about the number or the speed of bicycles passing by. Thus, the specific input is connected to an object, the bicycle, not to an individual, the person riding that bicycle. Therefore, simple counting cycling data is always anonymous data.

More sophisticated devices such as 3D-traffic camera technology would potentially enable identification of individuals. The resolution of the displayed image is deliberately low to counter this identification potential. Interviewed mobility experts assured that all implemented innovations are in line with the GDPR of the European union and if personal data was collected through an application, the data was anonymized. The combination of several datasets might however enable identification of the individual. Even if this is of no interest to any public authority, it sparks discussion about ownership and management of cycling mobility data (Koglin & Rye, 2014). A solution brought forward by interviewees are contractual agreements about data ownership when collaborating with commercial parties and provide full transparency towards the tracked individual by providing fully anonymised open data formats freely available to everybody. This is however a process academics and data experts should be observing carefully, as this research clearly shows that new technological developments and tracking potentials through AI-enhanced systems will only increase. Supporting the thesis of Finck et al (2020) that the transformation of urban mobility, the widespread sensing of peoples movements, coupled with advancements in analytical capabilities will become a significant challenge for society (Finck et al., 2020).

H3. Smart cycling innovations influence the way cycling is organized and governed as a mobility mode

The prior sections made clear how central data is to smart cycling innovations. Cycling has generally been seen as offline mode, which might change due to systematic data collection processes, potentially influencing the way cycling is governed and organized as mobility mode (Nikolaeva et al., 2019).

This statement is in line with the findings of this research. The newly emerging cycling data collection possibilities increase the modes visibility in statistics and datasets, thus make it tangible. The availability of real-time dashboards changes the way policymakers organize cycling in the urban environment as they can implement spatial interventions based upon cycling data and obtain

legitimization for cycling policies and funding of infrastructure. Data-driven governance is the new form of organizing and planning cycling in the urban environment and makes the interaction with traffic planning/monitoring in real-time possible. The concept of automobilization of cycling was brought up by Nikolaeva et al (2019), referring to the promise of smart innovations granting cyclists with similar privileges as car drivers. The content analysis of the smart cycling innovations catalogue showed that there are several categories of innovations which specifically address this concept (e.g., Improve speed, facilitate routing). Interviewed mobility experts apply these innovations to make cycling more attractive through decreasing travel times, increasing comfort as well as safety. In other words, they make cycling more attractive through ITS. The systematic and constant data collection makes the evaluation of effectiveness of newly implemented measures feasible, providing ground for informed decision-making and more sustainable long-term planning.

The potential of empowering and mobilizing communities by offering the involvement in city planning as incentive for cyclists have been highlighted in the section about cycling data. This might open up new ways of temporarily increasing institutional capacity, as cyclists actively and passively contribute to spatial and mobility planning activities.

H4. Smart cycling innovations contribute to the development of smart, green and integrated mobility systems

The European Commission defined the smart city as a place where *`traditional networks and services are made more efficient with the use of digital and telecommunication technologies for the benefit of its inhabitants and business*' (Publications Office of the European Union, 2014). Smart cycling innovations analysed in this research have been developed and implemented under the same premise, to improve efficiency of traffic flow and make cycling as a mode more attractive through ITS. The development of the smart cycling innovations catalogue highlighted the use cases of smart bicycle futures and the potentials of the bicycle as smart mobility mode.

The European Union acknowledged the importance of reducing greenhouse emissions of urban mobility systems with the establishment of a strategy for low-emission mobility (European Commission, 2016). A question this research aimed to explore is how smart cycling innovations can contribute to efficiency and sustainability of urban mobility systems.

Analysis of interviews made clear that it is very difficult to link cycling directly to CO2 emission reduction, a parameter usually applied in urban sustainability agendas. Thus, the general idea of public authorities is to decrease urban car trips whilst increasing bicycle shares. It has been shown that smart cycling innovations and its ITS potentials can be used by public authorities to make the mode more attractive through increased safety provision, facilitated routing leading to increased speed and lower trip length of the urban bicycle journey, rewarding or prioritizing cyclists in the urban traffic flow, mutual information provision between cyclist and their spatial environment to increase comfort and have the opportunity to provide user feedback. Thus, contributing to the European Commission's objective of building a low-carbon and sustainable transport for a greener urban environment (Horizon, 2020).

The European Commission further stressed the need for integrated urban mobility systems (Horizon, 2020). Results of this research highlight the potentials of smart cycling innovations regarding increasing the visibility of cyclists in the public space. Hence, they do not only support making cycling

as mode tangible but enable better integration of modes at specific intersections through live point data. Make the bicycle a potential data collection device which can provide detailed insights into urban traffic flow, infrastructure and air quality, near incidents as well as other KPI`s relevant to improve the urban mobility system.

Main Question: What is the role of smart cycling innovations in amplifying the integration of cycling into the smart urban mobility system of medium sized cities in Europe?

Smart cycling innovations can amplify the integration of cycling as active mode into the smart urban mobility system in several ways. Koglin & Rye (2014) highlight the existence of power relations in urban traffic space, claiming the need for bicycle planning to create spaces where cycling is not marginalized (Koglin & Rye, 2014). In order to successfully integrate cycling into the smart mobility system, it needs to be visible. Visible in the physical environment and visible in developments around ICT. Infrastructure-based smart cycling innovations identified and analysed in this research demonstrate the ITS potentials for cycling as a mode and further amplify the integration of cycling into developments around ICT. In their theoretical approach for bicycle planning Koglin & Rye highlight the physical movement from A to B through provision of cycling infrastructure without obstacles and free and safe flow for cyclists, as crucial (Koglin & Rye, 2014). Research findings have shown that smart innovations contribute positively to improved routing as well as safety and comfort for cyclists. Thus, these smart cycling innovations enhance safety and flow for cyclists through the urban environment.

Smart cycling innovations produce data or enable the collection of different types of data, which increases the modes visibility in datasets, dashboards and statistics, thereby, make the mode tangible in processes around urban ICT developments. Furthermore, the potentials of smart bicycles as data collection devices within the urban environment could benefit and improve efficiency of measures/spatial interventions to enhance integration with other modes and ultimately improve safety of individuals as well as the overall traffic flow. Traffic flow theory has been the foundation of justifying construction of urban highways to accommodate increased motorised traffic (Nuhn & Hesse, 2006). Treiber & Kesting (2013) hypothesize that traffic flow theory could be adapted to fit bicycle traffic in the future as it would exclusively be applied for motorized traffic. Findings of this research verify this hypothesis, as smart cycling innovations and mobilization of cycling data enable policymakers to display and calculate cycling traffic capacities and cycling specific KPI`s to justify funding as well as construction of cycling infrastructure. Thus, countering the argument about power and knowledge brought forward by Marcuse & Flyvbjerg, stating that the prioritization of motorized traffic in transport planning could be attributed to measurable knowledge which builds on positivistic theories (Flyvbjerg, 1998; Marcuse, 2002).

Koglin & Rye (2014) further stress the need for positive representations of cycling and the creation of shared meaning which would go beyond class, gender, ethnic and other boundaries in bicycle planning (Koglin & Rye, 2014). The emerging interactive landscape and the opportunities of mobilizing communities through smart cycling innovations have the potential to initiate a process of empowering communities and creating a shared meaning by fostering the narrative of citizens collectively reclaiming the public space through active forms of mobility such as cycling and walking. A narrative where the individual cyclist can contribute to urban liveability and sustainability agendas by cycling as well as being engaged through the interactive landscape. According to Pucher & Buehler

(2007) the representation of cycling in a city is positively influenced by bicycle-friendly infrastructure and the positive portrayal of cycling as a mode by public authorities (Pucher & Buehler, 2007). Smart cycling innovations and the emerging interactive landscape can help public authorities to proactively engage with cyclists, reward them for cycling or providing feedback. Therefore, smart cycling innovations can ensure that '*cyclists' experience, and practice of mobility, is more systematically reflected in the infrastructure that is planned and build*' (Koglin & Rye, 2014, p. 220)

Recommendations for municipalities

Throughout the prior sections this research has highlighted the potential of smart cycling innovations in amplifying the role of cycling as active mode into the smart urban mobility system. This research further aimed to address the academic and societal relevance of facilitating the transition of medium-sized cities to more sustainable and liveable urban environments with a focus on active modes of transport. Therefore, this following section presents six recommendations for municipalities to amplify the integration of cycling into their urban mobility system through smart cycling innovations.

1. Establish an efficient network/basis of mobile or fixed bicycle counters
    a. Different categories, from simple tier one counters to sophisticated tier three innovations which collect cycling insights through live point data
    b. Ask the question: What exact insights do we need for a better integration of cycling into the urban mobility system? Which intersections provide the best overview of urban bicycle trips?
    c. Identify and be aware of power relations among modes in the urban environment.
2. Build a cycling dashboard where all cycling related KPI`s are displayed. The dashboard should be open data-based and accessible to everyone. The dashboard KPI`s can be linked to mobility policy objectives, thereby improving legitimization for measure as well as transparency of policymaking activities. Thus, also lead to increased funding for cycling infrastructure and pilots.
    a. If there is not sufficient institutional capacity or technical knowledge, engage with commercial parties through co-creation.
        i. Be aware about issues around privacy & data ownership. Communicate this transparently to citizens to increase awareness and generate understanding.
3. Engage at least one (depending on the size of city) GIS expert who can make sense of the collected data and translate dashboards and maps into data-driven policy implementations.
4. Use this data to push for investments/funding for cycling infrastructure and legitimize the sustainable urban mobility transition.
    a. Identify potential funding possibilities by the European Union for cycling & ITS related developments.
5. Become part of the European Bicycle Data Hub, by uploading the gathered datasets, learn from European best-practices and engage with so called champions from mature cycling environments
6. Proactively involve the citizens in smart cycling futures: Embrace the potentials of mobilizing communities through smart cycling innovations to improve the urban mobility system and to foster the narrative of citizens collectively reclaiming the public space through active forms of mobility such as cycling and walking.

6. Conclusion and reflections

Against the background of the impacts of current urban mobility on our environment, pressing issues around globalization as well as the marginalization of cycling in European smart city developments, this research aimed to explore smart cycling innovations and their potential role in amplifying the integration of cycling in smart city futures. Therefore, also investigate their contribution to broader processes of the crucial sustainable urban mobility transition.

The development of an updated smart cycling innovations catalogue highlighted the ITS potentials of the bicycle, smart cycling infrastructure and emergence of the interactive landscape between cyclists and their spatial environment. Content analysis of innovations and expert interviews resulted in the formulation of specific use cases per innovations and data types. Providing valuable information for public authorities and policymakers starting to engage with cycling as smart/connected mode in their urban mobility system. Analysis of interviews further revealed cycling data as central topic of smart cycling futures, making cycling as mode visible in the physical as well as virtual environments. Opportunities are opened up to make the mode more attractive through ITS to increase the bicycle share, enable data-driven governance, informed decision-making and mobilize communities, among others. On the other hand, new challenges around cycling data emerge such as data collection, data ownership, data harmonization and broader processes of surveillance and personal data in a potential future smart environment where every journey is tracked or traced. Moreover, the contribution of smart cycling innovations towards the four lines of activities to develop smart, green & integrated mobility systems, formulated by the European Union have been worked out. Showing that smart cycling innovations can provide arguments for a more pro-active integration of cycling in future European strategies around smart mobility and ITS developments. Challenges of public authorities engaging with smart cycling innovation have been retrieved from the interviews to generate a deeper understanding regarding the barriers for public authorities aiming to amplify the integration of cycling into the urban mobility system. A synthesis of literature and results of interview and content analysis highlighted the potential of smart cycling innovations in amplifying the integration of cycling into the smart urban mobility system through: (1) demonstrating the ITS potentials of cycling, (2) increasing the modes visibility in the physical as well as virtual environment, (3) exploring the potential of smart cycling innovations to improve cyclists safety, comfort, speed, integration with other modes as well as efficiency of traffic flow, (4) showing the potentials of the smart bicycle as data collection device in the urban environment and (5) identifying the newly emerging opportunities in regards to the interactive landscape and its potential to initiate a process of empowering communities and creating a shared meaning by fostering the narrative of citizens collectively reclaiming the public space through cycling.

Methodological & personal reflection

The design of this research and its process resulted in several challenges, starting with the topic of smart cycling innovations itself. The domain does only have around 5 years of existence and is therefore does not provide an extensive amount of literature. This on the other hand made it such an important and interesting topic to study. The BITS project, its published documents and reports have been of great importance to obtain insights into the current status quo of smart cycling innovations in Europe.

At first the research design intended to study smart cycling innovations on the basis of a case study in Zwolle as the municipality is a frontrunner in cycling and ITS. However, I had doubts about being able to recruit enough interviewees for a qualitative approach and about the case study approach leading to meaningful results. Therefore, the BITS project was considered to explore smart cycling innovations and recruit interviewees. Contacting mobility experts from five different countries across Europe turned out to be a major challenge, as only the individuals actually involved in cycling and ITS related projects would be of interest. Ultimately reaching all participants through the Communications manager of the BITS project was successful.

The interview guide was developed based on operationalized concepts and tested in advance regarding its length and discussion flow. A test-interview with another researcher was done for this purpose. Due to the ongoing Covid-19 pandemic personal interviews where not possible, therefore several meeting tools were tested to evaluate which would be the best for interviewing, recording as well as storing the data. The online nature of interviews resulted to be beneficial for the process as it saved travel time, made scheduling and recording easier and improved overall efficiency of the data collection process. It could however also have influenced the interviews themselves as speaking through a webcam is very different from having a conversation in the same room. It should be stated that the results of this research are based on a limited amount of interviews and this small foundation of expert knowledge does influence reliability of this research. The results highlighted in this research represent a general exploration of the relationship of smart cycling innovations in amplifying the role of cycling as active mode in smart urban mobility systems. The BITS project and related pilot projects are still ongoing, which made a case study approach and complete evaluation in terms of effectiveness of cycling and ITS unfeasible. It would have been interesting to combine this qualitative explorative approach with the actual percentual change in the urban bicycle shares. A triangulation including quantitative methods would have strengthened the reliability of results. If I would do this research again in a years' time, I would conduct a case-study approach with triangulation to investigate how effective each pilot/project has been and how it actually contributed to bicycle shares and urban sustainability agendas. As many projects within the BITS are still ongoing, this was not an option. The domain of smart cycling innovations still bares many opportunities for future research and could be a crucial key towards our transition to sustainable urban mobility systems.

Personally, reflecting on the past six month it has been a very demanding process with highs and lows. Aligning the research approach/design to the questions I wanted to explore and the societal as well as academic knowledge gaps I wanted to contribute to, was a complicated endeavour. It was an iterative process with many adjustments and learnings along the way. The scale of this research heavily exceeded my expectations and I realized that the development of the smart cycling innovations catalogue itself could have been a master thesis. It took weeks to develop and categorize innovations per data types and categorize. With more time and people, the smart cycling innovations

catalogue could have been visualized to provide a very understandable and visually pleasing brochure for medium-sized cities which could be used to improve urban mobility planning. I would like to pursue this idea in the future, both in academia and practice, as I am more than confident in the sustainability potentials of smart cycling innovations for mobility systems in medium-sized cities.

The home-office situation made it challenging to stay motivated and productive every day, especially in the early stages of the research. Not fully having the grip on the line of argument caused a lot of frustration in the beginning. At some point it all came together which was a major breakthrough and felt empowering. The personal engagement with all these mobility experts who are at the forefront of cycling and ITS and seeing their passion for boosting urban sustainability and liveability agendas through cycling was very inspiring to me. Helping to further develop my knowledge and expertise in urban mobility and cycling and increasing my professional network of cycling advocates across Europe. The positive feedback, and appreciation I received from participants reassured my own passion and interest in active mobility and pressing issues around urban mobility and I hope I will be working with some of these people in the future.

Future research

This research has an explorative character, adding to the recently emerged academic domain of smart cycling futures (Nikolaeva et al., 2019; Brömmelstroet, 2020), whilst being a starting signal for further research on smart cycling innovations and their potential for urban mobility, data-driven governance and other narratives around smart technology and liveability.

Firstly, this research has shown that smart cycling innovations enable data collection of various and very specific KPI`s of the urban mobility system, whilst displaying them through dashboards in real-time. What is the potential of bicycles as systematic data collection devices within the urban environment? What is the implied potential for spatial and urban mobility planning? What could be their role in broader processes of sustainable urban transformation?

Secondly, the emerging interactive landscape between cyclists and their spatial environment could be a promising new field for adaptive and participatory planning approaches. The interactive landscape could be explored from a variety of perspectives, opening up a whole range of questions. Future research could explore how this mutual information provision influences the perceived empowerment of citizens in spatial planning. Does it influence acceptance towards spatial interventions? Does the engagement with the spatial environment through the interactive landscape influence place identity or even proactive behaviour in urban participatory planning processes? Could further developments of the interactive landscape change narratives around cycling as a mode? And what is the potential for public authorities in engaging with citizens through the interactive landscape?

Thirdly, this research described the importance of open data formats when displaying cycling and mobility data to foster regional collaboration, transparency and mobilizing communities. Future research could look into the potential of open data formats for community involvement in transport planning. Can collaborative open data formats contribute to lacking institutional capacity of smaller municipalities aiming to boost their active mobility network?

Fourthly, interviews with mobility experts from different countries/regions across Europe revealed the upcoming challenge of data harmonization. A topic of rising importance as municipalities

increasingly collect mobility data which needs to be shared across departments, provinces, regions and countries. Therefore, future research could explore how to tackle data harmonization challenges to foster interregional collaborations and learnings through mobility data.

The apparent potential of smart cycling innovations opens up numerous new opportunities for research. Promising research, which might bring us closer to the development actual smart, green and integrated urban mobility systems.

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Appendices

I. Smart cycling innovations catalogue

The following table is a summarized version of the smart cycling innovations catalogue. The full excel file contains the categories per theme as well as data types and is stored by the researcher and can be obtained on demand.

System name	Description	Link	Infrastructure-based	Bicycle data	Information provision to	Interactive ITS for cyclists	Other	Country
Mytripper	An RFID-tag is placed in one of the wheels of a bicycle. The tags are helpful when monitoring of the commuting behaviour of a selected group of people, e.g., employees, is required.	https://www.mytripper.nl		x	x			NL
Camera (video)	With only a camera, flow characteristics can be determined. In combination with other techniques (wi-fi, Bluetooth), other aspects can be established as well.	https://connectionsystems.nl/index.php/en/methods-articles		x				NL
Radar	With only radar, speed measurement and classification of mobilists is possible.	https://connectionsystems.nl/index.php/en/methods-articles		x				NL

Wi-Fi-detection	Wi-Fi can scan Mac-addresses of mobile (smart)phones for multiple purposes like track-trace, waiting/travel time and intensities.	https://connectionsystems.nl/index.php/en/methods-articles		x				NL
Bluetooth-detection	Bluetooth can scan Mac-addresses of mobile (smart)phones for multiple purposes like track-trace, waiting/travel time and intensities.	https://connectionsystems.nl/index.php/en/methods-articles		x				NL
Hybrid Cycle Data Radar	The Hybrid Cycle Data Radar is adjusted on location after installation and activated by a smartphone. After a successful quality check, the radar is registered as active in the central system. Built-in GPRS communication makes data reception and online remote communication possible. Via a user-friendly web-based interface, the bicycle mobility data can be monitored, viewed and analysed 24/7 from a workstation or tablet by means of a user login. The data provide 24/7 insight into bicycle traffic flows and others such as e-bike, speed pedelecs, light mopeds, etc. on bicycle paths. The online web-based interface provides real-time the desired data about how many vehicles are riding on the cycle path at what speed, in which direction and at what time. The use of the Hybrid Cycle Data Radar provides a better insight into bicycle traffic flows and as a result the policy in the field of bicycle mobility and infrastructure can be better geared to the actual needs and in particular for the safety of cyclists.	https://cycledata.nl/	x	x			x	NL
GSM-tracker	The bicycle can be connected to an app in the smartphone. This means the owner can always find it where he/she left it. Or where someone else left it. Via the app, users can learn how many kilometres they drove. Moreover, the average speed is displayed.	https://www.vanmoof.com/en_nl/smart-bikes			x			NL
Actime bicycle counter	Standalone camera that counts cyclists in both directions, with an accuracy of 98 percent.	https://www.actime.nl/diensten/verkeersmetingen-		x				NL

		fietsers/						
Diverse apps, e.g. MaxS, or 'Ritje van de zaak'	With the apps of Innovatory, technology is available for collecting bicycle data. The apps aren't developed for this purpose, so their effectiveness is limited. Innovatory has the know-how to develop a dedicated app for collecting bicycle data via smartphone.	https://innovactory.com		x	x			NL
Many apps, e.g. Routenet, Locator	Routenet helps customers with their navigation. This can also be used by cyclists. Locator helps customers of companies to travel to the companies' offices. The focus is on persons in cars. It is not clear if data can be retrieved. Focus is on users in cars.	https://www.locatienet.com		x	x			NL
SESAMO - SEnsing and SAmling for MObility	Sesamo is an app that facilitates the registration of trips of individual cyclists. Moreover, with Sesamo qualitative data can be collected, as users can be approached via Sesamo with questionnaires.	www.mobidot.nl; www.sesamo.nl		x		x		NL
Fairy trail	Fairytrail has an impact absorbing surface made of rubber and is mixed with fluorescent and glow-in-the-dark effects. It makes places where we move, sports and play safer and more beautiful. It goes against light pollution. Made in a concrete surface, Fairytrail is ideal for use on squares, pedestrian areas, cycle paths and hiking trails.	https://www.heijmans.nl/nl/fairytrail/	x					NL
Human	With the Human-app, tracking of movement is possible. The app facilitates comparison with other individuals. The aim is to inform individuals about their physical activity. The app hopes to enhance the physical activity of individuals.	http://human.co/index.html#		x	x			NL/ US
CrossCycle/ Give me Green	With the CrossCycle/Givemegreen-app, tracking of cyclists is possible. By using the app, a cyclist can be recognised by the system when he or she approaches a signalled intersection. It gives the opportunity to prioritize the cyclist when he or she arrives at the intersection.	https://dynniq.com/nl/producten-en-services/mobility/crosscycle/		x	x	x		NL/ US

Smart	By using SMART, Enschede municipality provides cycling challenge every month for two weeks. It started in March 2017 and is still ongoing. The focus of the app is on all travellers. The SMART app is used to register the mobility pattern of travellers through their smartphone. Based on the collected information, they are stimulated to use the 'active travel modes' such as cycling more often.	https://empowertoolkit.eu/ict-tools/ https://www.smartintwente.nl/		x	x	x		NL
Schwung	When cyclists approach a signalised intersection with an iVRI, the arrival of the cyclist is announced and the traffic lights turn green as fast as possible.	https://www.verkeerinbeeld.nl/nieuws/150317/schwung-lekker-snel-door-groen-zonder-iets-te-doen dankzij-de-app-schwung		x	x	x		NL

Ring-Ring®	With the Ring-Ring-app on the smartphones (iOS/ android) of citizens, cyclists are tracked (100% automatically) what distances and routes they cycle and how much carbon dioxide they have been saving in what weather conditions and how much time they are active. The cycle kilometres are the source of rewarding based on geographical area or in a specific private group or at shops and stores. These credits can be used to buy goods in local stores. Most used rewarding system with Ring-Ring in more than 6 cities/ regions in The Netherlands is cycling or collective community goals from a local citizen. This circular value allocation brings bottom-based consciousness about daily mobility choices and the opportunity to help local initiatives just to cycle. As an addition the cyclists can give feedback about their cycling experiences and about the road safety. The data (completely anonymised) about where, when and what time frames is shared to learn and innovate and improve the roads used and make it more convenient. Ring-Ring also implements Talking Traffic where cyclists with the app receive a green light in advance. Ring-Ring has a holistic approach that values a healthy mobility choice from 5 perspectives that all benefits from more cyclists. Think about: health, climate, public space, local economy and social interaction.	www.ring-ring.nu		x	x	x		NL
Bike sharing: Swapfiets	Swapfiets is a bike sharing / lease system. For a monthly fee, a cyclist can get their own Swapfiets. Swapfiets doesn't use a tracker so users can't be provided with information on their trips or where they can find their bicycle. They have a user app for navigation and reporting bike problems.	https://swapfiets.nl/				x		NL
Nazza Mobility driven by Intelligence	Bike sharing system, including app to open smart lock.	https://nazza.nl/		x				NL
Bicycle parking guiding system Utrecht (P-route fiets)	Cyclists get information on where they can park their bicycle in dedicated parking facilities in the city centre of Utrecht (not in public space). Also, information on the route to the location is provided. Therefore, they have to download an app (P-route Fiets) on their smartphone. The system registers empty spots in the parking	https://lumi.guide/en/smart-parking-management/		x	x			NL

	facility and communicates that information.							
Mezuro	Via GSM-data, HB-matrices of travellers are made. Data is derived from 5 million Vodafone-users in the Netherlands. Cyclists can't be determined in the data.	http://www.mezuro.com					x	NL
Traffic management of bicycle flow by camera-based speed and volume measurement adjusted by Bikesim simulation	The Bikesim model was in Copenhagen connected to real time data streams from mobile camera-based bicycle volume sensors and from traffic lights on a bicycle corridor. A stable and accurate travel time could be predicted using Monte Carlo simulation using these data. It facilitated traffic management of the flow of cyclists on a busy corridor in the city.	https://www.technolution.eu/nl/mobiliteit/155-bikesim-fietsverkeer-in-beeld-met-slimme-simulatie.html		x				NL
Flexradar	Flex Radar reliably and accurately detects bicycles, differentiates between a bicycle and a motorized vehicle at the stop bar, provides bicycle counts in dedicated bicycle lanes, and provides the most accurate parking space occupancy data available. Flex Radar installs as a supplement to existing wireless detection systems, lowering costs by leveraging existing infrastructure and communications.	https://sensysnetworks.com/products/flexradar		x				US
See.sense	Sees.Sense sensors collect various ride insights: on movement patterns, speed and dwell times, road roughness, safety and near-miss events. See.Sense offers the opportunity to collect qualitative data from users.	https://seesense.cc/pages/ride-insights		x				GB

Data collection bicycle (meetfiets)	The Data Collection Bicycle is a bicycle equipped with sensors to detect location, sound, vibration and air quality. These variables are measured to assess the cycling comfort that is experienced while riding a normal bicycle. The Data Collection Bicycle was used by the Dutch Cyclists Union (Fietsersbond) to be able to evaluate and compare the cycling infrastructure in various cities in the Netherlands (Fietsbalans programme). The Data Collection Bicycle measures GPS-position, speed, vibration level, sound level and particulate matter. The bicycle was developed by M+P, an expert consultancy company in the field of noise, vibration and air quality. The Data Collection Bicycle was one of the first bicycles to measure cyclist comfort and the concept was copied by parties in other European countries.	https://www.mp.nl/oplossingen/mp-en-fietsersbond-maken-de-ultieme-meetfiets https://www.fietsberaad.nl/Kennisbank/Fietsbalans-meet-en-vergelijkt-fietsbeleid-van-gem https://vroegevogels.bnnvara.nl/nieuws/fietsbalans-2008 https://www.fietsersbond.nl/nieuws/nieuwe-metingen-fietsbalans-van-start/		x				NL
Sniff bicycle (Snuffelfiets)	In the project, 550 ‘sniff boxes’ are attached to bicycles of volunteers in order to collect data about trips, air quality, quality of pavement and the temperature. The project is planned from May 2019-May 2020.	https://snuffelfiets.nl/		x				NL

Bicycle tracker Tallit	Tail it uses GSM, GPRS, Wi-Fi and LBS to detect the location of a bicycle for better accuracy indoor and in urban areas. Tail it also includes location algorithms for significant changes of location and known places. The units are basically sleeping when no location is requested, to save battery and to prevent radiation, which also can be detected by unauthorized persons with the correct measuring instruments. When location is requested the unit sends its location through encrypted communication protocols showing accurate location down to 5 meters. It also has a built-in speedometer, allowing the bike to send updates when it's moving (if the user wants to), as well as the option to enable live tracking (allowing the tracker to send position every 5 seconds -2 minutes).	https://www.tailit.com/bike/			x			NO
Mobbilock	The Mobilock facilitates bike sharing. With an app, a Mobilock can be unlocked. When a geofence is installed, this can be chosen at dedicated places. The Mobilock is of high quality, which means that theft of bicycles with the Mobilock is hardly possible. Data is generated on where the lock is opened and where it is closed. The technical configuration of app plus lock makes it possible to track the ride of the user. For reasons of privacy, this is option is not used.	https://mobilock.nl/		x				NL
Liberty Bell	Liberty Bell is a platform that helps with gathering quantitative and qualitative data about the movement of people through public spaces. The platform uses connected bicycle bells and pedestrian wristbands to allow participants to log, map and describe their experiences as they walk and cycle.	https://www.libertybell.io/#block-system-main		x				IE
Smart Grips	With smrtGRIPS, tactile feedback is given to riders via handlebars. This helps with navigation. A sign to the cyclist is given by vibrating on the side the user is expected to turn.	https://www.borealbikes.de/home-2-2-2-3/			x			DE

Ping if you care	The Ping button is a Bluetooth button that a cyclist can press to indicate a specific spot on their route that they want to comment on. This can be a feeling of unsafety, lacking good cycling infrastructure, aggressive behaviour of other road users, potholes, etc. The pings are indicated on their route, the cyclists are asked to give feedback on their 'pings' choosing from a drop-down category list that is provided by the city. The button can be attached to a bicycle handlebar and is connected to a smartphone app Bike Citizens. The Ping button is easy to use and it doesn't expect a cyclist to stop cycling when wanting to give report something to the government (like Fix my Street).	https://pingifyoucare.eu/		x		x		BE
Why Cycling Matters in Smart Cities	Research paper testing the implementation of a "Smart E-bike Monitoring System" (SEMS) in Brighton which collected bicycle use data, including location, rider control and other real-time inputs. A twitter feed regarding the study was later added at the request of participants. A fleet of 35 "smart- e-bikes" were deployed for use in 2012-2013 which were lent to 80 commuters for 6–8-week periods.	https://www.sciencedirect.com/science/article/abs/pii/S0966692316300746			x			UK
Whim	Phone application designed to facilitate the use of multiple types of transport use/hire (taxis, cars, trains, share cycle, etc.) as well as allows users to pay for these services through the app. Includes mapping to show users where these facilities are located.	https://whimapp.com/uk/				x		UK/ BE/ FI
Variable Message Signs (VMS)	Deployment of Variable Message Signs (VMS) in order to inform cyclists about cycle lane congestion, with tube counters (and later cameras) deployed to inform about disruption on the road.	https://ecf.com/news-and-events/news/visionarycities-series-city-copenhagen-introduces-variable-message-signs			x			DK

P-Route Cycle	Data is collected on the usage of cycle parking stands/facilities utilising optical sensors across Utrecht and used to provide details regarding this on dynamic routing information panels located across the city, as well as on a phone app. The information panels are also used to direct cyclists to available parking across the city. The collected data is also used to inform the council on where temporary "pop-up" cycle parking provision may be needed as well as other management decisions regarding cycling.	https://www.utrecht.nl/wonen-en-leven/verkeer/fiets/fiets-stallen/p-route/			x			NL
OV-Fiets	Provision of cycle rental locations across the Netherlands, situated to be used for the "last-leg" of journeys (bus stops, metro stops, etc.) with associated mapping provided detailing locations and allowing rentals to be organised online.	https://www.ns.nl/en/door-to-door/ov-fiets			x			NL
Naviki	Rout planner. Features – Turn-by-turn navigation, everyday routing, leisure routing, mountain bike routing, racing bike routing, s-pedelec routing, round trips, points of interest, offline maps, height profile, speed profile, connect fitness devices, convenient cockpit, record trips, turn by turn instructions for recorded routes and memorise routes. Gamification – Height profile. For all routes Naviki provides a height profile, the highest and lowest points and the total altitude to be cycled upwards.	https://www.naviki.org/en/naviki/app/				x		DE
Mywindsock	Application that provides users with wind speed/direction information along their chosen route, as well as feedback as to the impact this may have had on their journey. Colour coding informs the user of the impact of wind along a chosen route (red indicating lots of headwinds, with blue indicating light wind).	https://mywindsock.com			x			UK
Next Generation of Journey Planner in a Smart City (JPlanner)	Research paper regarding an alternative multi-modal journey planner in Singapore, includes other forms of transport outside of cycling. Comparisons also made with alternative solutions such as Google Earth.	https://ieeexplore.ieee.org/abstract/document/7395700			x			SG
Donkey Bikes	Bicycle rental scheme across multiple European cities. Users can pay for and unlock bikes via their phone, with mapping provided to show the locations of	https://cities.don				x		DK

	these facilities.	key.bike/contact/						
Cycle Specific Green Waves	Provision of LEDs embedded in cycle lanes in order to inform cyclists as to whether they will be able to reach the next green light at a set of traffic signals and the pace required to so. Also includes sensors at junctions in order to prioritise green time at future junctions for groups of cyclists detected.	https://www.swarco.com/stories/greenwave-copenhagen-denmark	x					DK
Brighton Cycle Hub	Provision of a 500-cycle space storage facility at Brighton Rail Station, including swipe cards for entry into the facility and signing outside and within providing details on the number of spaces available, as well as directions to these. Targets Southern Rail users at Brighton Station.	https://www.cyclepods.co.uk/case-studies/brighton-cyclehub/	x					UK
Bike Citizen	Discover new cycle routes, record journeys, discover new places, be guided by voice prompts, explore the city via a cycle tour, summary of your activities.	https://www.bikecitizens.net/app/				x		DE/ AT
Komoot	Route planner. Features – Customizable, Navigation, offline functionality, share adventures, highlight favourite moments, invite others along for the ride.	https://www.komoot.com/				x		DE/ AT
Strava	Track & analyse all activity. Features – Track & analyse, share & connect, explore & compete, measure performance, social network concept.	https://www.strava.com/						US
Locus map	Map displaying application. *Features* – Wide Selection of Maps and GPS Location, GPS Navigation for your Biking and Hiking, Offline Maps, Geocaching, Track Recording, Own Points and Tracks, Live tracking. *Gamification* – no gamification	https://www.locusmap.eu/				x		CZ
bike map	Mapping for bicycles Features: Bicycle routes worldwide, can be created by user, can be used online and offline, real-time information, big bicycle community.	https://www.bikemap.net/de/apps/				x		AT
Radfahren - Fahrrad Tracker	Bicycle fitness app. Features: App for tracking our own bicycle progress (e.g., speed, distance, calories), GPS, statics about own progress is available.	https://play.google.com/store/apps/details?id=com.zeopoxa.fitness.cyc				x		DE

		ling.bike&hl=de						
mapmyride	Bicycle fitness app. Features: workout plans, challenges, routing, blog, statistics and goal tracking and shop.	https://www.mapmyride.com				x		DE
Poliscan Redlight	Laser-based red light enforcement. It does not require loops or additional piezo sensors near stop lines. The sleek pillar is both stylish and functional: Based on rotatable individual segments, it allows monitoring of two travel directions from a single location.	https://www.vitronic.com/traffic-technology/applications/traffic-enforcement/red-light-enforcement.html	x					DE
Bike counter (Eco-Display Compact)	Real time bike counter (three versions). Two versions highlight safety with a flashing icon triggered whenever a cyclist is in a nearby bike lane, alerting drivers of their presence.	https://www.eco-compteur.com/en/home/	x	x	x			CA/ FR
Solar Path (bike lanes with solar collectors)	Prefab concrete Easy path bike path elements are equipped with a top layer with solar collectors. The energy will be used for surrounding buildings, housing, public spaces and street lighting.	https://easypath.nl/solarpath-fietspadelementen-zonne-energie	x					NL
ThermoPath (heated bike lanes)	Used in Ede on one of their most busy bike paths (2.500 – 3.500 cyclist a day) to ensure that in winter conditions the roads are ice free. During the manufacturing process of the concrete cycle path elements special heating pipes are added. The heating pipes keep the bicycle lanes ice-free and snow-free.	https://easypath.nl/thermopath-zonnefietspad	x					NL
Green Wave	The Green Wave helps cyclists to keep a steady pace to avoid unnecessary stops at signal controlled intersections, saving themselves some energy. The Green Wave is visualized by LED lights fixed in the road surface, on posts or using „countdown signals“. The system connects to the traffic signal controller which can also be coordinated with the adjacent intersections for a better flow through multiple	https://www.swarco.com/	x					DK

	signal-regulated junctions.							
Lane Light in-road Bike Safe system	RED in-road warning lights activate in sync with the overhead traffic lights reinforcing the red-light phase (and optional amber light phase) to approaching cyclist.	https://lanelight.com/bike-lanes-3/	x					CA/ DK
Cyclometer	The cyclometer is installed along cycle paths and can be equipped with multiple displays presenting information such as the number of bicycles per today, per year or any other time range. Additional information like date and time, air temperature or the city ‘s logo can also be shown. In addition to providing this information to cyclists and citizens, the city’s traffic engineers also get a more detailed picture of the city ‘s bicycle traffic.	https://www.swarco.com/	x	x	x			W W
Solar road	The SolaRoad Kit consists of four elements, which can be combined to a road section of 12 meters. The SolaRoad Kit delivers approximately 3,500 kWh per year (Dutch climate conditions), which is enough energy to power an average household for one year. SolaRoad is an innovative and sustainable energy solution for a business park, a courtyard, a square, a bike path or a footpath. The kit can provide energy for lighting, illuminating a shop window, heating, Wi-Fi access points or a charging point for e-bikes or mobile phones.	https://www.solaroad.nl/	x					FR/ NL
Ice Alert	Ice Alert® temperature sensitive reflectors report the temperature by changing colour from white (above 36F) graduating to blue at freezing alerting employees, customers and visitors of possible icy conditions and hazardous walking conditions.	https://lanelight.com/ice-alert/	x					CA
Intelligent road studs	The M100BR Bicycle Radar Detector has been designed to uniquely detect the presence of a bicycle within a defined zone and differentiate it from other forms of traffic. The M100BR works in conjunction with the M100 wireless vehicle	https://www.clearview-intelligence.com/	x	x				UK

	detection system.	products/irs2-hardwired-intelligent-road-studs						
Traffic light with countdown timer	Traffic Light Countdown Timer is a device developed and manufactured in order to increase the safety in traffic by displaying the remaining time of red or green light.	https://www.sphere.hr/en/products/traffic-light-countdown-timer/	x		x			HR
Bike scout	Bike scout improves the safety of cyclists at pedestrian crossings by detecting them in an early stage and by warning motorists on time through LED lighting on the road surface.	https://www.heijmans.nl/nl/bikescout/	x					NL
Crossover	Heijmans has developed a special marker with a fluorescent pigment. This pigment is activated by UV-light in the dark. An intelligent system detects the pedestrian or cyclist and sends the interactive lighting to go on.	https://www.heijmans.nl/nl/crossover/	x					NL
Flo radar	The Flo radar detects the speed of individual cyclists about hundred metres before a traffic light. It calculates the speed a cyclist has to cycle to stay in the green light flow. The sign meanings; a turtle: slow down, thumb: same speed, hare: go faster, cow: not possible to stay in the green flow.	www.fietsflo.nl			x			NL
Bicycle Presence	Accurate real-time bicycle actuation. The FlexRadar sensor accurately detects bicycles near the stopbar, including non-ferrous bike frame materials like carbon fiber. FlexRadar can be installed in either dedicated bike lanes or shared lanes, where bikes and other vehicles can be differentiated, enabling the controller to extend green when bicycles are present. Plus, the sensors are easy to add for bicycle counts or onto existing Sensys Networks signal actuation systems.Also, there is the smartphone app, GiveMeGreen!", that enables bicyclists and electric scooter riders to be automatically detected up to 300 feet from the intersection.	https://sensysnetworks.com/solutions/?watch=signal#bicycleactuation		x		x		US

Bike Box	Space-saving system of parking that keep bikes out of sight below the ground. No employees are needed. There are four types of bike parking products: automated bike tower, bike circle, pedal clip and the street box. They all have the option to charge a bike. Only the bike tower can go under the ground for saving street space.	https://bike-box.nl/	x					NL
Blue-lockers	Individual bike safes from Blue-Bike with charge for electric bicycles. (Only one safe in Vilvoorde)	https://fietsberaad.be/nieuws/nieuw-mobipunt-in-vilvoorde-met-digitale-infozuil-en-fietskluizen-met-ingebouwd-oplaadpunt/	x					BE
COBI. Bike	System that is attached to the bike. It comes with an app (fitness tracker, music control, …). The hub has a light and charges your phone. It also comes with an alarm for security and an electronic bell.	https://cobi.bike/				x		DE
Day Bright PLUS	LED Zebra crossing signs. It gives enhanced visibility and warning of pedestrian or cyclists crossings.	https://www.twmtraffic.com/	x					UK
Digital panels with information	The recent installation of digital panels (also called Variable Message Signs or VMSs) with traffic information for cyclists highlights the city's bike-friendly policy. Traffic volume on bicycle lanes is measured using sensors along the side of the road. In addition, travel times for cyclists are monitored in real time across entire corridors. The travel times of motorized traffic are monitored using 'floating car data', data derived for instance from the navigation systems of cars. The information is then analysed in the back office and is displayed on VMSs through Mob Maestro, the city's central traffic management platform.	https://www.technolution.eu/en/about-us/news/209-digital-panels-are-stimulating-bike-use-in-copenhagen.html	x	x	x			DK

DRIP panels	DRIP products are dynamic route information panels or electronic signs that provide pertinent travel information to people at stops and stations	http://www.valmont.nl/valmont-netherlands/en/traffic/traffic-information-/drip			x			NL
Dynamic traffic sign	The dynamic traffic sign shows cyclists the fastest route across big intersections.	https://bicycledutch.wordpress.com/2014/10/09/dynamic-sign-to-indicate-the-fastest-cycle-route/	x		x			NL
Fietstelpunt	The cyclemeter count the amount of cycles and displays the amount. Information is collected that way. The meter gives data about: amount of cyclists, peak times, how many cyclists during peak moments, night use of roads.	https://wegenenverkeer.be/fietstelpunten		x	x			BE
Flow Cube	The box contains a camera and a processing unit that utilizes artificial intelligence to identify and re-identify traffic participants of different modalities, including bicycles and pedestrians. With Flow Cube, traffic management systems can monitor, track and count all types of traffic on the road, generating reliable information about the traffic flow along the urban routes.	https://www.technolution.eu/en/mobility/flowcube/		x				NL
fride. - Mountain bike Tracker	Gamification of Mountain biking. Features: Game of Bikes, maps and lists of all German bike parks, routing, tracking, chat, measuring time and distance	https://appadvice.com/app/fride-mountainbike-tracker/1456260413				x		DE
Glowing bike lanes	The surface of the bike lane is made of a fluorescent material. This material absorbs the sun's rays during the day and then emits them at night. It was inspired	http://www.strabag.pl/	x					PL

	on the Van Gogh's bike lane in the Netherlands.							
Intersection conflict warning system	This system is designed to increase the safety of cyclists at traffic lights by warning vehicles that a cyclist is present.	https://www.dot.state.mn.us/trafficeng/signals/conflictwarning.html	x					US
Mobimaestro (intelligent streetlights)	MobiMaestro is the system for coordinated network-wide traffic management. Cyclists and pedestrians need proper street lighting, but this does not mean that it should be continuously lit. Intelligent Street lighting reacts to passing cyclists and pedestrians by increasing the amount of light. = Talking Traffic	https://www.technolution.eu/en/mobility/mobimaestro/	x		x			NL
Omni flow (smart lighting)	Integrated smart energy platform for IoT applications, powered by wind & solar with battery storage. Multiple services in one smart pole infrastructure (surveillance, security, traffic control, bike charger, ...)	S	x	x				PT
Rain sensitive traffic lights	The rain-sensitive detecting system has the purpose to increase the green time and give priority to the bicyclist when it's raining to improve the traffic safety.	https://www.eltis.org/discover/news/groningen-installs-rain-sensors-cyclists-traffic-lights-netherlands-0	x					NL
Real-time collision avoidance device	This handlebar-mounted scanner searches an image of the oncoming landscape and can pick out the road and irregularities on it based on shadow measurements.	http://www.byxee.it/			x			IT

Short Range Radar	The radar helps protect cyclists and pedestrians. It helps car drivers to detect and avoid dangerous situations in the vehicle's immediate surroundings. The radar sensor is installed at both ends of the rear bumper.	https://www.continental-automotive.com/en-gl/			x			DE
Smart Road Stickers	The technology consists of a small, solar-powered device to facilitate communication between roadway users. Installed on light poles or other infrastructure near the roadway, the basic function of the SRS is to detect wireless signals from mobile devices that have the STAR Detection app installed, as well as communicate with vehicles through onboard wireless communication units (OBUs). The technology is part of a research to understand the opportunities with connected vehicles in the smart city context.	https://www.psrc.org/sites/default/files/rtoc201803-pres-smartroadstickers.pdf			x	x		US
Smart traffic lights with thermal camera's	At an intersection the thermal camera detects cycling peaks and gives e.g. one time more green in the cycle. Or another example, on the route to a high school, the green time can be insufficient to groups up to 120 students to leave. Heat sensors measure such a group already on 100 metres before the crossing and give absolute priority, then the students often do not even need to stop	http://www.verkeerskunde.nl/dossiers/fiets-vk3-2018/rotterdam-werkt-aan-groene-golf-voor-fietsers.54452.lynkx	x					NL
Talking Traffic	When a cyclist using a Talking Traffic app approaches an intersection, the traffic system is notified. When the system detects a group of several cyclists, this group can get priority over other traffic. The app also gives speed recommendations	https://www.talking-traffic.com/en/whats-in-it-for/cyclists	x			x	x	NL

The Dynniq CrossCycle	Users simply download the app on their smartphones and it's ready to use, without the user having to operate or look at the app. When a cyclist using the Cross Cycle app approaches an intersection, green light time can be extended or the traffic lights will change to green earlier.	https://dynniq.com/product-and-services/mobility/crosscycle/	x				x	NL
The Smart Crossing	The 22-metre-long smart road surface can pre-empt pedestrians' movements, marking out Zebra crossing lines by lighting up the road surface with LEDs. It alerts drivers when pedestrians are crossing the road and lets them know when it is safe to walk	https://www.directline.com/smart-crossing	x		x	x		UK
The Xfire bike lane laser lights	Red laser beams enable cyclists to create their own bike lane around the bike.	https://thexfire.com/	x					US
Thermal traffic camera	TrafiData is an intelligent thermal sensor capable of counting and classifying vehicles, bicyclists, and pedestrians, in addition to travel-time for comprehensive congestion analysis. Integrated Wi-Fi technology allows simultaneous thermal-based data collection, while calculating travel-times and origin-destination by securely, and anonymously, tracking MAC addresses as people move throughout the traffic network. Since the TrafiData relies on thermal energy, rather than light, it offers 24/7 traffic monitoring and can detect road users at night, through glare, and in harsh weather conditions.	https://www.flir.com/		x				US
The Smart Cone	Cone equipped with a camera, speaker module for audio warning and LED strips to warn cyclists. It can be used to separate bike lanes from roads and it has a camera for real time visual.	https://www.thesmartcone.com/	x	x				CA
TMP	The TMP is designed for the detection of pedestrians and cyclists. It adapts the duration of the pedestrian green to the flow on the protected passage. It can also wake up a standby light or call a green phase for cyclists, without them having to step down to press the call button.	https://icomsdetections.com/project/tmp-en/	x					BE
Traffic Cam 3D	A 3D traffic camera used to improve traffic enforcement	https://www.viionsystems.com/		x				CA

Vierkant groen	"Vierkant groen" is a traffic lights phase for cyclists and pedestrians. During this phase, all cyclists and pedestrians have a green light at the same time, so they don't conflict with heavier traffic such as cars, buses or trucks.	https://wegenenverkeer.be/vierkant-groen	x					BE

Table 7: Smart Cycling Innovations Catalogue

(CIE, 2020; adapted & updated by the researcher)

2. Deductive code tree

Deductive Code Tree		
Themes	**Codes**	**Sub-codes**

Smart cycling innovations	• Smart bicycles
	• Smart cycling infrastructure
	• Interactive landscape
		• Simplicity
		• Connectedness
		• Multiplication of functions
		• Gamification
		• Tracking/Tracing/Counting
		• Interactive landscape
		  ○ Information provision
		  ○ Facilitate parking
		• Adaption of cyclists to their environment
		  ○ Increase safety
		  ○ Increase cyclists comfort

Smart mobility system	• Smart • Green • Integrated	• Integration of modes • Resource efficient transport • Congestion • Safety/security • Global leadership of European transport
Cycling governance	• Automobilization of cycling • Cycling data	• Tacking/Tracing/Counting • Rewarding cyclists • Improve Speed • Facilitate Routing • Legitimization • Learning through data • Data ownership/privacy

Table 8: Code tree

3. Code Book

Codes – Deductive/Inductive	Code Groups				
	Cycling governance	**Data**	**Empowering communities**	**Smart cycling innovations**	**Smart mobility system**
adapting intelligent systems to bicycles					Smart mobility system
added value of cycling pilots	Cycling governance				
anonymity of bicycles		Data			
anonymization of personal cycling data		Data			
augmented reality glasses				Smart cycling innovations	
automobilization of cycling	Cycling governance				
avoid sole focus on bicycles	Cycling governance				
baseline data		Data			
bicycle data project		Data			
bike lending scheme				Smart cycling innovations	Smart mobility system
car vs bicycle as starting point for policymaking	Cycling governance				
challenge of adapting cycling infrastructure to innovations	Cycling governance				Smart mobility system
challenge of anticipating cycling futures					Smart mobility system
challenge of common data format		Data			
challenge of quantifying benefits of cycling	Cycling governance				
changing mindset pro cycling	Cycling governance				
co-creation	Cycling governance				
co-creation require time & costs	Cycling governance				
collaboration of public authorities and universities	Cycling governance				
combining aggregated weather		Data			

data and cycling data					
combining point data to get journey data		Data			
comparing bicycle and car data		Data			
connected bicycles and mobility systems					Smart mobility system
contested road planning objectives	Cycling governance				
costs of collecting cycling data		Data			
costs of commercial cycling data		Data			
costs of gamification	Cycling governance			Smart cycling innovations	
criteria to measure quality of infrastructure	Cycling governance				
cycle data hub		Data			Smart mobility system
cycling as offline vs online mode				Smart cycling innovations	
cycling dashboard	Cycling governance	Data			
cycling dashboard kpi's	Cycling governance	Data			
cycling data	Cycling governance				
cycling data as evidence	Cycling governance	Data			
cycling data as ground for narrative	Cycling governance	Data			
cycling data for spatial planning	Cycling governance	Data			
cycling data in policy agendas	Cycling governance	Data			
cycling data is anonymous data		Data			
cycling data makes the mode tangible	Cycling governance	Data			Smart mobility system
cycling data sets		Data			
cycling data to receive funding		Data			
cycling data to transform companies mobility management		Data			
cycling futures as gradual process in policymaking	Cycling governance				
cycling infrastructure vs data		Data			

collection					
cyclists driving faster in the morning		Data			
data analysis		Data			
data as ground for framing cycling futures		Data			
data collection		Data			
data collection vs surveillance		Data			
data harmonization		Data			
data harmonization for European mobility systems		Data			
data is not used		Data			
data protection impact assessment		Data			
data protection team		Data			
data-driven governance	Cycling governance				
determining road quality with sensors	Cycling governance				
difficulties of linking cycling measures to CO2 reduction	Cycling governance	Data			
difficulties of collecting provincial cycling data		Data			
difficulties of funding for cycling projects	Cycling governance				
diversification of cyclists					
division of space					
do we need common definitions for kpi's?		Data			
drivers of change				Smart cycling innovations	
empowering & mobilizing communities			Empowering communities		
encouraging people to cycle more	Cycling governance				
ensuring car is the least logical option through spatial measures	Cycling governance				
environmental benefits of cycling					

European collaboration	Cycling governance				
exclusion of certain groups in society in cycling futures					Smart mobility system
free floating vs hub based	Cycling governance				
funding problems for bicycle infrastructure	Cycling governance				
gamification				Smart cycling innovations	
green					Smart mobility system
health benefits of cycling			Empowering communities		
identification of issues	Cycling governance				
importance of bike parking facilities					Smart mobility system
importance of sharing data across departments	Cycling governance	Data			
improve routing	Cycling governance				Smart mobility system
increase bicycle share	Cycling governance				
increase cycling comfort	Cycling governance				
increased safety and efficiency through ITS					Smart mobility system
increased speed of bicycles	Cycling governance			Smart cycling innovations	
increasing funds for cycling and walking infrastructure	Cycling governance				
informed decision-making through ITS	Cycling governance				
institutional capacity	Cycling governance				
integrating data sets		Data			
integrating users			Empowering communities		
integration of modes	Cycling governance				Smart mobility system
interactive landscape			Empowering communities	Smart cycling innovations	
intrinsic motivation			Empowering		

			communities		
investing in the transition	Cycling governance				
involvement in city planning as incentive			Empowering communities		
issue of data ownership		Data			
journey data		Data			
journey data and privacy		Data			
learners and champions	Cycling governance				
learning through cycling data	Cycling governance	Data			
legitimization	Cycling governance				
low camera resolution				Smart cycling innovations	
making car journeys less attractive	Cycling governance				
making cities comparable through kpi's		Data			
making cycling data available		Data			
making cycling more attractive	Cycling governance				
making cycling more attractive through ITS				Smart cycling innovations	
measuring bike				Smart cycling innovations	
measuring social values of cycling pilots		Data			
mindset vs data-driven policymaking	Cycling governance				
mobile counters				Smart cycling innovations	
motivation to share cycling data		Data			
multimodality					Smart mobility system
municipalities do not embrace potentials of smart bicycles yet	Cycling governance				
new policy questions regarding e-bikes and delivery bikes	Cycling governance			Smart cycling innovations	
non-comparability of data cross cities and countries		Data			

nudging	Cycling governance				
open data		Data			
outsourcing	Cycling governance				
pedestrian data		Data			
personal data		Data			
point data		Data			
policymaking cannot keep up with pace of cycling innovations	Cycling governance				
potentials of commercial cycling data		Data			
potentials of smart cycling applications				Smart cycling innovations	
potentials of smart lock systems for multimodality				Smart cycling innovations	
pressure on municipalities to start collecting data	Cycling governance	Data			
prioritizing cars in road planning	Cycling governance				
prioritizing connected bicycles?	Cycling governance				
prioritizing cycling and walking over car policy	Cycling governance				
protecting individuals anonymity		Data	Empowering communities		
providing incentives for cyclists	Cycling governance		Empowering communities		
public discontent with cameras			Empowering communities		
public private partnerships	Cycling governance				
public vs private	Cycling governance				
quality of life as central point in policymaking	Cycling governance				
quantifying bicycle journeys		Data			
quantitative vs qualitative data		Data			
real-time data for traffic management	Cycling governance	Data			
reporting	Cycling governance				

representativeness vs efficiency		Data			
responsible use of cycling data		Data			
road improvements	Cycling governance				Smart mobility system
road ownership					Smart mobility system
road planning	Cycling governance				
safety/security	Cycling governance				Smart mobility system
Schwung application				Smart cycling innovations	
Seesene collaboration	Cycling governance	Data		Smart cycling innovations	
sharing data		Data			
simply data vs meaningful data		Data			
smart					Smart mobility system
smart applications				Smart cycling innovations	
smart bicycle				Smart cycling innovations	
smart bicycle as gadget				Smart cycling innovations	
smart cycling futures					Smart mobility system
smart cycling infrastructure				Smart cycling innovations	
Smart cycling innovations anticipate GDPR				Smart cycling innovations	
smart cycling sharing models				Smart cycling innovations	Smart mobility system
smart helmet				Smart cycling innovations	
sniffer bike analysis				Smart cycling innovations	
surveillance/privacy	Cycling governance	Data			
survey data		Data			
sustainable long-term benefits of data collection		Data			
technical knowledge	Cycling governance				

tendering for applications	Cycling governance				
the importance of data for policymaking	Cycling governance	Data			
the importance of subsidies for e-bikes	Cycling governance				
the issue of bicycles & parking					Smart mobility system
the more data the more insights over time		Data			
Tomtom GPS data to compare modes		Data		Smart cycling innovations	
tracking near incidents at intersections		Data			
tracking your bike		Data	Empowering communities		
traffic flow management	Cycling governance				Smart mobility system
traffic monitoring	Cycling governance				Smart mobility system
transparency in data collection		Data			
understanding the value of data		Data			
user feedback			Empowering communities		

Table 9: Code book

3. Interview guide

Introduction

- What is your relationship to cycling innovations mobility in general?

RQ1: 1. How can smart cycling innovations help to reduce CO2 emissions in urban environments?

1. Would you say smart cycling innovations have the potential to increase bicycle use? If yes, how?

1. Is there a potential for Smart cycling innovations to further decrease CO2 emissions in the urban environment?

RQ2: What is the impact of mobilizing cycling data for the development of smart & sustainable mobility systems?

2. Do you collect cycling data in your municipality? If yes, what types?

3. How do you use cycling data to organize and govern cycling as a mode?

4. What is the influence of cycling data on the integration of modes within urban transport?

4.1 Does it influence congestion, safety, and security? If yes, how?

5. Data collection is not unproblematic. How can governments deal with issues related to data-ownership and privacy?

6. What is the influence of mobilizing cycling data for future spatial planning & policy-making activities? → Opportunities for local public authorities?

RQ3: What is the influence of cycling innovations on how cycling is organized and governed as mobility mode?

7. How would you describe the influence of the 'smartified bycicle' on the way cycling is governed as a mode? / How does the multiplication of functions on bicycles influence cycling governance?

Challenge to get people using these?

8. What is the influence of smart cycling infrastructure regarding the way cycling is governed as a mode?

8.1 There is a newly emerging interactive landscape between cyclists and smart cycling infrastructure → Does this influence the way cycling is governed and organized as a mode? Opportunities? Challenges?

9. Are we seeing a change between bicycles in relation to cars when it comes to governance and organization?

RQ4: What are the relationships of smart cycling innovations to future smart mobility systems?

10. How would you describe the influence of the 'smartified bycicle' on transport efficiency in future urban mobility systems?

10.1 Does it influence congestion, safety & security? If yes, how?

11. What role will the 'connected' bicycle have in future smart mobility systems?

12. What role will Smart cycling infrastructure have in the future smart mobility system?

Conclusion

13. What are the main drawbacks of smart cycling innovations for future urban mobility?

14. What are the main opportunities of smart cycling innovations for future urban mobility?

4. Letter of consent

Consent to take part in research

□ I…… voluntarily agree to participate in this research study.

□ I understand that even if I agree to participate now, I can withdraw at any time or refuse to answer any question without any consequences of any kind.

□ I understand that I can withdraw permission to use data from my interview within two weeks after the interview, in which case the material will be deleted.

□ I have had the purpose and nature of the study explained to me in writing and I have had the opportunity to ask questions about the study.

□ I agree to my interview being audio recorded.

□ I understand that all information I provide for this study will be treated confidentially.

□ I understand that in any report on the results of this research my identity will remain anonymous. This will be done by changing my name and disguising any details of my interview which may reveal my identity or the identity of people I speak about.

□ I understand that disguised extracts from my interview may be quoted in a final report.

□ I understand that a transcript of my interview in which all identifying information has been removed will be retained for the period of this research project.

□ I understand that under freedom of information legalisation I am entitled to access the information I have provided at any time while it is in storage as specified above.

□ I understand that I am free to contact any of the people involved in the research to seek further clarification and information.

Researcher: David Thein d.b.thein@student.rug.nl

Dr. F. (Farzaneh) Bahrami f.bahrami@rug.nl

Signature of research participant

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Signature of researcher

I believe the participant is giving informed consent to participate in this study

D. Thein

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5. Information sheet

Dear Participant,

I am a master student at the university of Groningen and currently conducting research about the role of smart cycling innovations in processes of smart & sustainable urban mobility. The results of this research aim to improve understanding of how smart cycling innovations can potentially contribute to future mobility systems and urban sustainability agendas.

To collect data, semi-structured interviews will be conducted with a homogeneous group of stakeholders with differing vicinity to the BITS project as well as policymakers, experts and researchers in the field of cycling innovations.

You are being invited to participate in this research study on the role of smart cycling innovations in processes of sustainable urban mobility. The interview will require about 45min of your time. During this time, you will be interviewed about topics related to: (1) Smart cycling innovations (2) Cycling data (3) Cycling governance (4) Smart sustainable mobility and spatial planning. Due to the current situation the interviews shall be conducted via Teams. The interview will be tape-recorded and transcribed at later stage. All records will be deleted after completion of the report.

The results of this research will be published in a final report. At no time, however, will your name be used, or any identifying information revealed.

If you require any information about this study, or would like to speak to the researcher, please contact me under d.b.thein@student.rug.nl at Rijksuniversiteit Groningen.