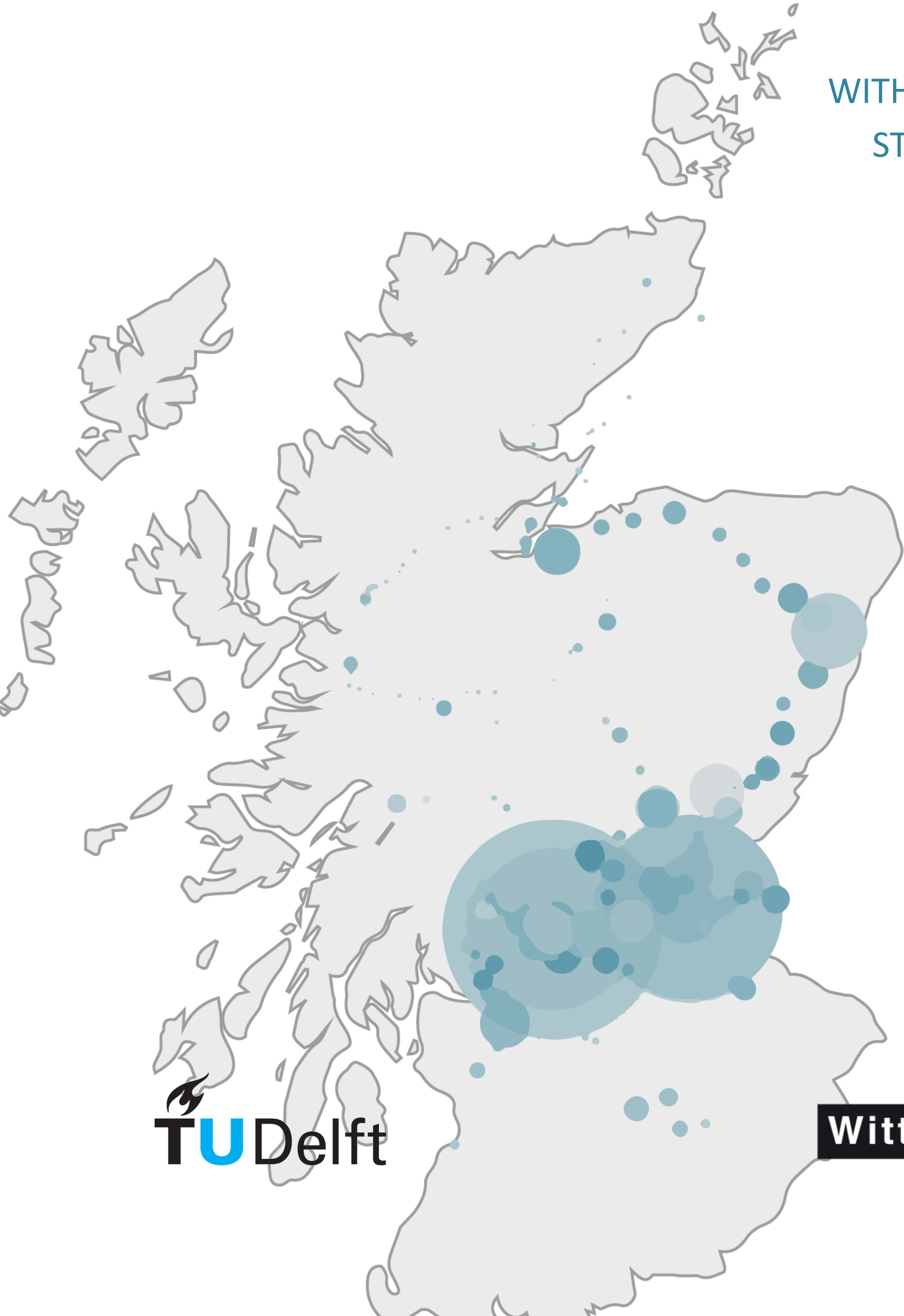
WHY CYCLE TO THE RAILWAY STATION?

A STATION SCANNER BASED ON FACTORS THAT INFLUENCE BICYCLE-RAIL USE

WITH A STUDY ON STAKEHOLDERS IN SCOTLAND



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MASTER THESIS
MAY 2017

TU Delft

Witteveen + Bos

This research was undertaken in partial fulfilment of the master's degree *Transport, Infrastructure & Logistics* at Delft University of Technology, with an annotation in Technology in Sustainable Development (TiSD). Witteveen+Bos has agreed to supervise and support this research, in addition to the supervision from TU Delft.

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PREFACE

Half a year ago, Witteveen+Bos welcomed me to their offices in Amsterdam, Deventer and London. I got the freedom to "do something with bicycles in the UK", which was exactly what I had hoped for. The work in front of you is the result of this project: my thesis for a MSc title in Transportation, Infrastructure & Logistics of Delft University of Technology. I would like to first of all thank my company supervisor Martijn Akkerman for making this possible and sharing his international experiences as a cycling expert and motivating suggestions with me. In the day-to-day process of reading, thinking and loud typing, I want to thank the colleagues from all three offices for keeping me good-humoured, and the great people from Abellio for hosting me in their Glasgow headquarters during my visits to Scotland.

During my master's degree at TU Delft I met professor Bert van Wee and remember how he compared being a student to "feeling like a child in a candy shop". There are so many opportunities for interesting lectures, international projects and thought-provoking activities, which are all part of university life. I want to thank him for chairing my committee with both wisdom and enthusiasm: a very inspiring combination. Jan Anne Annema was the most positive and motivating supervisor one can wish for and it was a pleasure to see the joy Niels van Oort conveyed when discussing all sorts of career advice and the combination of doing research and practice. It seems nearly as great a synergy as well-integrated bicycle and train systems. However, for now, this is my final piece of academic research.

A very big thank you goes to my two older sisters and my twin Amée Leferink in particular for critically reading my thesis numerous times and giving me confidence when I needed it most. To my loving friends and caring flatmates who I saw too little. And last but not least thanks to my parents, for their support and for teaching me how to ride a bicycle.

For now, a lovely thought to bear in mind:

This is the world,
This is the weather,
Let's ride a bike in it.

Tessa Leferink
Delft, May 2017

EXECUTIVE SUMMARY

Cities are growing, their populations are growing and the number of motorised trips is growing (Pucher & Buehler, 2010). However, as the number of passenger car kilometres increases, the severity of congestion and air pollution grow merrily along. To keep our cities liveable and transportation fast and reliable, this trend should be reversed.

A well-integrated bicycle-rail system can provide an excellent alternative to motorised vehicles. However, whilst the combined use of the bicycle and train provide a convenient, competitive, healthy, and sustainable travel option in theory, bicycle-rail use is limited in practice. This thesis aims to help seize the opportunity of bicycle-rail by answering the following research question:

Which factors influence the combined use of bicycle and train, and how can these findings be applied to help advise (Scottish) stakeholders improve bicycle-rail use?

Besides a literature review to identify what factors influences bicycle-rail use, the framework for a "Station Scanner" is developed. This tool can help in the early strategic design and decision phases by identifying the relative potential of bicycle-rail use at station level, for a large set of stations. The scanner is tested by creating a prototype for Scotland. Additionally, as an illustrative example of how bicycle-rail use can be improved in practice, an explorative analysis of the relevant stakeholders and (in)formal systems in Scotland is done. This section summarises the relevance, structure and findings of the research.

Opportunity for the bicycle-rail combination

The study looks into an upcoming, sustainable multimodality: the combination of bicycle and train ("bicycle-rail"), and considers both bike-and-ride (BaR) and bike-on-board (BoB) journeys. Bicycle-rail combines the advantages of speed and accessibility of the train with the flexibility and (particularly in an urban context) reliability of the bicycle. Together they can form a competitive mode of transportation. When well-integrated, the benefits are evident for various parties: train operating companies see an increase in their catchment area, governments have less congested and more attractive cities, and travellers can choose a cheaper, faster and/or healthier alternative.

The advantages in theory are evident. However, bicycle-rail use is limited in worldwide practice. In the European Union on average four percent of rail users arrive or depart from the station by bicycle (BiTiBi, 2016). There is an exception: in the Netherlands on average 42% of the home-bound train journeys start or end with a bike ride (KiM, 2014). With increasing numbers of general bicycle and rail use worldwide, the number of bicycle-rail rides may be expected to rise too. This increase in demand requires more and better supply of bicycle-rail services. Vice versa: better bicycle-rail services can stimulate or unlock demand further and lead to a modal shift away from the car in particular. There are various design guides to help tailor services, and audit instruments that consider (potential) bicycle-rail use. However, there is no tool that combines relative potential bicycle-rail use estimates on station level with interactive and attractive user-interfaces for strategic design and decision making. The framework for a Station Scanner is developed based on the research findings.

Scotland is selected to test the Station Scanner and illustrate the current roles and collaborations of relevant stakeholders to improve bicycle-rail use. Scotland has a particular receptive context for increasing bicycle-rail use: the government has high ambitions for general bicycle use, and current train operator ScotRail Abellio is implementing a "Cycle Innovation Plan". Additionally, the large variation in land-use, from very remote to highly urbanised, makes Scotland an excellent place to test the Station Scanner.

Research Design

A combination of methods is chosen to answer the research questions. First of all, an extensive literature review is undertaken based on a selection of academic literature. From this review a selection of potentially influential factors is made and summarised to define their respective relations to bicycle-rail. These factors are discussed with two experts. Next, this knowledge is translated into the framework for a strategic analysis tool: the "Station Scanner". It is created in an iterative creative design process, parallel to testing the idea in data software and collecting input from Dutch and Scottish practitioners. The study then focuses on Scotland. A combination of desk research on (policy) documents and semi-structured and open interviewing techniques is used for this explorative research. Semi-structured interviews are undertaken with twelve representatives of eight parties identified as most influential on various relevant scale levels (local, regional, national), all involved with integrated transport in general or improving bicycle-rail in particular. Additional interviews with Dutch and Scottish transport specialists ensure an objective analysis of the context in which the various stakeholders work. These findings combined give an impressionistic analysis organised by theme.

Findings on factors, advice tools and strategic collaborations

Bicycle-rail as a detailed trip chain and attractive choice

The bicycle-rail can be seen as a chain of different links and nodes, connecting a point of origin and point of destination (see Figure 1 below). As any multimodal trip chain it is relatively complex and its success depends on a good integration between the links. Each trip chain can be divided into many more detailed steps. Particularly bike-on-board can proof challenging to facilitate as space for bicycles on trains is usually limited.

The bicycle-rail option will only be chosen when it is competitive to alternative modes of travel. This can either involve the bicycle as a competitive first or last mile solution, or the bicycle-rail combination as an attractive alternative for a door-to-door travel option, typically by car. For both types, particularly the travel time (often translated into distance) to and from the railway station appears key to determine attractiveness, with cyclists typically travelling between one, and three up to five kilometres. Foot is typically found most attractive for shorter distances, and bus, tram metro (BTM) or the car for greater distances.

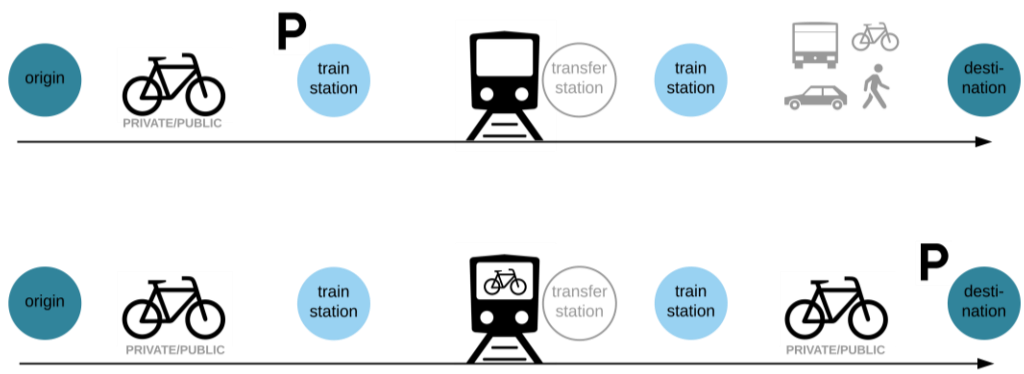

Figure 1 top) **Bike-and-Ride (BaR);** bottom) **Bike-on-Board (BoB) trip chains**

Good bicycle-rail integration entails three aspects according to the literature: physical and network integration, an integrated ticket system and high quality information system. Practical guidelines mention services such as bicycle parking, public bicycles (e.g. London's Santander bikes), collaborations of bicycle-rail organisations, integrated payment systems (e.g. the Dutch OV chip card), positive communication and safe cycling infrastructure. Positive communication to raise awareness can be expected to be particularly important in places where people are unfamiliar with this mode. Also among higher-level stakeholders and researchers, there is limited knowledge on how to best facilitate the growing or even unlock the potential demand.

Influential factors

Different stations and train services appear to attract different types and levels of bicycle-rail use. A literature review of Dutch and English academic publications yielded nearly forty factors to capture such variations. The most influential factors according to the review are the first/last mile distance (people will cycle up to five km), current bicycle and rail use, competition of other modes, safe and high-quality bicycle routes to the station, share of commuters among railway passengers and number of rainy days. The influential factors can be grouped in the three categories *context*, *rail journey* and *first/last mile journey* to align with the trip chain components.

The literature review made clear that there is variation between both countries and socio-demographic groups in how much they value these different factors. Where income or gender may highly correlate with bicycle(-rail) use in one place, it is insignificant elsewhere. As bicycle-rail literature is limited and considering these large variations, more than a generic overview cannot be given. However, it may be assumed that a combination of the factors can give a first indication of the potential for bicycle-rail use at station level.

Station Scanner

To move from academic findings to a practical tool, the conceptual framework for a “Station Scanner” is developed. Existing bicycle-rail guides and analytical tools from different countries are studied to build upon and ensure a unique tool. The scanner enables its user to combine data of a (large) group of stations and provide a quick-scan of their relative bicycle-rail potential. This potential is based on scores of ten clusters derived from the factor overview. The first five clusters are more adjustable: bicycle use, bicycle infrastructure, rail use, competition BTM and competition car, the last five are established and harder to influence: land-use with potential, population with potential, trains with potential, climate and trip length/hills.

The scanner outcomes are shown on interactive dashboards that give the user a birds-eye view of all stations within a chosen boundary - e.g. a country. This can help in the first steps of the design and decision phase to decide where to focus improvements of bicycle-rail use. To ensure an objective view, we suggest a scanner should be designed and built by an independent party. The main two elements are a database and dashboard, with five steps required to design and create the scanner. They are shown in Figure 2 below.

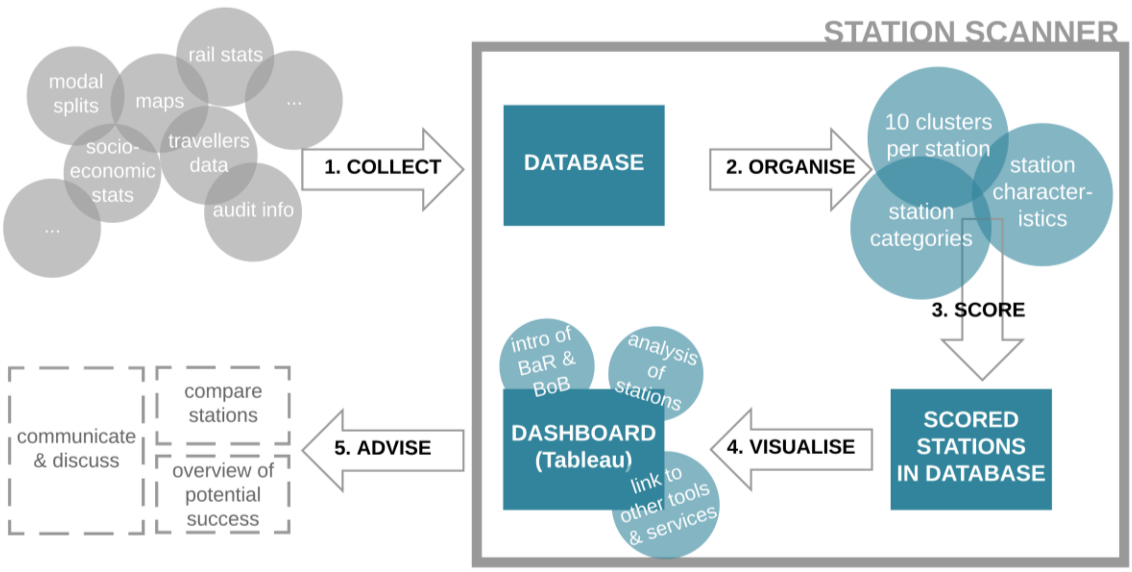

Figure 2 Elements of the Station Scanner framework

The framework has been tested by designing and creating a prototype for Scotland.

Context & Prototype Scottish Station Scanner

Both the number of rail passengers and cycling kilometres increased by nearly thirty percent between 2006 and 2014 (Transport Scotland, 2016). Data on bicycle-rail use in Scotland alone is not found, however the British cycle-rail user is typically a commuter and nearly half of UK's bicycle-rail journeys are BoB (bike-on-board).

Various open data sources and datasets made available for this study are combined to make a prototype to test the framework. The data covers three different zone levels: 32 councils, 350 stations and 6000+ local zones. The score for bicycle-rail potential gains extra depth by integrating an estimation of cycle use derived from an existing tool in the British railway sector. This process provides input for the generic framework.

Scottish Stakeholders & Opportunities

A Station Scanner can roughly indicate the potential for bicycle-rail use on a station level. To unlock the potential for bicycle-rail, action is required from various stakeholders. To illustrate what current practice may look like, the Scottish stakeholders' (in)formal objectives, tools and relations are mapped. On a national level already eight parties can be identified as being able to influence bicycle-rail. When including regional and local authorities this number increases quickly. The stakeholder's level and the (trip chain) locations of (in)formal influence varies.

A number of opportunities are identified in Scotland where improvements for bicycle-rail are or can be realised. Examples include the renewal of the ten-yearly ScotRail franchise agreement, station development projects or the moment when new funding from public parties comes available. Generally, attempts from any party to step out of the typical pragmatic paradigm and think beyond the party's formal boundaries and collaborate strategically are an excellent opportunity. This is important everywhere, as the findings of chapter 3 already suggest: integration requires collaboration. Who exactly collaborates and how financial, legislative and organisational powers are organised will differ from country to country. For bicycle-rail levels to take off in any place including Scotland, a shared vision among the stakeholders is vital.

Discussion & Recommendations

This thesis deals with a multimodal travel option which has been researched to a limited extend and is only marginally used in most countries, including Scotland. The risk in such a research is a lack of data and thus of generalising too quickly. Nevertheless, this research helps build a common understanding of bicycle-rail and suggests the station scanner as a strategic tool to provide a bridge between academic work and often pragmatic practice.

For improving the concept of a "Station Scanner", particularly more insight in the complex relations between the factors should be studied to increase reliability. Also, more sophisticated ways to score and benchmark the stations would improve its use. Consideration should be paid to match the datasets well with both the ten clusters and the stations' catchment areas. Still, a combination of tools and professional advice is required to help stakeholders improve bicycle-rail use. Whichever tool is most suitable should be selected. Recommendations for practice include collaboration and shared strategic plans to improve bicycle-rail use. Particularly at railway stations there are many parties active on little space with potentially conflicting objectives and a limited supply of resources. The main challenge may lie in involving the various stakeholders to remove barriers from the bicycle-rail trip chain. We may understand where and how the opportunity for bicycle-rail can be seized, but this does not mean it will.

Conclusions

The research presented in this thesis helps to bridge the gap between theoretic knowledge and everyday practice of improving bicycle-rail use. The formulated main question can be divided into two components:

1. What (in)direct factors influence the combined use of bicycle and train?

2. How can these findings be applied to advice (Scottish) stakeholders to improve the bicycle-rail combination?

The first component builds from the idea that bicycle-rail use will increase, as it becomes an attractive option in an individual user's choice set. Besides various bicycle-rail services that can influence bicycle-rail use directly, a literature review found that many other factors can influence the (potential) demand for bicycle-rail use. A total of 39 factors is found in the literature. Their overlap and weights are expected to differ from place to place. Similarly, we may assume that different situations and stations require different strategies and services to ensure the demand is facilitated. These findings answer the first part of the main question.

The framework for the Station Scanner is a direct answer to the second component of the main question of this research. The scanner introduces the concept of bicycle-rail and enables its user to gain a bird's-eye view on the relative bicycle-rail potential of a set of stations, by scoring each station on ten clusters derived from the literature review.

The prototype scanner and explorative stakeholder analysis in Scotland provide a proof of concept and recommendations for the scanner's framework and illustrate day-to-day practice in improving bicycle-rail. Some of these findings apply to other countries as well: project-based and pragmatic working appears to be the norm but windows of opportunity include working beyond formal boundaries, ambitious formal agreements, funding availability for sustainable or active travel and development of strategy plans.

This study is part of a growing body of research undertaken on bicycle-rail travel. Nevertheless, change can only happen through action. It depends on influential stakeholders to make a difference and actively stimulate a better integration of bicycle-rail. Only then bicycle-rail can grow to its full potential.

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LIST OF ABBREVIATIONS

ATOC	Association of Train Operating Companies
BaR	Bike-and-Ride. A cycle-rail trip where the bicycle is parked at or collected from the station
BoB	Bike-on-Board. A cycle-rail trip where the bicycle is taken aboard the train
BRT	Bus Rapid Transit
BTM	Bus, Tram, Metro
CBA	Cost Benefit Analysis
CTU-index	Cycle Transit Index (Krizek & Stonebraker, 2010)
DfT	Department for Transport
MRT	Mass Rapid Transit
NGO	Non-Governmental Organisation
NS	Nederlandse Spoorwegen (Dutch Railways)
ORR	Office of Rail and Road
RDG	Rail Delivery Group (former ATOC)
ROSCO	ROlling Stock Company
RTP	Regional Transport Partnership
SHS	Scottish Household Survey
SPT	Strathclyde Partnership for Transport
SQUIRE	Service Quality Incentive Regime
TOC	Train Operating Company
TRL-tool	A “cycle-rail prediction model” for the UK by TRL consultancy (Jones, York, & Ball, 2015)
UK	United Kingdom

1 INTRODUCTION

Mobility is an essential part of our days, lives and economies. Every day the world population travels a total of 23 billion kilometres by car, train, airplane, bus, foot and the bicycle combined - to undertake journeys to reach their respective destinations. Every day the average world citizen travels 1.1 hours, making passenger transport relevant to everybody (Schafer & Victor, 2000). This thesis looks into an upcoming, sustainable multimodality: the combination of bicycle and train, including both commuter and recreational journeys. Whilst "bicycle-rail" is a great opportunity in theory, it is not common practice in most places. This thesis aims to translate academic knowledge into practical advice and help seize the opportunity for bicycle-rail use. First of all by an extensive literature review of factors that influence the demand for bicycle-rail use and second through the development of a practical framework to assist in strategic bicycle-rail advice: the "Station Scanner". A prototype is made in Scotland. Finally, an explorative analysis is undertaken on who are the most influential parties and how they currently improve bicycle-rail in Scotland. This chapter first of all introduces the success of the bicycle-rail combination, both in theory and practice. Second, the main question and objectives of this thesis' research are presented and the report structure presented. As a conclusion, the practical and scientific relevance of the study are highlighted.

1.1 Bicycle-rail: an opportunity

This theoretic paragraph introduces why bicycle-rail is a competitive mode both in theory and practice.

1.1.1 Growing cities, growing congestion, growing potential for bicycle-rail

Cities are growing, their populations are growing and the number of motorised trips is growing (Pucher & Buehler, 2010). However, as passenger car kilometres increase, the severity of congestion and air pollution grow merrily along. To keep our cities liveable and transportation fast and reliable, this trend should be reversed. The external side effects of motorised traffic are unsustainable - an increasingly important topic. Walking, cycling and public transport are sustainable alternatives to the car (Bachand-Marleau, Larsen, & El-Geneidy, 2011).

Each travel mode comes with its pros and cons. Public transport can provide a great alternative to the car, both on short and long distance, but its rigid schedule and fixed stations decrease convenience. Particularly in the urban environment of increasingly congested and densely populated cities, and during peak hours, motorised vehicles including cars can be unreliable due to congestion (Planbureau voor de Leefomgeving, 2014; Scheltema, 2017). Furthermore, the search for a car parking space varies and adds to the travel time. The car is, however a flexible and thus convenient mode of transportation, suitable for door-to-door and longer distance travel. Similarly flexible are travel by foot or bicycle, with the additional advantage of lower costs and a healthy activity. However, muscle power can only get you so far. Many of our trips require a distance too far to undertake by foot or bicycle ("active travel") alone. For those trips the benefits of the bicycle-transit combination are most profound.

The flexibility of the bicycle combined with the speed and comfort of good public transport can be a highly competitive alternative to the car. This research considers one particular transit type: the train. Figure 3 on the next page illustrates how bicycle-rail can be a competitive alternative to other modes of transport, both as a first or last mile and a door-to-door journey. Good bicycle-rail integration increases a station's catchment area. A more analytical description of the trip chain and details on bicycle-rail competitiveness are given in chapter 3. Besides bicycle-rail as a competitive travel option for individuals, there are also external advantages for society as a whole. Bicycles require less space than cars both on the road and parking spaces at stations and have no negative side effects like exhausts or congestion (Pucher & Buehler, 2008). Railway infrastructure too requires less space and - whilst depending on particularly train type, service and the number of car occupants, the train is often a sustainable choice (Smith, 2003). Both individual and societal benefits will appear most evidently in urban areas where congestion is growing and space limited.

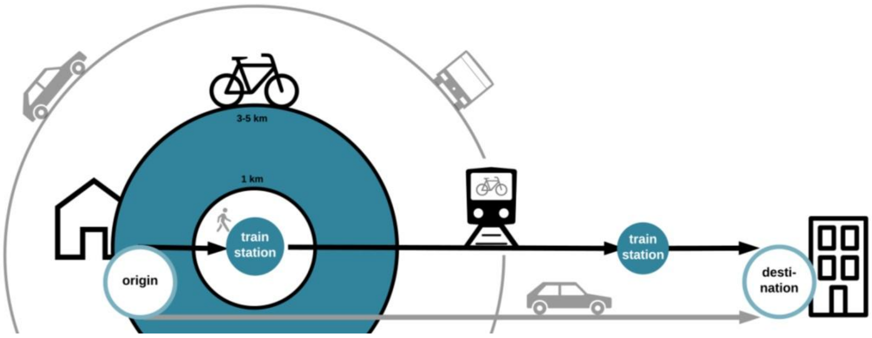

Figure 3 The competition for a home-work journey, comparing the bicycle-rail combination to other (door-to-door) alternatives. Visualisation by author.

Recent publications have highlighted the potential of the marginalised and little researched bicycle-transit combination (Kager, Bertolini, & Te Brömmelstroet, 2016; KiM, 2016b; Scheltema, 2012; Singleton & Clifton, 2014). Particularly when combined with the train, bicycle-transit can be very successful (Martens, 2004; Van Nes, Hansen, & Constance, 2014). Due to its higher level of service compared to other forms of public transport, people will cycle further to reach train stations (Flamm & Rivasplata, 2014), directly increasing the catchment area and accessibility of the railway system. The railway sector can thus also gain from bicycle-rail.

1.1.2 Bicycle-rail in practice

The theoretical advantages of bicycle-rail were introduced. Unfortunately, theory alone does not make it common practice for most citizens of the world. For example in the European Union on average four per cent of railway passengers begin or end their trip with a bicycle (BiTiBi, 2016). There is an exception. In the Netherlands, nearly half of rail journeys start with a bicycle ride: 42% of "first mile home-bound" trips are done by the sheer force of pedalling power (KiM, 2016a).

Also in the United Kingdom (UK) less than five percent of rail journeys involve a bicycle (Rail Delivery Group, 2016). The potential does seem to be there: 60% of the UK's population live within 15 minutes cycling from a railway station, and 85% of the British population lives within five kilometres of a railway station (Rail Delivery Group, 2015, 2016). Close enough to cycle and catch a train, according to most catchment area definitions (more details in paragraph 3.3.3). It is worth noting that the aforementioned five percent of access and egress by bicycle is a significant increase already. In 2009 the British Department for Transport indicated only two percent of rail users arrived by bicycle (DfT, 2009), and this trend may be expected to continue upward.

There will naturally be a relation between general cycling levels and bicycle-rail use. Considering the synergy of bicycle-rail for its users, the wider societal benefits and non-cycling-related stakeholders (most importantly the railway industry), it is worthwhile to study in more detail what influences and improves bicycle-rail use. Improving and sustaining good bicycle-rail integration does however come with its challenges. Two are described below.

1.1.3 Challenge 1: suitable supply for (potential) demand

The first challenge lays in the limited transferability of good practice. Considerations of local differences in both number and type of services are important to ensure supply matches demand. Guidelines can help design good bicycle-rail services but local tailoring is always required. Examples include the selection of sufficient number and type of bicycle parking, their location, suitable communication campaigns to attract certain bicycle-rail user types and tying in with existing bicycle infrastructure networks.

To give an indication for how large local variation may be: in the Netherlands, over 65% of train passengers that depart from station Amsterdam RAI and Gouda reach the station by bicycle, whilst other stations attract hardly 25%, as statistics provided by Dutch Railways (NS) for this study indicate. Besides different numbers of bicycle-rail travellers per station, there are also different types. Commuters who ride inexpensive bicycles require secure parking facilities whilst families that take their bicycle on board for a leisure trip would wish convenient on-board services and ideally cycle route information at the station. A suitable supply of services should be realised to satisfy wishes of current bicycle-rail users, or rather unlock potential demand. This is however difficult. Bruno van Zeebroeck, a researcher who was involved in the EU-commissioned BiTiBi ("bike-train-bike") conference in March 2017 pointed out well:

"Implementing BiTiBi-services in a good way is easy.
There is only one thing easier: doing it wrong."

Knowledge is available on how to design bicycle-rail services and intentions are often good, but mistakes are made due to lack of experience or insight. This can result in low-quality or badly located bicycle parking spaces which remain empty, whilst nearby public bike shelters are packed, or lead to perfectly smooth routes inside stations but several barriers to reach the entrance. The question is how to invest wisely and ensure that good door-to-door journeys are facilitated there where demand is highest.

1.1.4 Challenge 2: strategic collaborations

There is another challenge when considering bicycle-rail in theory to practice. Also in the Netherlands bicycle-rail was not always commonplace. This is illustrated by the following history lesson. A more strategic approach was the solution to a growing problem in the nineties. Bicycle demand grew but the supply of particularly bicycle parking lagged behind. As many bicycle-rail users were unsuccessful in finding a dedicated bicycle parking spot, the public space quickly clogged up through fly parking ("weesfietsen"). When a number of large station development projects were planned simultaneously, more planned bicycle-rail integration became the norm (Kwink Groep, 2015; ProRail, 2016; Tijssen & Van Boggelen, 2007). Kaj Mook, integrated transport manager at NS (Dutch railways) and former employee at Abellio Group in the UK, was interviewed for this thesis' study and made a remark that illustrates perfectly the shifting mindset:

"Over the course of ten years, cycling changed from a necessary evil to
the lucky charm of NS."

The Dutch went from ad hoc programming to more strategic interventions to facilitate and even stimulate bicycle-rail use. The involvement of different parties, from railway authorities to operators, local, regional as well as national government and input from various action groups, developers and businesses was required (Martens, 2007). They together enabled the success of bicycle-rail. With the launch of the increasingly popular OV-fiets (public bicycle) in 2003 the last mile on the activity-end of the rail journey could be covered (Fietsersbond, 2011). The most recent example of collaborative bicycle-rail policy in the Netherlands is the Bicycle Parking Agreement ("Bestuursakkoord Fietsparkeren") signed in January 2016 (Ministerie van I&M et al., 2016), in which sixteen different parties (including national and local governments, private rail parties and cycling action groups) agreed upon a shared ambition and strategy for bicycle parking at stations. The newest developments include self-service for bicycle sharing and paying for parking after 24 hours, to deal with limited capacity.

Improving multimodal travel in general comes with its challenges, as different transportation systems need to be combined. The two challenges highlighted above indicate that particularly in the case of bicycle-rail, which is a fairly novel and niche combination in most countries, knowledge on how to do it well is limited. Ensuring that influential parties within these different transportation systems understand the benefit of bicycle-rail and actively work cooperatively is vital to delivering good bicycle-rail services along the complete trip chain.

Other countries can leapfrog the Dutch trial-and-error phase and facilitate bicycle-rail right from the start. The question is how to ensure both of the challenges described are overcome.

1.1.5 Zooming into Scotland

In Scotland - one of the four countries part of the UK, an attractive climate for increasing bicycle-rail use is found. The Scottish government has set an ambitious goal: 10% of daily passenger trips in 2020 by bicycle. They are putting money where their mouth is, investing 40 million pounds annually on cycling alone for the coming years (Transport Scotland, 2017). With a similarly ambitious train operating company that rolls out a "Cycle Innovation Plan", there appears to be an optimistic outlook for improving bicycle-rail use. As Scotland has both very remote and highly urbanised areas, the local differences are likely to be large and thus the tailoring for good bicycle-rail services clear - making it an excellent place to test the Station Scanner developed in this thesis. Furthermore, as a recent study indicated that particularly in Scotland many more bicycle parking spaces at stations are required (Jones, York, & Ball, 2015), Scotland is selected to test this research' findings on.

The introduction above describes the opportunity of bicycle-rail in theory. Dutch figures show that this opportunity can be seized in practice, but places like Scotland still have a long way before reaching similar levels of success. As mentioned earlier, general cycling cultures differ greatly: in the Netherlands over 25% of daily trips are undertaken by bicycle, in Scotland this is only just over 2% (KiM, 2015; National Statistics, 2016). However, bicycle-rail has additional benefits, requires different services and considers other users and stakeholders than cycling on its own. Considering the receptive context for bicycle-rail in Scotland as stated above, and national trends in rail and road (see paragraph 6.1.2) it appears that improving bicycle-rail will unlock a large potential demand. Moreover, the British Rail Delivery Group stated that *"Cycle-rail [is] one of the fastest growing segments [of] cycle use in the UK in modern times."* (2016). Making well-tailored services and strategy to improve bicycle-rail by strategic collaborations of the various stakeholders involved, can turn this theoretic opportunity into daily practice for many citizens.

1.2 Research objectives & questions

The introduction highlighted two challenges in seizing the opportunity for improving bicycle-rail. This thesis aims to assist in tackling both by answering the following main question:

Which factors influence the combined use of bicycle and train, and how can these findings be applied to help advise (Scottish) stakeholders improve bicycle-rail use?

The infobox below introduces the associated sub-questions. The relations between them and the report's structure is presented in Figure 4 on the next page. They are described in more detail after the figure.

RESEARCH QUESTIONS

Which factors influence the combined use of bicycle and train, and how can these findings be applied to help advise (Scottish) stakeholders improve bicycle-rail use?

The main question can be answered by the following seven sub-questions, namely:

1. What is bicycle-rail?
2. Why do people choose to use bicycle-rail and how can we make it more attractive?
3. Which factors influence the use of bicycle-rail?
4. How can better understanding in bicycle-rail use and its influential factors be translated into a practical tool to help find the opportunities for improving bicycle-rail use on station level?
5. How can a "Station Scanner" be created for Scotland?
6. Which Scottish parties can influence bicycle-rail use and how?
7. When does the opportunity for Scottish stakeholders to improve bicycle-rail use arise?

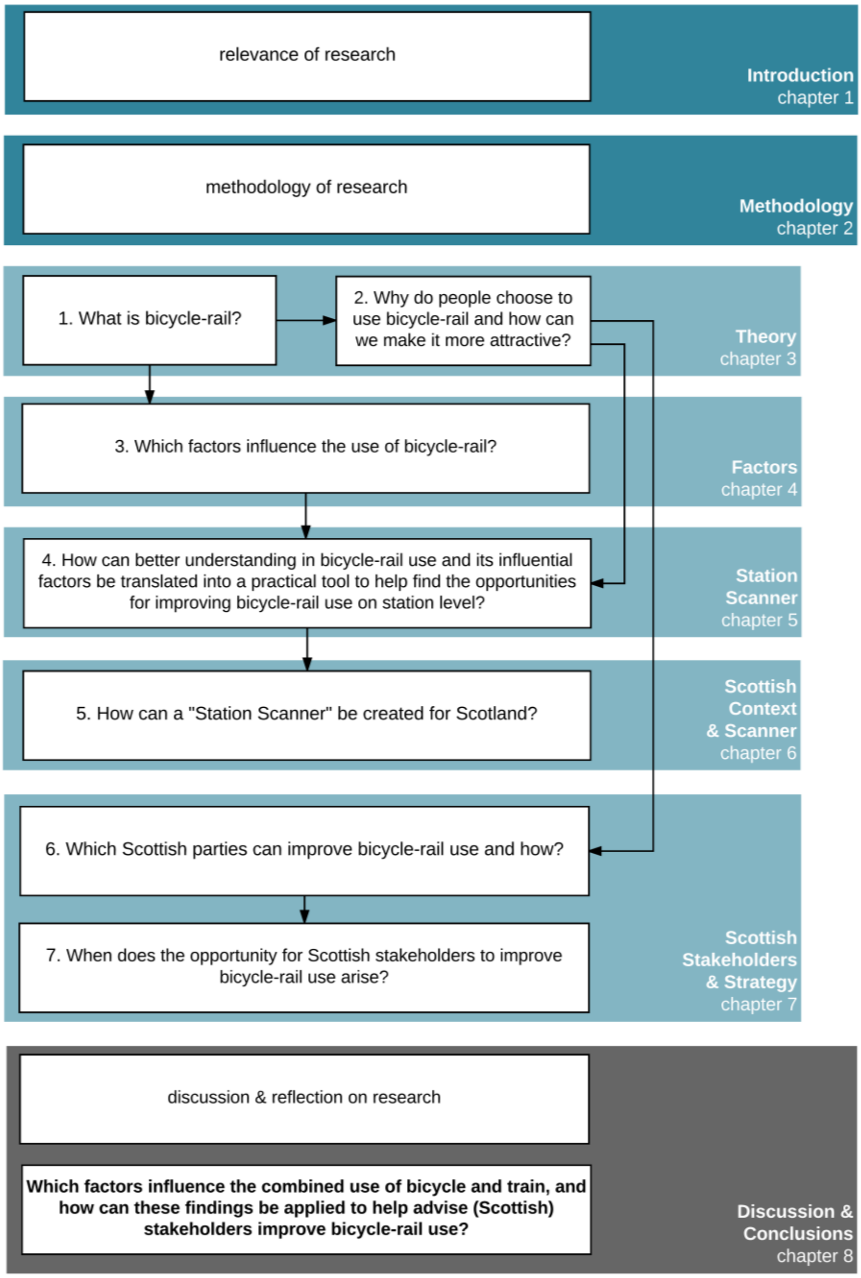

Figure 4 Overview research questions and report structure

The report is structured around the sub-questions. After the various research methodologies are introduced in chapter 2, the elements of bicycle-rail are described around the trip chain in chapter 3. The most prevailing ways to improve bicycle-rail are also presented here. Subquestions 1 and 2 combined ensure a common understanding of what bicycle-rail is and how it may be improved directly. Chapter 4 gathers and reflects on existing academic literature to present an overview of the various factors that influence bicycle-rail use in the wider context. Next, this theory is translated into a practical tool which scores the main factors that influence the demand for bicycle-rail use on a station level: the “Station Scanner” (chapter 5). Combined with a storyline on how to improve bicycle-rail use, this quick-scan gives a birds-eye view of a large set of stations and can help to make more strategic and tailored bicycle-rail services. The consecutive chapters zoom into Scotland. First of all by sketching the current situation for bicycle-rail use, and then by describing the development of a prototype Scottish Station Scanner (chapter 6). To gain understanding in the actual delivery of bicycle-rail services, the various influential stakeholders and their playing field are mapped. Finally, we identify where and when the opportunity for improving bicycle-rail use in Scotland can be seized chapter 7. With these findings, both challenges are considered in generic theory and Scottish practice, and the main question can be answered. After a detailed discussion and reflection on the research, the study's conclusions are presented in chapter 8.

1.3 Scientific and social relevance

This study has both scientific and social value, pointed out particularly in the paragraphs below. Recommendations for further research and practice are presented in chapter 8.

1.3.1 Scientific value

Much research has been done on the access, transit and egress parts of multimodal trips, capturing the importance of the complete door-to-door journey. However, the focus is usually on BTM (bus, tram, metro) or foot as feeder modes - as these are most common in the majority of countries. The option of cycling is often marginalised. As Dutch expert on bicycle-rail use Ronald Kager pointed out in personal communication in October 2016: any research on this topic now is part of paving the way for future research.

Much recent research on bicycle-rail is fragmented and much grey literature written in the Dutch language, making it inaccessible for non-Dutch audiences. The first generic part of this research (till chapter 5) attempts to bring this knowledge together and enlarge understanding of this upcoming modality to help advise practitioners. The literature review can provide a starting point for further research in any of the identified factors, and the translation into a quick-scan framework useful in understanding tools to tailor (transport) services.

In the second half, the research zooms in on Scotland. The main scientific value lays in the recommendations for the scanner and the stakeholder overview. Insight into the complexity of the stakeholders' playing field when two sectors (bicycle and rail; private and public) cooperate in a market-oriented economy to change the status quo can yield generic insights for further research.

1.3.2 Practical & societal value

The findings of this research help build a shared language for bicycle-rail practitioners and give an overview of existing tools to improve bicycle-rail use, like guidelines or audit scorecards. The research first gathers and then translates academic knowledge into a practical tool to make more tailored and thus better decisions to improve bicycle-rail use. When developed further, the output of the Scottish Station Scanner and stakeholder analysis may be of particular value for those wishing to improve bicycle-rail use in Scotland.

On a broader level, more bicycle-rail use has benefits for different parties. Various were introduced in this chapter, and are described in more detail in paragraph 3.3. The sustainability aspects are discussed in the green boxes as introduced on the next page. The added value of bicycle-rail itself is clear for:

- **Train operating companies** who can attract new customers in a larger catchment area, improve customer satisfaction among existing bicycle-rail users or improve the complete door-to-door journey's reliability. Research found that investing in station access or egress rather than the rail journey can be effective for lower costs (Krygsman, Dijst, & Arentze, 2004), whilst common practice is still to focus on the rail journey alone (Brons, Givoni, & Rietveld, 2009).
- **Travellers** who can find an additional cheaper, faster and/or healthier travel alternative.
- **Cities** which are less congested, have improved air quality, are healthier and more lively. Cycling infrastructure and parking additionally require less space in the public area.
- **Local businesses** near the station, as research has indicated that increasing levels of cycling has a positive spin-off effect on local economies (Blue, 2013).

- **Governments** who wish to see a shift to more sustainable and active travel, affordable and available to all.

The time is now to realise bicycle-rail theory in practice: both cycling and rail shares are increasing, governments are ambitious for more active and sustainable travel and a growing number of cities deal with similar issues like high mobility demands, congestion and air pollution. Practical experience in bicycle parking at stations and other measures has increased, making it less obscure and the number of best-practices is growing. Proactive and strategic ways of improving bicycle-rail use, rather than the initial Dutch responsive approach where supply followed demand, can stimulate and facilitate this growing sustainable and convenient mode.

From a more general planning and policy making point of view, the research is relevant to increase understanding of local variations that influence transport decisions. Initiatives like the EU project BiTiBi with bicycle-rail pilots in the UK, Belgium, Italy and Spain highlights the demand for knowledge sharing. There are no off-the-shelf solutions to become a bicycle(-rail) paradise. The literature review and Station Scanner developed in this study can offer a helping hand in the first explorative design and decision phases of improving bicycle-rail.

1. INTRODUCTION TO SUSTAINABILITY

Bicycle-rail is introduced in the literature as a sustainable opportunity for passenger transport. But what is sustainable? What makes bicycle-rail sustainable? How can interventions to improve bicycle-rail use be made sustainably? Using "Green Boxes" like this one, these questions are answered throughout this thesis. They can be read separate from the text.

What is sustainable? Derived from the Brundtland report, sustainable development can be seen as related to economic, social & human development and environmental & ecological health development (Goldman & Gorham, 2006). These three forms of development align with the framework of "Triple bottom line", similar to the "3P's" commonly used in the Netherlands: **people, planet, profit**. These frameworks can help to evaluate business plans or projects beyond profit alone and seek sustainability on the long-term. It can therefore also help us to understand how sustainable bicycle-rail really is.

The Green Boxes dotted around chapter 3 and 4 will consider the 3P's. The Green Boxes later in this thesis consider the sustainability of bicycle-rail services and reflect on the overall sustainability of bicycle-rail.

2 RESEARCH METHODOLOGY

The previous chapter introduced the main and sub-questions of the research described in this thesis. Each chapter answers one or several of the questions posed, with the most suitable methodology. This chapter will state the various methods used and explain the reasoning behind the selection of them. The first section explains this per chapter and related sub-question(s). Throughout the thesis, more detailed descriptions of the methods used and assumptions made are integrated in the text.

As stated, the main question this thesis aims to answer is:

Which factors influence the combined use of bicycle and train, and how can these findings be applied to help advise (Scottish) stakeholders improve bicycle-rail use?

Each paragraph describes one of the four chapters the research is divided over. Chapter 3 and 4 build upon existing literature, chapter 5 translates this into a practical framework of a quick-scan, created for and applied, on Scotland and chapter 6 is an explorative research on the playing field of the various Scottish stakeholders that can influence bicycle-rail.

2.1 Sub-questions 1 & 2: The bicycle-rail trip & services (Chapter 3)

1. **What is bicycle-rail?**
2. **Why do people choose to use bicycle-rail and how can we make it more attractive?**

Chapter 3 zooms in on the definition and elements of a bicycle-rail trip. Academic literature is first used to explain the trip chain and applied on bicycle-rail to provide a detailed trip chain. This is used throughout the study, to ensure a complete door-to-door journey integration of the modes and user perspective are considered.

The second sub-question requires more literature research to explain trip choice and value of time. Four different design guidelines on good bicycle-rail integration are studied and summarised. Only guidelines written for the EU and the United Kingdom are considered to ensure practical applicability for the later focus on Scotland: BiTiBi Guidelines, RDG cycle-rail toolkit 2, Sustrans Cycle and Rail Integration Design Manual and ScotRail Abellio Cycle Innovation Plan.

2.2 Sub-question 3: Influential factors (Chapter 4)

3. **Which context factors affect the use of bicycle-rail?**

This chapter aims to present the different factors that influence bicycle-rail travel in a structured manner by means of a review of the existing academic literature. The literature is selected through searches in the database of Google Scholar. A first search is done for combinations of keywords "bicycle/bike/cycle - transit/train/transit/public transport" and "bike/bicycle-and-ride/bike/bicycle-on-board". A selection of the results is made after reading the abstract, to only include papers considering "factors" (as defined in paragraph 3.1.2 in this report). Snowballing is used in a second search by looking at the reference list of the selected papers. In this chapter only academic work is considered and publications in the Dutch and English language.

The overview of the factors and their relationship to bicycle-rail use are found iteratively. By cross-reading the selected papers, an initial list of significantly influential factors (according to the studies reviewed) is made. Referencing software of Mendeley is used to summarise the main topics per paper. In a table, the described factors per paper are summed-up. Then, per factor, the various papers' relevant sections are re-read and summarised, and based on that, assigned a relationship with bicycle-rail use This approach ensured that influential factors are not only described in text, but also captured in more general relationships with ++, + , -, --

symbols or "depends" description. We are well aware that this last aspect is a simplification of reality and of relative size to other factors so it must be interpreted together with the text of the literature review.

Note that also studies on the combination of cycling and BRT (bus rapid transit), light rail and metro systems are included in this search, considering the limited amount of research that has been undertaken worldwide. As a critical reflection, the findings are discussed with Dutch cycling experts Roland Kager and Marco te Brömmelstroet. The discussion includes a comparison of the factors with a causal diagram on bicycle-train use in the Netherlands - the result of a group modelling session of twelve Dutch practitioners organised in 2014 (see Appendix A).

2.3 Sub-question 4: From theory to Station Scanner (Chapter 5)

4. **How can better understanding in bicycle-rail use and its influential factors be translated into a practical tool to help find the opportunities for improving bicycle-rail use on station level?**

The introduction of this thesis described how strategies and services for bicycle-rail are known, but tailoring supply to match (latent) demand remains a challenge (chapter 1).

The framework of the tool is developed in an overall highly iterative and creative design process. Already available tools are studied and built upon, factors from the literature review are combined and through logic reasoning, trial and error, and structuring of the findings, a final framework of two components and five steps is made. The "Station Scanner' is tweaked further as the prototype for Scotland develops in parallel (next sub-question). During the development of the tool, further input comes from Dutch engineering and consultancy company Witteveen+Bos and Scottish interviewees.

2.4 Sub-questions 5: Scottish context & Station Scanner (Chapter 6)

5. **How can a "station scanner" be created for Scotland?**

A small study into general passenger transport and particularly bicycle-rail use in Scotland is done via deskwork to better understand the context and test a number of assumptions required to build a scanner. Mostly grey literature published by government agencies is used. These are selected with help from the various interviewees as introduced later.

Next, the five steps as stated in the framework are followed to design and create a prototype "Station Scanner" for Scotland: collect data, organise data, score stations, visualise findings and give advice. The last step is not tested considering the limited scope of this study.

To gain more insight in data availability for Scotland, Neil Ferguson from Strathclyde Unversity and Marta Nicolson from the Urban Big Data Centre in Glasgow are consulted. More data sources are considered than used for the prototype. The final selection includes open data from Census Scotland, the Scottish Household Survey, ORR and Scotland's annual cycling monitoring report. Additionally, the train operating company Abellio Group provided station specific data from audits and British traffic consultants TRL shared the outcomes of a cycle parking estimation tool they made for Rail Delivery Group in 2013 with financing from RSSB. An overview of these different data sources can be found in Appendix H.

The organisation of data is done in spreadsheet software and for the station scoring percentile ranking statistics are selected. The data visualisation is done with Tableau software. Prototype dashboards are made with input from Mattijs Stam, a data management expert at Witteveen+Bos.

2.5 Sub-questions 6 & 7: Scottish stakeholders & opportunities (Chapter 7)

6. **Which Scottish parties can influence bicycle-rail use and how?**
7. **When does the opportunity for Scottish stakeholders to improve bicycle-rail use arise?**

To answer these questions, empirical qualitative data collection is required as no similar studies have been done so far that we are aware of. A combination of desk research on (policy) documents and semi-structured and open interviewing techniques is used for this exploratory research. These interviewing techniques are selected as being most suitable for exploring the context (Saunders, Lewis, & Thornhill, 2009, p. 322).

The findings are presented in various diagrams, following guidelines from Enserink et al. (2010, Chapter 4: Actor Analysis). An initial list of stakeholders to consider is derived from a review of the "potential parties" recommended in the RDG's Cycle-rail toolkit 2, for collaboration with TOC's and by looking into the partnerships mentioned in the cycle strategy of Glasgow (Rail Delivery Group, 2016; SUSTRANS, 2015). This list shrinks as insight in the relevance and influence of parties grows. Representatives of the main parties are interviewed using semi-structured interviewing techniques. Furthermore, for additional reflections on the playing field, a number of other parties are also interviewed. The list below gives an overview of the different Scottish interviewees used for this chapter and the parties they represent.

- Allan Comrie | Strathclyde Partnership for Transport (SPT)
- Clare Strain | Strathclyde Partnership for Transport (SPT)
- Collin Little | City Council Glasgow
- Conrad Haigh | Rail Delivery Group (RDG)
- Dave Holladay | Independent transport consultant
- Gordon MacLeod | Transport Scotland
- Iain Docherty | University of Glasgow
- Joost Mortier | Abellio Group
- Kaj Mook | former Abellio Group, current NS
- Karen Furey | Transport Scotland
- Kathryn MacKay | ScotRail at Abellio Group
- Matt Stacey | Abellio Group
- Peter Collins | Network Rail
- Tessel van Essen | Dutch Embassy
- Twan van Duivenbooden | Sustrans Scotland

A complete overview of all the interviewees of this research, their roles and interview dates can be found in the reference list at the end of this thesis. Semi-structured interviews are done to obtain different views on similar topics. In appendix A a list of the questions can be found. Setting-permitting, the interviews are audio-recorded, either via the Smart Recorder application or MP3 Skype recorder. During the interviews, notes are taken and translated into digital reports directly after. The quotes by and references made are verified and approved by interviewees via E-mail. Where requested, amendments are made. A more detailed description of the processing of the information is described throughout chapter 7.

The findings on the Scottish playing field are verified in a second round of interviews with Kathryn MacKay (Abellio ScotRail), Collin Little (Glasgow City Council) and as a second half of the interview with Karen Furey (Transport Scotland) to ensure internal validity. These parties are found to be most influential and thus suitable. The verification entails an open interview, where a diagram of the stakeholder's main roles, relations, and responsibilities are discussed to structure the conversations. The final diagram of stakeholders can be found in Figure 22 of chapter 7. The interviewees also reflect on the stakeholders' positions in the detailed trip chain. The second round of interviews ensured more reliable conclusions could be drawn from the findings.

3 THE BICYCLE-RAIL TRIP & SERVICES

The sub-question this chapter aims to answers are:

1. **What is bicycle-rail?**
2. **Why do people choose to use bicycle-rail and how can we make it more attractive?**

This chapter will first define "bicycle-rail" and the term "factors" which will be used frequently in this thesis (3.1). Second, a trip chain is used to describe bicycle-rail from a user's perspective and sketch the relevant context on a local level (paragraph 3.2). Next, the competition of the bicycle as a first or last mile solution to a rail journey is described, building upon the theory from the introduction. Also, the size and shape of a station's catchment area for cyclists are discussed (paragraph 3.3). In the last paragraph, we discuss what good bicycle-rail is and how to improve it directly with bicycle-rail services, based on various guidelines (paragraph 3.4.2).

3.1 Definitions

The definitions used in this thesis and how we arrived at them are presented here to better understand the vocabulary used by scholars and practitioners.

3.1.1 Definition of a bicycle-rail trip

This research uses the term **bicycle-rail** when a private or public bicycle is used as access and/or egress mode for a journey by train. Such a combined use of transport modes makes it a multimodal trip. The main travel segment is made by rail. A trip takes place between two separate points of origin and destination, unlike a tour which starts and ends at the same point.

The train is a rail transit mode. It is independent of streets and runs between stations of a considerable distance, often in large or medium-sized urban areas (Vuchic, 1981). In this research the focus lays on national, regional and commuter rail, thus excluding rail rapid transit with higher frequencies (e.g. lower capacity metro's) and light rail systems which require less heavy infrastructure and typically have a lower capacity.

The term **cycle-rail** is currently mostly used in British practice and comes from the Rail Delivery Group, with the national cycling action group Sustrans using the variation **bike-rail**. This thesis will adopt these terms. When distinguishing between bicycle-rail journeys with or without the bicycle on the train specifically, the terms **Bike-on-Board** (or abbreviation BoB) and **Bike-and-Ride** (BaR) are used (similar to the study by Ensor & Slason (2011)).

Other terminologies found in the literature include **bike-and-ride** (as a variation on park-and-ride) (Cervero, Caldwell, & Cuellar, 2013; Martens, 2004), **cycle transit use** or **integration** (or even **CTU** and CT-integrators) (Bachand-Marleau et al., 2011; Krizek & Stonebraker, 2010) or **bike-transit** and **bicycle-transit** (Pucher & Buehler, 2009; Villwock-Witte & van Grol, 2015). Note that these often included a larger range of transit vehicles than train alone.

3.1.2 Definition of factors

The introduction of this thesis highlighted the importance of understanding the context. The term "**factors**" is used to define the various elements that make up this context. There are many other words in the literature to describe such contextual factors. For example **characteristics** or **key variables,** as Van Acker, Van Wee, & Witlox (2010) use in their study to address how spatial and social context influence individual travel behaviour. In a study that builds upon their framework, Harms, Bertolini, & te Brömmelstroet (2014) use the term **determinants**. They look into various factors to explain differences in local Dutch cycling levels, dubbing them **socio-cultural aspects**, and referring to relevant developments as **aspects of change**.

3.2 Bicycle-rail as a trip chain

Before zooming into improving bicycle-rail, we should understand what it is. The trip chain is used as a way to structure our thoughts. Public transportation runs from station to station but people move from door to door. The components of a public transport trip chain are therefore typically described with at least two nodes (transit node 1, transit node 2) and three links (first mile, transit, last mile). Some bicycle-rail studies also include the points of origin and destination, and action of parking as trip chain components (Kager et al., 2016; Van der Loop, 1997).

3.2.1 Two bicycle-rail trip chains: BaR and BoB

Considering these different trip chains and the definition of a bicycle-rail trip (paragraph 3.1.1), two types can be distinguished: Bike-and-Ride (BaR) and Bike-on-Board (BoB), see Figure 5 below. This division indicates the different needs of BaR- and BoB-passengers - for example, the need to find a safe bicycle parking spot near the platform versus the need to find a spot for your bicycle on a crowded train.

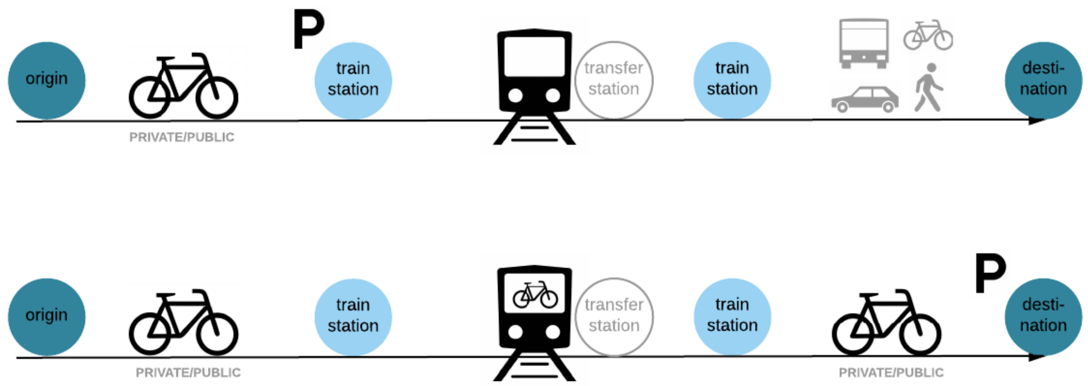

Figure 5 Combinations for a cycle-rail travel. Top) **Bike-and-Ride (BaR);** Bottom) **Bike-on-Board (BoB)**

During the train component of a trip, a transfer between trains may be made too, probably causing extra difficulty for BoB-travellers. As a general remark, it should be realised that particularly a public bicycle (like OV-fiets, Nextbike, Boris bike, etcetera) could be used on either end of the journey. Private bicycles are typically most popular on the home-end of the route as various studies indicate (KiM, 2016a).

3.2.2 Detailed trip chain

Some researchers zoom into the trip chain further. More spatial and demographic elements, as well as pre- and post-trip elements such as travel information collection or filling complaints have been mentioned as part of the bicycle-transit trip chain (Brand, 2015; Cheng & Liu, 2012; Van der Meijs, 2015). These steps from an individual's user perspective are gathered and linked to the trip chain in Figure 6 on the next page.

In discussion with Dave Holladay, a British rail and cycling expert, some more steps were added (e.g. be inspired, becoming a pedestrian upon arrival at the train station). For the sake of description, we assume the first leg of the journey is made by bicycle, both BaR and BoB trip types are explained for the transit and train component and the final destination may be reached by the same bicycle as taken aboard, a second private bike, or a public bicycle. Note that some actions only occur sometimes or for some people. For example, it may be expected people are only required to look up the route once and will only buy a BoB ticket if required.

The trip chains introduced in this section can be used as a point of reference both for those readers very experienced but possibly unaware of potential obstacles for new users, and those unfamiliar with bicycle-rail so far. The detailed trip chain is used explicitly as an analytical tool later in this thesis (Figure 21 in chapter 7) to map the situation in Scotland.

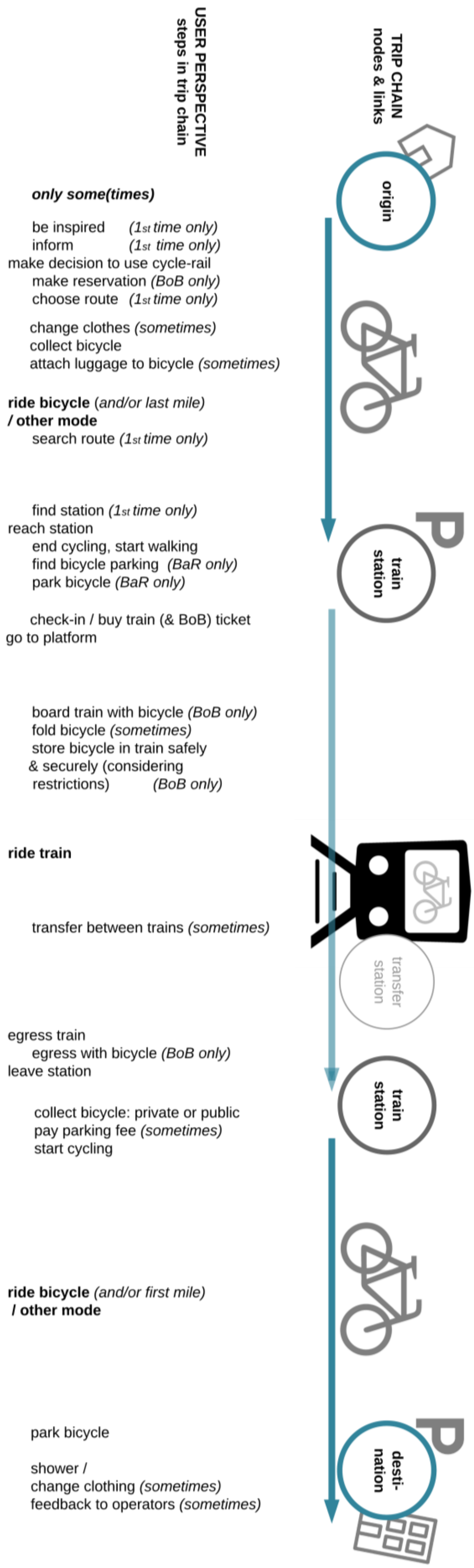

Figure 6 Detailed bicycle-rail trip chain. Visualisation by author.

3.3 Bicycle-rail as a competitive choice

Understanding bicycle-rail improvement requires understanding the choices that individuals make. If we wish more people to switch to sustainable modes like bicycle-ride we must understand why they choose a certain mode or even wish to undertake a trip at all. This section goes from abstract trip choice theory (3.3.1), to the importance of trip length for the bicycle as a first or last mile solution to connect to rail (3.3.2), the associated cycling catchment area (3.3.3) and the final paragraph (3.3.4) translates to the practical choice set for bicycle-rail.

3.3.1 Trip choice theory

Reality can be simplified to capture the most influential elements. A common method used to describe the mode choice for a trip (assuming it will be made) is the generalised utility formula. This line of reasoning assumes that people take the most attractive option in terms of cost, time, comfort, etcetera. They make a rational decision.

The two independent variables typically considered most relevant are travel costs and travel time. The more attractive (low costs, short travel time) the mode, the more likely it will be chosen. To compare travel time to costs, the minutes or hours are monitarised, using a certain "value of time". Theory of Peek & Van Hagen (2002) describes how the value of time for a public transport trip differs, depending on the moment in the trip chain. This is visualised in Figure 7 below. It shows that the first and last mile, and particularly the transfer time (or "waiting time") at or around a train station is valued lower than the rail journey. Decreasing the transfer time will have a larger effect on the overall attractiveness (or "generalised utility"), than the exact same decrease in train travel time. This will consequently make it more attractive compared to the alternative modes of travel, like the car. Linking to bicycle-rail use: improvements trip chain elements that affect transfer time may have a larger influence on its overall attractiveness than decreasing the travel time of the train journey.

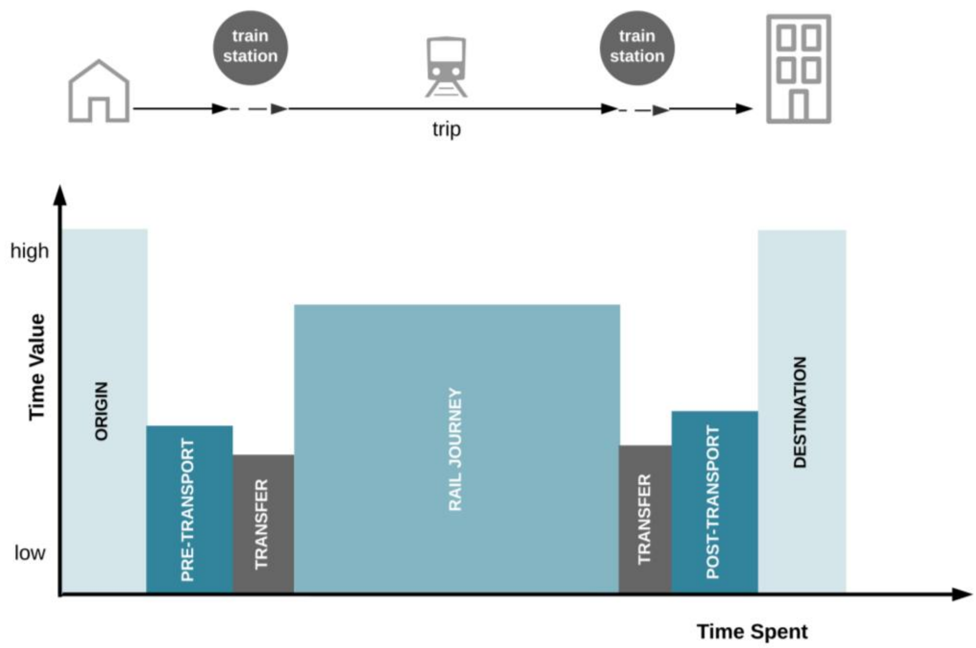

Figure 7 Different value of time along the trip chain, adapted from Van Hagen & Exel (2014)

2. PLANET BENEFITS

Does the planet benefit from more bicycle-rail? The more people choose bicycle-rail over car, the larger the benefit for our environment can be. A recently published evaluation report on the BiTiBi project (*bike-train-bike*) considers the environmental effects of modal shifts to bicycle-rail and considered fuel consumption, CO_2 emissions and energy savings for three projects in two years time. They consider the emissions of both the bicycle and train leg of the journey.

The project's survey found that prior to using bicycle-rail, 10% of respondents completed the whole door-to-door journey by car, 15% undertook the first mile by car and 20% switched from the car to bike share for the last mile. In a study in the Netherlands it was found that 8% of public bicycle users at the last mile would previously have taken the car for the whole journey. (Fietsersbond, 2011). Mode switch at these door-to-door trips are particularly valuable, considering their greater length of 40 kilometres on average in a number of EU projects (BiTiBi, 2016, p. 34).

The BiTiBi report translates these numbers into a calculation on decreasing emissions. The report assumes that if in the EU on average 20% of railway journeys in 2030 would begin by bicycle, an annual **reduction** of 800ktons of **CO_2**, 55 tons of **PM**, 250 tons of **NOx** and a decrease in **energy use** of 2,500 Mwh could be made annually (BiTiBi, 2017b, p. 4). Some critical notes should be made. Twenty percent is ambitious, as the current share is four percent. Another critical note may be that cars are getting increasingly energy efficient too. As the world's car fleet updates quicker than rolling stock (Smith, 2003), the added value of bicycle-rail may be smaller than expected.

A wider effect of more bicycle-rail use is that it may improve overall bicycle use - a mode that could particularly improve air quality in cities. The more people combine the modes, the more people get aware of the bicycle as a means of transport in general and discover it can replace other (motorised) modes too. More cyclists on the road also mean increased safety (Jacobsen, 2003) and as a spin-off help push the general cycling agenda and inspire a new group of people to try cycling. As stated: the more people seize the opportunity for bicycle-rail, the larger the environmental benefit.

3. PEOPLE BENEFIT

Do people benefit from improved bicycle-rail? When people are free to take travel choices, they are assumed to optimise their personal benefit. The text of this chapter presents bicycle-rail as a travel option which will be chosen when it is most attractive compared to its alternative. People switch from another form of transport to make the same trip with a different mode or make trips they otherwise would not have made.

The main benefits are twofold: health and improved mobility. When people switch from a motorised form of transport to bicycle-rail, the cycling and transfer parts of the trip require active movement. The relationship between exercise and **health** is well-known. Health effects are not only for bicycle-rail users themselves but also have indirect health benefits on societal level when reducing car use (e.g. effects of air quality), also when taking into account traffic injuries (Pucher & Buehler, 2010; Woodcock et al., 2009).

The second benefit is **improved mobility**. Bicycle-rail can enable people to make trips they otherwise would not have made, for example due to costs or a lack of access to a car or bus network to reach their destination or the station. Moreover, bicycle-rail can also increase equity for more remote or less affluent areas. The bicycle is an individual mode of transport and can thus reach locations too far to walk or not connected by the BTM-feeder network. Bicycle-rail use has a lower thresholds than car use (high costs, license required), making it accessible to more people. The benefit of an individual's improved mobility is clear. A possible indirect effect is that as people switch from car to bicycle-rail, there are less cars on the road, less congestion and thus more reliable and lower travel times for the remaining car users.

3.3.2 Trip length

The two common components for calculating the generalised utility were defined to be travel cost and travel time. Travel time relates directly to travel distance: it typically takes longer to cover thirty kilometres than ten kilometres, when using the same mode of transport.

The distance people are willing to cycle to a railway station varies in the literature. Averages can differ greatly, as the following numbers indicate. Cycling distances found in empirical research range from 1.8 (San Francisco) or 1.9 kilometres (Bollate, Como in Italy) on average up to 3.2 (Bolder, US), 3.7 (Bristol, England) and even 4.5 kilometres (Southport and Liverpool, England) (BiTiBi, 2016; Cervero et al., 2013; Krizek & Stonebraker, 2010; Sherwin & Parkhurst, 2010). A lower service level metro system in China found 2.6 km to capture 85% of users (Meng, Koh, & Wong, 2016).

Reasons for this could be local differences and/or depending on transit service level (Rietveld, 2000). This can again be interpreted as an argument to be careful with off-the-shelf solutions, as differences between stations surroundings as well as train services, systems and stations are large. Furthermore, research by Flamm & Rivasplata (2014) in Philadelphia and San Francisco found that the median travel distance lays lower than the mean, indicating that some people cycle much further than the average and distorting the practical use of this value.

The influence of distance on mode choice is clearly visualised in so-called "distance-decay"-graphs, of which a recent one based on Dutch OViN data is depicted in Figure 8 below. It shows the modal share per distance in kilometres, mapped out for station access (home-bound in the considered study) compared to egress (Shelat, 2016). It tells us that on distances below 500-1000 metres people rather walk. For trips of over 2 km (home-side) or 4 km (activity-side), people prefer BTM. Similar differences in home-bound and activity-bound journeys are found in both Chinese and Dutch studies (Krygsman et al., 2004; Meng et al., 2016). This may be a result of the added inconvenience of cycling the last mile (e.g. renting a bicycle or storing it overnight at the station), according to Keijer & Rietveld (2000) who found a similar result. An overall preference for walking over both cycling and bus seems international, up to a distance of 1 km (Chen, Pel, Chen, Sparing, & Hansen, 2012; KiM, 2015).

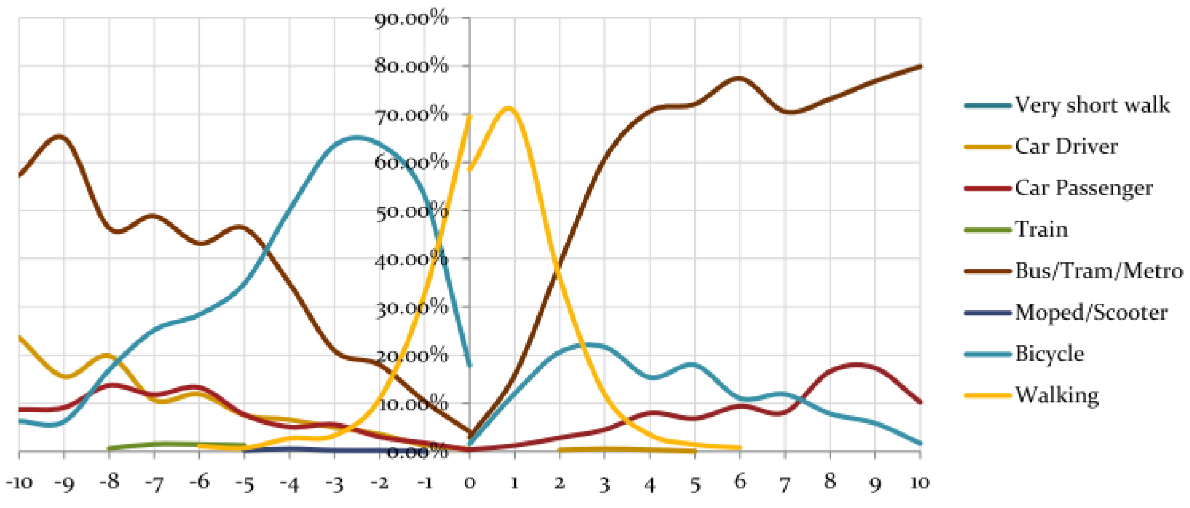

Figure 8 Distance-decay graph for the access/home-end (left) and egress/activity-end (right) trip for different modes to/from a train station, with distance in kilometres. Figure by Shelat (2016), based on Dutch OViN datasets from 2010-2015 in the Netherlands.

Perhaps also worth realising is the importance of the perceived distance: "*An individual who considers the train station easily accessible is more likely to travel by train*" (Heinen & Bohte, 2014). From this discussion, we learn that a various set of factors influence the distance that people are willing to cycle to a railway station. The aforementioned variations found for average distances seem plausible. Until around 1km, people will typically prefer to walk but for distances ranging from 3 up to 5 kilometres, many people can still be captured - particularly when considering lower travel time for covering the same distance.

3.3.3 Catchment area shape

The catchment area of a station captures the largest share (typically 90 percent) of its users points of origin and destination. It is often formulated in kilometres but more reliable when stated in units of (travel) time - a more reliable factor to understand travellers choices.

Typically, the shape of a catchment area is described as a perfect circle around the station. Whilst a very convenient method, this practice is datable due to barriers in the infrastructure (e.g. traffic lights, detours) or landscape (e.g. rivers or hills work as barriers). The practice is improving with isochrone maps to capture travel time rather than circles “as the crow flies”. Roland Kager describes how train stations attract people from comet-shaped regions in a high-density rail network: a result of people’s aversion to travel in the opposite direction of the train they wish to catch (personal communication, 2016).

That the shape of a catchment area can be even more diverse becomes clear in the research of Robert Cervero and his colleagues (2013), who mapped the different points to find the catchment area (“bike sheds”). Their images clearly visualise how these changed over time as cycling became more common and infrastructure expanded (Figure 9). A star-shaped area is then perhaps a more accurate description.

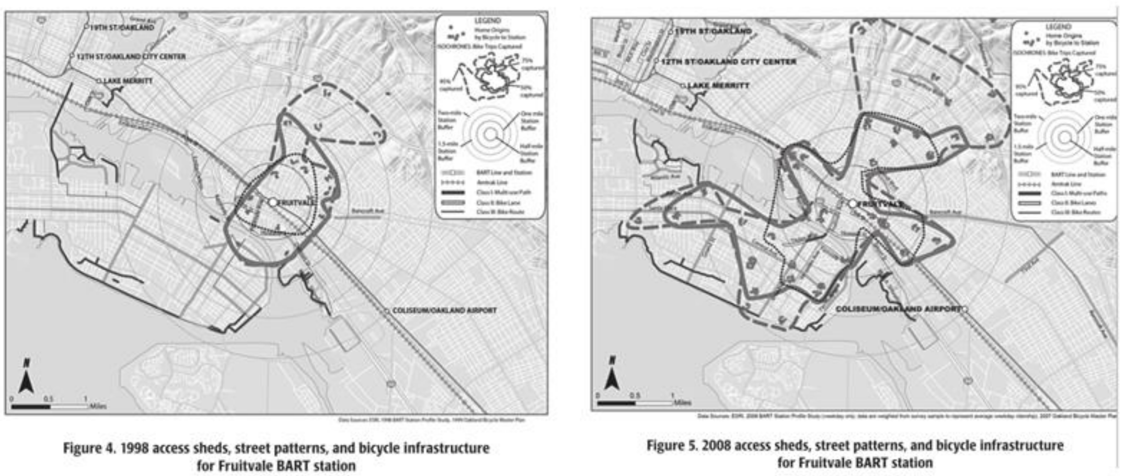

Figure 9 The catchment areas ("bike shed") of Fruitvale BART station in 1998 and 2008. Figures by Cervero et al. (2013)

The catchment area size and shape is relevant for this study when discussing how to improve bicycle-rail. It is in these areas particularly that potential bicycle-rail users go from or to, and where bicycle-rail services should be considered. To illustrate the potential of catchment areas: 60% of the Dutch population lives within five kilometres of a train station, and even 85% of the British. Thus, definitely on the home-side of the rail journey, a bicycle ride should be possible (Klinkenbergen & Bertolini, 2014; Rail Delivery Group, 2015).

To conclude, in many cases the bicycle-rail combination can proof an excellent travel option, both for door-to-door journeys and the bike as travel alternative for the first and last mile. As travel time is directly related to travel distance, the distance to a train station is a first and large indicator for bicycle-rail use. Considering this importance, we must bear in mind the great variation of catchment area sizes and shapes. Other factors that are of play are presented in chapter 4.

3.3.4 Competition other modes

Bicycle-rail will only be chosen if it is the most attractive in a set of options. This section describes some natural advantages and disadvantages of bicycle-rail compared to other modes. Both the door-to-door competitiveness of bicycle-rail to (particularly) the car, as well as the bicycle's position compared to the popular foot and BTM (bus, tram, metro) as a first or last mile solution to a train journey is described. It highlights the opportunity and benefits of bicycle-rail and when these appear most clearly, as was already introduced briefly in the introduction (chapter 1).

A cyclist is faster than a **pedestrian**, which increases a train station's catchment area, possibly up to 16 times (Rail Delivery Group, 2016; Sherwin & Parkhurst, 2010). This enlarges the group of potential rail users and decreases travel time for those previously walking. The competitive advantages grow further if e-bikes (pedelecs) are considered. For short journeys however, travel by foot may be quicker and particularly more convenient when considering the required time for collecting and parking a bicycle.

For train stations of greater distance from the point of origin or destination, the **bus, tram or metro** (BTM) can be excellent alternatives to a bicycle in both comfort and speed. However, particularly in suburban and rural areas those services can be limited, making the bicycle a perfect substitute, according to Canadian research (Engel-Yan, Rudra, Livett, & Nagorsky, 2014). Research in Helsinki on public bicycles also pointed out that particularly outside the city centre the comparative advantage can be large compared to BTM, presumably due to limited level of service there (Jäppinen, Toivonen, & Salonen, 2013). Furthermore, the bicycle is a private mode and thus more flexible and reliable than BTM, two of the main reasons why Dutch travellers choose the bicycle in general (KiM, 2015). This reliability is naturally important for commuters, the largest group of cycle-rail travellers in the Netherlands (Heinen & Bohte, 2014; Shelat, 2016).

A **car** travels faster than a bicycle in theory, but this is not always reality in congested or inner-city areas (Jensen, Rouquier, Ovtracht, & Robardet, 2010). Also, both the direct private costs for parking fees as well as the public costs for building parking spaces at stations are high. Many car parks in England are full from early day on, which decreases a station's accessibility the remainder of the day (Department for Transport, 2015, p. 18). Bicycle parking and infrastructure takes up far less space and requires lower investments than infrastructure for motorised vehicles (Wedderburn, 2013). Other downsides include the private costs for parking, ownership, maintenance and fuel, as well as the societal costs of congestion, air pollution, and large infrastructure investments.

Besides an excellent first and last mile addition to train travel, one can also consider the competitiveness of the bicycle-rail combination as opposed to the car as the sole transport mode for a **complete door-to-door trip**. The train can overcome longer distances easily but operates from station-to-station, whilst the bicycle and car are individual and thus flexible modes of transport. Where the flexibility and low costs of the bicycle are combined with the speed and convenience of travel by train, it makes a good alternative to a car journey - especially in peak-hour travel when also trunk roads are congested or people need to search for a parking spot, and travel time by car increases.

3.4 Bicycle-rail integration in theory & practice

We now have a shared understanding of what is bicycle-rail and why people choose it. The third sub-question of this thesis is: how can we make it more attractive? A chain is only as strong as its weakest link. The bicycle-rail trip chain is complex and consists of many different components, as Figure 6 in paragraph 3.2.2 earlier indicated. There are therefore many places and thus ways to improve and increase bicycle-rail use.

This section will first introduce what good integration of bicycle-rail entails from an academic point of view. Next, various guidelines are introduced. Finally, a number of main strategies and services of good integration are presented in an overview. This list does not intend to be complete but does convey an impression of how transport professionals, authorities and city planners currently facilitate and integrate bicycle-rail travel.

3.4.1 Bicycle-Rail integration in theory

In her thesis on the integration of non-motorised travel and bus networks, Brand (2015) defines four main types of integration: physical, network, fare and information integration.

The **physical integration** is described by Brand as "*seamless trips through the provision of efficient transfer facilities*". The paper by (Keijer & Rietveld, 2000) describes seamlessness as a function of waiting time, with a direct relationship to the frequency of transit systems. Parkin (2010) describes how "*a network of routes needs to be provided which is coherent at a fine level of detail and should offer many journey possibilities which minimize time, distance and effort*". This counts for all traffic users. **Network integration** considers higher level and more strategic planning. For example via White Papers or national transportation plans. Particularly with the use of a public bicycle or paid bike parking, an **integrated ticket system** can improve the convenience of bicycle-rail travel. Van der Loop (1997) links integrated payment systems among the different links of the trip chain as an important part of marketing the bicycle-transit as one seamless journey. Finally, the **information system** can be an important aspect in stimulating cycle-rail. With the extended user-perspective of (Cheng & Liu, 2012) pre- and after service stage, the importance of a good information system and customer service is clear.

To compare different levels of integration, one could look at the "**ladder of integration**" as suggested in a conference paper on integration for seamless travel (Preston, 2012). This suggests that some (parts of a) system(s) may be more integrated, requiring different interventions than those at a higher or lower level of integration. Furthermore, increasing more bicycle-rail usage implies behaviour change of passengers whom currently choose for other transport modes. Some transition time is required for this, as MaxSem theory suggests. This theory on behavioural change considers the following four stages: pre-contemplation, contemplation, preparation/testing and maintain (Carreno, Rye, & Bamber, 2009). Considering that cycling is not common in countries with overall low cycling levels, this lagging behind must be considered.

3.4.2 Bicycle-rail integration in practice

To introduce the practice, we like to copy a phrase from the Scottish' transport department's handbook "Cycling by Design 2010" (2011), where the chapter on integration with public transport mentions:

> *"People are **more likely to cycle** if the **journey** to the public transport terminal is **convenient** and there is **good, reliable provision of cycle parking** or **bicycle carriage** to allow them to **continue their journey** using public transport."*

Such a vision may be realised by following guidelines. A hands-on description of good bicycle-rail in particular comes from the **six building blocks for good bicycle-rail integration**, from the EU-coordinate BiTiBi project, based on Dutch practice (BiTiBi, 2016). The building blocks and associated barriers they aim to overcome according to the project's final report are shown in Table 1 below

Table 1 BiTiBi six building blocks for improving bicycle-rail and associated barriers, derived from (BiTiBi, 2017b, p. 5)

#	BUILDING BLOCK	BARRIERS FOR IMPLEMENTING BICYCLE-RAIL
1	Build safe, sheltered, and convenient **bike parking**	Lack of secure parking (first mile)
2	Offer convenient **public bikes**	Lack of shared bicycle systems (last mile)
3	**Unite** the bike-train organisations	Lack of coherence between bike and train service
4	Integrate **payment systems** of bike and rail services	Lack of fare integration
5	**Communicate** positively	Lack of knowledge among users
6	Safe bicycle infrastructure to the station	Lack of safe and bicycle friendly railway access (first mile)

The list clearly shows both "hard" physical interventions (parking, public bikes, payment system) and "soft" immaterial measures (unite, communicate), a common division made in transport policies in general (Harms et al., 2014). Point six of safe routes can be achieved by a combination, for example dedicated cycling lanes and education or legislation for all road users.

For this overview, a selection of guidelines was made, based on which were mentioned by the interviewees. Except for the BiTiBi evaluation report, with guidelines based on Dutch practice, they are all designed for use by British practitioners. Note that this selection has its limitations, and international good practices will certainly be missing. However, for this study, it is only intended to give an impression of current services, which must still be tailored locally. The guidelines and their publishers are summed up in Table 2.

Table 2 Guidelines for bicycle-rail services, more details in Appendix B.

SOURCE	TITLE	AUTHOR INFO
1	BiTiBi Services Guidelines (BiTiBi, 2014)	EU-funded pilot projects on bicycle-rail integration.
2	Cycle-Rail Toolkit 2 (Rail Delivery Group, 2016)	RDG (former ATOC) is the umbrella organisation of all British train operating companies.
3	Cycle and Rail Integration Design Manual (Sustrans, 2014)	Sustrans is a British cycling charity that aims to make cycling accessible for all ages and abilities.
4	Abellio ScotRail Cycle Innovation Plan (Abellio, 2015)	Abellio is a public transport operating company, running services in Germany, the UK and the Netherlands.

The various services mentioned in these documents are presented in an overview of 25 bicycle-rail service strategies summed up in Table 3 Summarized overview of solutions, as mentioned in the four guidelines below. They can be categorised at five locations in the trip chain: at origin/destination, the bicycle journey, at the station entrance/exit, at the station or along the BoB train journey. A sixth group applies to the whole bicycle-rail trip in general. The number in the third column of Table 3 indicates which of the aforementioned four sources describes the respective service in more detail. A complete overview of the different published guidelines of Table 2 as well as more detailed examples and design variations on the solution types of Table 3 can be found in Appendix B. It should be noted that some interventions have spill-over effects, think of wheelchair ramps at a station entrance or cycle highways connected to the railway.

Table 3 Summarized overview of solutions, as mentioned in the four guidelines. A detailed overview is in appendix B.

SOLUTION	DESCRIPTION	SOURCE
AT ORIGIN/DESTINATION		
Employer bike scheme	Via co-funding from employer people can get a bicycle, possible tax benefits	1, 4
O/D facilities	Additional to parking, other facilities may be of added value (for cycling in general).	1
O/D parking	Place to store bike securely at point of origin/destination, in- or outdoor, collective or individual. Possibly collaboration with employers, universities, etc. (for cycling in general).	1
BICYCLE JOURNEY TO/FROM STATION		
Cycling crossings	Road crossings with considerations for the cyclist	3
Cycle route maps	Maps with cycling routes, the stations are signed and marked	2
Cycling paths	Dedicated lanes on the road for cyclists. Should be safe, convenient and direct	3
Signposting surroundings	Signs from/to the train stations	2, 3
STATION ENTRANCE/EXIT		
Bicycle hub	building of varying size at the station, with typically a bike shop, tools to borrow, secure parking spots and information point combined	2, 4

Bicycle sharing	Last-mile solution of public bicycles. It can be back-to-one (B21), where people return the bike to the point of collection, or back-to-many (B2M) with stations. Development is dockless via e.g. Bluetooth. Can be seen more as service than profit making activity.	1, 2, 4
Last half mile to/from station	Particular attention to last half mile to or from station, as high density of all modes causes potential conflicts.	3
Seamless station access	Smooth access to and inside the station (for BoB or on-platform bicycle parking) with a bicycle	2, 3
AT STATION		
Bicycle parking location	A good location concerning both cycling routes and entrances to the station and platforms, where people feel safe and the bike is secure. BiTiBi describes "location as the absolute priority" for good parking	1, 4
Bicycle parking quality	Covered and where no damage to bike can be done. Ensure parking is visible	1, 2, 3
Bicycle parking quantity	Good estimation for the number of bicycle parking spots to prevent over- or under-capacity. Roughly 20% more racks than bikes, beware of snowballing effect (able to expand). Beware to remove abandoned bikes.	1, 2
Bicycle parking security	Ways to ensure that bicycles can be parked securely at the station	1, 2, 3
Signposting at station	Make parking visible, for 1st-time users and non-users. Also directions to bicycle hire	2, 3
TRAIN JOURNEY BoB		
BoB cycling carriage	Various ways to board and store bicycles securely and conveniently.	2, 3
BoB regulation	Regulations to cap use of BoB, concerning capacity limits.	2
THROUGHOUT TRIP CHAIN		
Award	Giving a price to motivate and inspire staff and gain publicity to put cycle-rail on the map	2, 4
Facility maintenance and management	Both bicycle (parking) infrastructure and information systems (e.g. websites) need maintenance	2
Information supply	Off- or online, and off and on station site information on BaR and/or BoB facilities and regulations	1, 2, 3, 4
Integrated ticket	High level of integration, for easy payment systems, processes, fares	1
Monitor bicycle-rail use	Monitoring before and after cycling use when improving bicycle-rail services to find effects	2, 4
Promotion	Targeted positive communication for cycling related topics	2, 4
Trial days	Removing barriers by introducing rail travellers to using a bicycle	2, 4

The guidelines also give recommendations for good collaboration to deliver the various services. This requires more general project and process management tools. How the relevant Scottish parties currently collaborate is described in chapter 7 of this thesis.

3.4.3 Variation in bicycle-rail use and demand

Paragraph 3.1.2 introduced the trip chain and mentioned the different needs of BoB and BaR passengers. There are more differences in bicycle-rail journeys and users to consider which we may wish to facilitate. Preference and possibilities of these different combinations vary per person, station, city, system and country. For example, the theory of paragraph 3.3 already taught us that bicycle use is much more common on the home-end of the journey. We then may assume that commuter stations in residential areas require more bicycle parking spaces than the destination stations in an office area, where bicycle sharing may be required more.

The Dutch practice has shown that transport practitioners and possibly the railway sector can actively steer a certain user. This should be borne in mind particularly concerning BoB, as there is a maximum capacity constraint in transit vehicles to consider. Train operators may regulate such use, for example via booking, a fee or limiting BoB to off-peak hours or certain routes only.

To illustrate how the share of BoB trips relates to BaR trips differ per place, consider the following. A recent presentation by the Rail Delivery Group (Haigh, 2017) showed that the number of bicycle journeys in the UK involving a bicycle has been 50/50 BoB and BaR during the last decade, with BaR slightly more common. Of the BoB trips, nearly 1/3rd involves a folding bicycle. In Bristol, England from 2010. 80% of cycle-rail travellers use their bicycle on one side of the trip, 15% took the bicycle on board (8% folding, 7% fixed bicycle), and 5% used a private bicycle on both sides (Sherwin & Parkhurst, 2010). Note that public bicycles were not available here. In the Netherlands, the sales of bicycle tickets on board the train (fixed frames) have increased by 15% the last five years according to a newspaper article (Eg, 2015), but no absolute numbers have been found. Nevertheless, with general bicycle-rail use increasing steadily on both sides of the trip chain (KiM, 2016a) and active policy in most trains to discourage BoB use (limited spaces on the trains, a daily fee of 6 euro and no BoB allowed during peak-hour at most train services) it can be assumed that the share of BoB compared to BaR is far lower in the Netherlands than the UK. No information on folding bicycles has been found.

This chapter introduced the bicycle-rail combination as an attractive travel option for many journeys. It can be described as a trip chain, to ensure the traveller's perspective is considered and create a shared language between stakeholders. It is most attractive as a first or last mile solution for travel distances ranging from 1 to 3/5 kilometres. Various bicycle-rail services are known from practice and published in guidelines, which can be grouped around the bicycle-rail trip chain. Besides trip distance, there are many other contextual factors that influence the potential result of such services. Briefly mentioned in this chapter were train service level, the competition of other modes, actual cycling travel time rather than distance and user type. We look further into these aspects in the next chapter.

4 INFLUENTIAL FACTORS

Chapter 3 described bicycle-rail as a trip chain and traveller's choice. Several interventions to improve bicycle-rail use were introduced. We may expect that more and better bicycle-rail services improve integration of the two modes and thus increase the number of users (Heinen & Bohte, 2014). There are however more factors that influence bicycle-rail use. These, for example, explain why the exact same bicycle shed will be crowded in one station, but empty at the next. This chapter presents the factors that influence the use of bicycle-rail according to the academic literature. It are these factors that should be considered when estimating the potential for bicycle-rail at a station and tailoring bicycle-rail services for their local context. This section aims to answer the following sub-question:

3. Which factors influence the use of bicycle-rail?

The first paragraph of this chapter highlights the importance of accounting for these factors and the consecutive chapters will summarize the literature review. As mentioned in the methodology chapter, also studies on the combined use of the bicycle with non-rail transit systems are included (chapter 2) . A complete overview of the factors discussed in can be found in Appendix C.

4.1 Introduction factors

4.1.1 Why capture local variation in factors

The last part of chapter 1 shared the important notion that off-the-shelf solutions do not work. Bicycle-rail services require tailoring to ensure a unique demand is met. This demand can be translated into user numbers and user types. Simply consider the different wishes of a commuting student on a cheap bicycle looking for a parking space at the station, compared to a geared-up recreational cyclist making a three-hour journey with an expensive mountain bike: different users, different wishes. However, considering the limited experience and research on bicycle-rail worldwide, the focus of this chapter lays on the first indicator of success: the number of bicycle-rail users. Whilst knowledge on good bicycle-rail services has been growing, a literature review on the underlying factors has not been undertaken as far as we are aware.

An illustrative introduction on the Netherlands highlights the relevance of understanding local variation. Even in a country where cycling is a daily means of transportation, and generally both hard and soft pro-cycling policies are in place, the levels of cycling vary from place to place. Other factors than these policies must then explain the variations. Different studies found factors that influence (rail-)cycling use in the "matured cycling country" of the. Harms, Bertolini, & te Brömmelstroet (2014) studied the variations of bicycle trip frequency and distance by spatial and social differences from the Dutch National Travel Survey. They found that particularly the population density, age and ethnical background determine bicycle use in terms of frequency and distance. Zooming into bicycle-rail use in the Netherlands, we may look at the study of van Hagen & Exel (2014) that presents the modal split for first and last mile of the six station typologies in the Netherlands - with station typology based on land-use and station footfall. Different typologies yielded different modal splits, for access as well as egress journeys (described in more detail in paragraph 4.3.3 later in this chapter). Assuming that in the Netherlands both general cycling as well as good bicycle-rail facilities are in place, these differences must thus be the consequence of other factors.

There is much consideration in the literature for such factors. The railway sector has been using and optimising passenger demand estimate models for decades to improve the train system and services, and the number of studies on factors that explain bicycle use has been growing as cycling gained popularity worldwide. An example of the latter is a book by Oldenziel, Emanuel, De la Bruhèze, & Veraart (2016) which analyses over twenty European cities and their cycling levels and describes how urban landscape, transportation alternatives, policy, social movements, and culture are important contextual factors for cycling success and shape bicycle culture and use.

Building upon this train of thought: the opportunity for bicycle-rail will vary locally. As bicycle-rail is still a peculiar choice of transport for many, let us begin with the low-hanging fruits first and seize the opportunity where it is largest. This chapter will pave the way for better understanding of where exactly those large opportunities arise, from an academic point of view. The consecutive paragraphs bring together the factors discussed in the literature. Where available, examples and studies from the UK, Scotland and the Netherlands are used, considering the scope of the second half of this research and the expected audience of this thesis report. Note that some factors are fairly fixed over time (population density, climate, location of train station), whilst others are more subject to change over time (train frequency, car ownership, cycling infrastructure).

4.1.2 Outline of paragraphs

The factors are clustered in three groups and presented in paragraphs accordingly as follows:

Paragraph 4.2 Context factors
Paragraph 4.3 Rail-related Factors
Paragraph 4.4 First/last-mile Factors

Each paragraph opens with an overview of the identified factors in a table to give a summarized overview of the text. The degree in which these individual factors influence bicycle-rail use is simplified with a ++, +, -, -- symbol, as was interpreted from the literature. They indicate "large positive influence", "positive influence", "negative influence", "large negative influence" respectively. The "depends" statement is used when the literature is contradictory. This may be a result of national differences, for example in the influence of education level or income on cycling use (Harms et al., 2014). After each table, the factors are described in more detail with references to the applicable scientific papers. A discussion on these relationships as well as overlapping relations between the factors is given in the next chapter 5: From Factors to Station Scanner).

As a final remark: these factors are a great simplification of the world's complexity and many of the literature studies discussed based on averages of the trip choice of many individuals. The relations reflect an even greater level of simplification, considering the limited generic transferability of findings. It is in combination with the text and understanding of travel choices that they should be interpreted. Nevertheless, capturing the differences in factors is a useful first step in estimating success the potential for bicycle-rail use at station level. A practical translation of this is presented in the ten clusters in chapter 5. A complete overview of the factors can be found in Appendix C.

4.2 Context factors

To understand individuals' motives, one must understand the larger context of a culture and attitude and typical user-characteristics. How is bicycle and rail use perceived? What characteristics do bicycle-rail-users share? How do transportation alternatives affect the share of bicycle-rail? What transport policy is in place? Answers to these questions will vary depending on where and to whom they are asked. Note that they are often more qualitative, making it harder to assign a direct relation.

Table 4 below gives an overview of the contextual factors discussed in this paragraph and indication for their effect on the number of bicycle-rail trips.

Table 4 Overview Context Factors, with indication of the factor's influence on bicycle-rail use and relevant sources.

FACTOR	RELATION	SOURCE
Culture & Attitude		
positive attitude towards cycling	+	Link between general cycling levels and perception (Rietveld & Daniel, 2004), (Pucher, Komanoff, & Schimek, 1999), (Miles Tight a et al., 2011), (Forsyth & Krizek, 2010).
positive attitude towards rail	+	General understanding of how mode perception influences use and vice versa (Heinen & Bohte, 2014), with attitudes varying per user type (Department for

		Transport, 2015).
low perception of barriers	+	Considering to try cycling. This is relevant as bicycle(-rail) use is limited in practice (Gatersleben & Appleton, 2007).
car as status symbol	-	According to Miles Tight a et al. (2011), but the bicycle is also winning ground. Heinen & Bohte (2014) consider further perception per user group.
User Characteristics		
high number of commuters	++	Commuting trip purpose scores high (Martens, 2007; Van Boggelen & Tijssen, 2007); (Wedderburn, 2013) (Flamm & Rivasplata, 2014), (Meng et al., 2016) and utilitarian travel in general (Bachand-Marleau et al., 2011).
high number of students	+	Strong correlation in various Dutch studies (Keijer & Rietveld, 2000); (KiM, 2014); (Martens, 2007); (Shelat, 2016).
full-time employment	+	Above average employment in general and full-time in particular (Sherwin & Parkhurst, 2010); Most bicycle-rail trips are work-related (KiM, 2014).
share of mid/higher income	+	Study in the UK (Sherwin, 2010) and in the Netherlands (Shelat, 2016) found bicycle-rail users are often higher income than average population (not than average rail user).
economic growth	+	According to reflection on Dutch bicycle-rail development (Van Boggelen & Tijssen, 2007).
high number of frequent rail travellers	+	Found by various studies (Flamm & Rivasplata, 2014), (Cheng & Liu, 2012; Krizek & Stonebraker, 2010). Also defined as route knowledge (Molin & Timmermans, 2010). Relates to frequent commuters and low perception of barriers.
high share of males	+	Found in England, China and the Netherlands (Heinen & Bohte, 2014; Meng et al., 2016; Sherwin & Parkhurst, 2010).
higher level of education	+	Influence of education (Heinen & Bohte, 2014)
many 20-39 year olds	depends	Slight advantage for young to middle-aged adults (Krizek & Stonebraker, 2010; Shelat, 2016; Sherwin & Parkhurst, 2010), CR-use increases with age (Meng et al., 2016) or does not affect use (Heinen & Bohte, 2014).
travel with heavy luggage	-	According to a stated preference survey in the Netherlands (Molin & Timmermans, 2010)
wearing smart clothes	-	In top-3 reason for not considering to cycle to the station (Sherwin & Parkhurst, 2010). Connected to both culture and trip purpose.

4.2.1 Culture & attitudes towards cycling, rail and cycle-rail

The culture around, perceptions of and attitude towards various modes of transport, are all contextual factors which influence a traveller's choice. Particularly the perception of cycling seems to differ per country or social group and is an interpretation of the actual number and type of cyclists or rail users. If only affluent white males cycle on expensive road bikes (dubbed Mamil in the UK: middle-aged man in lycra) or contrarily students on cheap bicycles, cycling will be perceived accordingly (Aldred & Jungnickel, 2014). The same counts for expensive train travel that only affluent people can afford or vice versa, the train (or bicycle) as a poor man's mode of transport who cannot afford a car. If many accidents take place involving cyclists, cycling will be perceived as dangerous and less people cycle. The correlation is evident. Negative or stereotypical perceptions can become a barrier to changing people's travelling habits. The phrase "cycling for all ages and abilities" used by various pro-cycling groups, indicates work is being done on changing perception and hopefully practice.

The **attitude towards cycling** is likely to influence its use but seems to differ greatly both between user groups and countries (Rietveld & Daniel, 2004). In the United States cycling is seen as a means of recreation (possibly with expensive bicycles) and children's activity, and only as a mode of transportation for lower-classes (Pucher et al., 1999). A similar low status is subscribed to both walking and cycling by a British study (Miles Tight a et al., 2011). How this can differ regionally clearly shows in a study in England where perceptions on cycling in four urban areas were compared (Forsyth & Krizek, 2010). In Hull, cycling culture is defined as "established", where people associate cycling with working class. In Cambridge however, it was described as classless, or even weakly associated with affluence. Hackney and Bristol residents felt cycling was for the middle class, with typically expensive bikes, compared to Hull and Cambridge.

Gatersleben & Appleton (2007) undertook a study in Surrey, South-East England and described the influence of **perceived barriers** to change travel behaviour to cycling. A majority of people indicated they would be interested in cycling if the circumstances were right.

It may be expected that the **attitudes towards rail** also vary. The Department for Transport regularly publishes a report on both users' and non-users' perceptions on the rail services in Britain. It indicates that perceptions strongly depend on the user type (e.g. commuter vs. leisure and frequent vs. non-rail user) (DfT, 2015b). Research on the perceptions of rail as a transport option, or attitudes towards (non-)users, rather than the service was not found using the search methodology as described in chapter 2.

The car a **status symbol** is well known, although some studies state this is changing. The bicycle too can be seen a status symbol, just think of the many hipsters now flocking the roads in Berlin or London (Miles Tight a et al., 2011). When considering attitudes per user group rather than country, more variation can be found. Heinen & Bohte (2014) found that Dutch bicycle-rail commuters are similar to single mode cycling commuters and even more similar to rail commuters with regards to their attitudes on different modes of transport. All travellers actually found cycling most **status-providing**, and all of them, except for the car drivers themselves have a negative belief regarding the status of car use. This may be specific to the Dutch. Car drivers also found public transport has a negative status. Quite interestingly, the cycle-PT users were most positive about public transport in general.

4.2.2 Characteristics of cycle-rail users

Traffic flows are the sum of travel choices made by individuals. Research on who are travelling by bicycle, by rail and even by bicycle-rail has accumulated over the years. This section focuses on factors for the combination of the two modes only. Naturally, if a region has high shares of cyclists and rail users, and they have similar characteristics, the potential for bicycle-rail can be expected to increase. A number of mainly **socio-economic factors** have been identified in different researches focusing on bicycle-rail over the last years. Research on trip purpose, education levels and employment rates and types are mentioned, then income, riding frequencies, and route knowledge are described. Age, gender, household size, and clothing are also highlighted.

To first state the obvious: if many people cycle and many people take the train, then we may assume more people discover the opportunity of the bicycle-rail combination. Although not mentioned as factors explicitly this can be derived from a number of studies (Kuhnimhof et al., 2010; Martens, 2007) The factors **high level of cycling** and **high level of rail use** should thus be included.

Many studies point out that **trip purpose** is a clear indicator for mode choice. Particularly commuter trips are found to combine the two modes gladly, for example in studies undertaken in the Netherlands, (Martens, 2007; Van Boggelen & Tijssen, 2007), New Zealand (Wedderburn, 2013), North America (Flamm & Rivasplata, 2014) and Singapore (Meng et al., 2016). Some of these also found high **shares for students**, the development described in a Dutch report (Keijer & Rietveld, 2000) and on user characteristics (Shelat, 2016). The Dutch national mobility report indicates 6 out of 7 bicycle-rail trips have **work** or **education purposes** (KiM, 2014).

In the Netherlands, the bike-rail travellers have a particular **small share of less-educated** travellers, which could reflect typically shorter commuting distances of this group, according to the researchers (Heinen & Bohte, 2014). In a study in Bristol, England, Sherwin & Parkhurst (2010) found that 89% of the bicycle-rail users were **employed**, of which 81% **full-time**, both higher than the national average. Greatest interest of current train-travellers to switch to cycle-rail comes from **utilitarian travellers**. **Recreational** and **non-cyclists** are least likely to switch (Bachand-Marleau et al., 2011).

Typically, train travel is one of the more expensive forms of public transport. Particular frequent train users have **higher incomes**, and bicycle-rail integrators reflect this according to a case study in Bristol, England

(Sherwin, 2010). Shelat (2016) found similar results based on datasets in the Netherlands, with an exception for students who have a low income but use the bicycle-rail combination frequently. In a Dutch publication (Van Boggelen & Tijssen, 2007), **economic growth** in general was also identified as a main driver in the growth of bicycle-rail share.

Possibly aligned with perceptions of barriers to try bicycle-rail use, a higher **riding frequency** was found to have a positive effect on bicycle-rail use (Flamm & Rivasplata, 2014), for bike-on-board travel in Taiwan (Cheng & Liu, 2012) and as translated in a tool by Krizek & Stonebraker (2010). These studies all defined around 3x/week as indicative. Do note that also full-time employees may not always make the same trip, as a result of more flexible working. A public or folding bicycle may then be more interesting than a second private bike.

The finding that frequent travellers make recurring trips (like commuters) choose the bicycle-rail combination aligns with research by (Molin & Timmermans, 2010) who described **route knowledge** to make bicycle-rail more likely**.** Thanks to portable navigation devices (e.g. Google maps on a smartphone), getting knowledge about routes may be easier and thus navigating from the station to the point of destination.

The influence in trip choice by **age** is debated and seems to vary between countries. Naturally, cycling demands a certain level of physical fitness and responsibility. Small children or people struggling with physical problems are thus less likely to undertake a bicycle journey. 40% of bicycle-rail users in the aforementioned English case study were in their thirties (Sherwin & Parkhurst, 2010) and Krizek & Stonebraker (2010) identified 20-39 years of age to capture higher levels. In Singapore cycle-rail levels increased with age, although it must be noted here data was collected during peak time only, so possibly not reflecting those above retirement-age and less fit (Meng et al., 2016). According to Heinen & Bohte (2014), within their study group of a Dutch population of 18-65, age is not a factor and the same was found by Flamm & Rivasplata (2014) when comparing the Californian cycle-rail respondents of their study to the average transit passenger there. Shelat (2016) however mentioned that ages 17-27 are over-represented among bicycle-rail users in the Netherlands. This again indicates the importance of knowing national differences.

Another factor is **gender**, particularly on the cycle part of the trip. Whilst in Denmark and the Netherlands both men and women cycle a similar share of their trips, in countries where cycling is less common, men typically take the lead. This will reflect in the share for cycle-rail, for example, 71% of bicycle-rail integrators in the study in Bristol are male (Sherwin & Parkhurst, 2010) and in Singapore men chose bike and foot over the bus, whilst women preferred bus and foot over a bicycle (Meng et al., 2016). Perhaps surprisingly considering the overall equal overall bicycle use, a similar result was found in the Netherlands. Heinen & Bohte (2014) saw a larger share of male bicycle-rail users, whilst bicycle-only had a majority of women, and transit-only equal shares of the genders. A link has also been made between gender and aforementioned perceptions. The study in Taiwan highlighted how men felt more able to overcome inconvenience in the BoB-trip, particularly when “entering into transit stations with bicycles”. An explanation may be that at some train stations the bicycle must be carried up or down stairs where men’s larger physical strength can come in handy.

Carrying **heavy luggage** or wearing **smart clothing** like a suit or heels can also decrease the choice for bicycle-rail (Molin & Timmermans, 2010; Sherwin & Parkhurst, 2010). In the English study “smart clothing” even came in third after station too far away and lack of secure parking as railway passenger’s reasons for not considering access by bicycle. These are harder aspects to find from socio-economic data but are interesting to bear in mind when considering services, e.g. offering cargo bike parking space at stations or clothes lockers in the workspace.

On a broader note, the difference in bicycle use between demographic groups (e.g. age and gender) seems to decrease as overall cycling shares increase (Harms et al., 2014). This may well apply to bicycle-rail use: the more common, the more people use it.

4.3 Rail-related factors

As described in the two types of trip chains in chapter 3.2, travellers that park or rent a bicycle at the station (bike-and-ride users) are similar to other train users once they parked their bicycle, whilst bike-on-board travellers will experience different transfers and train rides. This counts particularly for those with a fixed frame rather than a foldable bicycle.

The literature highlights a range of different factors related to the rail network, train station, and rail journey. Trains run on rails which together form a set network in the physical landscape. Typically rail networks are described as a set of nodes, connected by links. Some nodes and routes in the rail network types seem more likely to attract cyclists.

The various factors are described in these three categories in the section below.

Table 5 Rail Related Factors, with indication of the factor's influence on bicycle-rail use and relevant sources.

FACTOR	RELATION	SOURCE
Rail System		
direct routes (no transfers required)	+	People only undertake a maximum number of transits (1 transfer or 2 modes is best) and are thus particularly willing to switch from BTM-rail to cycle-rail if this means one less transfer (Bachand-Marleau et al., 2011; Heinen & Bohte, 2014)
high train service levels	+	Higher level train services (e.g. greater distances, speed, directness) attract more rail users (Blainey, 2010; Verschuren, 2016) in general and thus bicycle-rail users (Martens, 2004); Stefan de Graaf, personal communication
Rail Journey		
(rail) trip of significant length (min. 10-15km)	+	Catchment area increases with rail journey travel time (Flamm & Rivasplata, 2014; Krygsman et al., 2004) and transfer only pays off on longer distance (Van der Loop, 1997)
Station Typology		
station at small or medium-sized city's centre, out of town or urban areas with parking	+	Interpretation of numbers from study by Van Hagen & Exel (2014) and study of Cervero et al. (2013), also related to competition other modes.
urbanised areas (e.g. population density and jobs in zone)	+	Popularity for multimodal travel in general (Van Nes et al., 2014)

4.3.1 Rail system

There are different types of passenger train services as well as network typologies. Some rail systems or stations seem to be more likely to attract cyclists.

Both the study by Bachand-Marleau et al. (2011) as well as Heinen & Bohte (2014) found that if people are able to substitute one leg of their journey currently undertaken by (any form of) public transport with the use of a bicycle, they are more keen to switch. This aligns with the common theory that people have a dislike for transfers. Train services that operate **direct routes** are then more attractive for bicycle-rail integration, and those currently undertaking their first/last mile by BTM particularly likely to switch (more on this in 4.4.3). We may assume that particularly BoB users with a fixed frame bicycle experience greater reluctance to transfer during their journey as they need to carry it (similar to "travel with heavy luggage" from the previous section) further underpinning the influence of this factor. Also, it implies that people may travel to a railway station further away than the one most near to catch a direct train. Strategic decisions can then be made e.g. on whether to facilitate park & ride or rather bike-and-ride at such stations.

Bicycle modelling expert Stefan de Graaf from Goudappel Coffeng argued a similar concept when stating that particularly stations with "**intercity train services**" attract cyclists from greater distances and thus more users, than small stations only serving sprinter trains (personal communication, 2017). Sprinter trains halt at each station whilst intercity trains leave out a number to allow faster journeys between larger stations. This aligns to a station's attractiveness: a station's popularity decreases if a station of higher service level is close by, as findings from a study in Wales and England show (Blainey, 2010). Similarly, higher train capacity (often related to line frequency) will attract more travellers in general (Verschuren, 2016) and it can be assumed the absolute number of cycle-rail users then increases too. This aligns with the overview on modal splits per PT-type by (Martens, 2004) which shows regional train is more attractive for cyclists than suburban trains.

4.3.2 Train journey

The largest part of the bicycle-rail combination is the train journey, both in terms of time and distance. Nevertheless, a study in the Netherlands using active travel diary indicated that 30-50% of the travel time is spent on station access and egress (Krygsman et al., 2004) with similar findings in the US (Flamm & Rivasplata, 2014). It can be concluded that to compensate for the extra time required to and inconvenience of collect and park or board a bicycle, the rail journey must be of **significant length**. For short trips, people may be more inclined to cycle the whole trip or use the car for greater convenience. A similar discussion stating that for bicycle-rail the travel distance must be at least 10-15 km was also found (Van der Loop, 1997).

4.3.3 Station typology

There are many studies on station attractiveness and accessibility available, ranging from its cleanliness to location in the network and from the feeling of security to the amount of benches (Groenendijk, 2015). The station's spatial location also influences the share of cyclists it attracts and produces. The Dutch Railways (Nederlandse Spoorwegen) use six typologies to classify their railway stations, based on the train service level and its location in the urban network as Table 6 below indicates.

Table 6 Station typology in the Netherlands. Note that footfall roughly corresponds to type (with type-1 attracting most passengers). Information from Van Hagen & Exel (2014).

STATION TYPE	TYPE 1	TYPE 2	TYPE 3	TYPE 4	TYPE 5	TYPE 6
n of stations	6	30	11	95	85	51
train service	high-speed	intercity	intercity	sprinter	sprinter	sprinter
location	city-centre, big city	city-centre, medium-sized city	city-edge	city-centre, town/village	city-edge, suburban	out-of-town

A study by van Hagen & Exel (2014) presents the average modal split for first and last mile travel of the six typologies. When compared to the average of all stations combined, three types stand out for their larger shares of cyclists both for access and egress (as can be derived from Figure 10 and Figure 11 on the next page): the type-4 **"sprinter" train stations in smaller city centres** like Zwijndrecht (on average 5% more cyclists above the mean on the access side, 3% on egress), the type-6 **"sprinter" train stations out of the town centres** like Putten or Hillegom and also the type-2 stations with "**intercity" trains in medium-sized city centres** such as Den Bosch or Leeuwarden score slightly above average. The bicycle-rail success of type-6 may seem surprising as rural areas imply long travel distances but it also implies lower BTM services, and it must be noted that all forms of individual transport score above average here. Also, note that the Dutch idea of out-of-city-centre is probably not that far considering the country's high population density.

Note that these numbers are slightly contradicting to what paragraph 4.3.1 indicated: higher service level indicates more bicycle-rail use. However, the Dutch numbers refer to shares of cyclists: if 30% of 20,000 railway passengers arrive by bicycle, or 50% of 2,000 - the first demand requires more bicycle-rail services than the latter. Higher service level does indicate more passengers (Verschuren, 2016). Least popular stations for cycle-use are type-3 "intercity" stations at the city-edge like Rotterdam Alexander (7% below average for the first, 6% for the last mile), where BTM takes a large share. Another Dutch study indicated that the main growth of cyclists over the years occurred at the commuter towns around the turn of the century ("voorstadstations") (Van Boggelen & Tijssen, 2007).

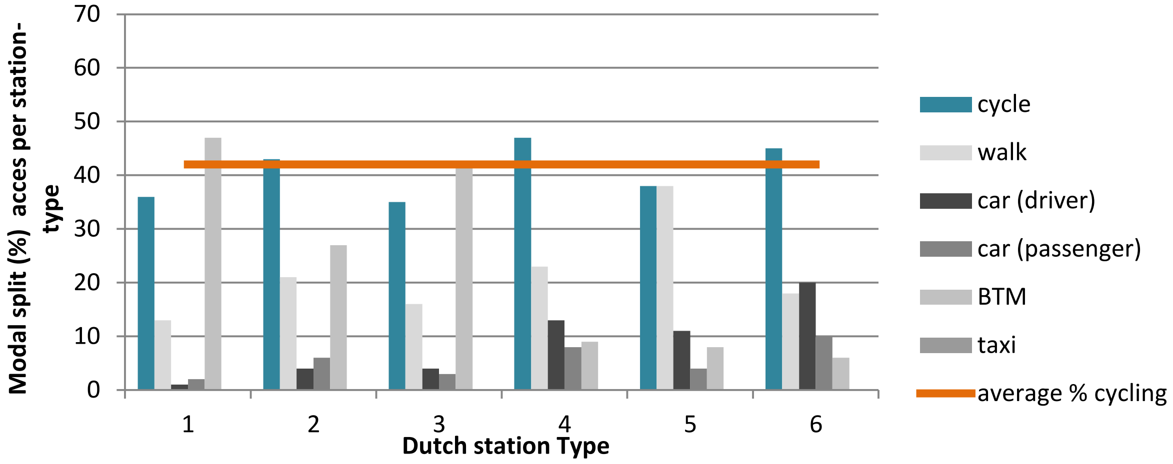

Figure 10 Modal splits of access to the 6 Dutch train station typologies (adapted from (Van Hagen & Exel, 2014))

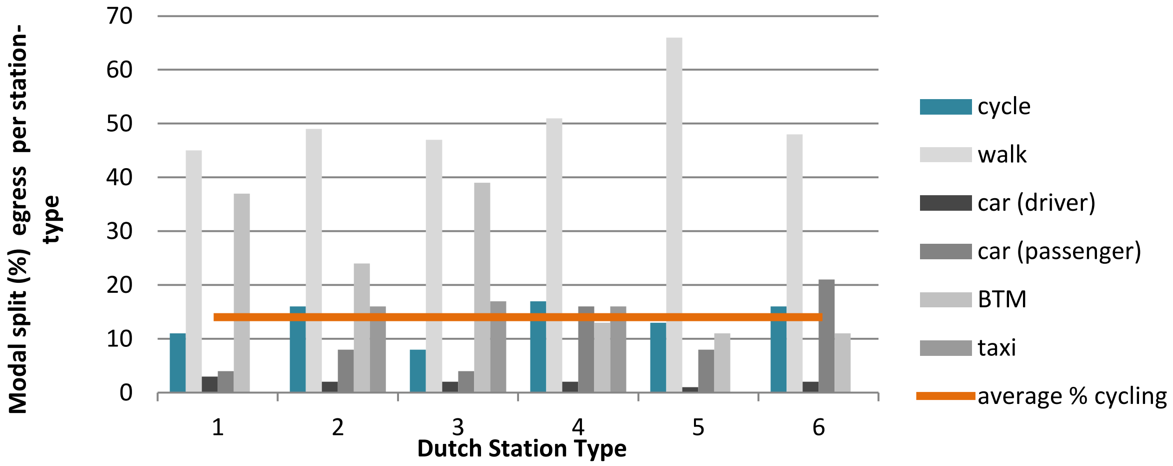

Figure 11 Modal splits of egress from the 6 Dutch train station typologies (adapted from (Van Hagen & Exel, 2014))

A variation on this typology comes from the research by Cervero et al. (2013), who divided the 42 light rail stations in the San Francisco Bay Area in five categories based on urban setting and parking provisions. Note that the transit service offered at each station was identical (same frequencies, fares, etc.). The "**urban with parking**" station type was found to have the largest share of access by bicycle (7% in 2008). This type is somewhere in between the Dutch type 2 and 4: a station in an urban environment with enough space to provide car parking, thus probably not fully downtown. The next two most popular types are "urban" and "intermodal-auto reliant". Studies on bicycle-rail travel by station type in other countries have not been found.

On a more system-wide level, multimodality is most common in urbanised regions, mentions a Dutch study. Whilst e.g. cycle-bus and car-rail are also included, the train comprises nearly 90% of multimodal trips and of those nearly half is bicycle-rail on the access side and 10% on the egress side - again mostly in peak hour, aligning with findings from paragraph 4.2.2 on trip purpose. Particularly the cities located more centrally in the rail network are more popular for multimodal travel, including bike-train (Van Nes et al., 2014). Concluding, the exact influence of station location and typology is somewhat unclear but some rough factors indicating the role of a station's location in both the land-use and railway network can be derived from those.

4.4 First/last-mile factors

The bicycle leg of the trip is an important component. The competition with other modes is also most evident on this limited space. Naturally, a bicycle journey to or from a train station naturally shares many characteristics with other bicycle journeys. The overview in this chapter aims to focus on studies that look into bicycle-rail trips in particular and sum-up the relevant competition with other modalities.

Table 7 Overview first/last-mile factors, with indication of the factor's influence on bicycle-rail use and relevant sources.

FACTOR	RELATION	SOURCE
Regions bike ability		
long summers / many hours of daylight	+	Indicated for bicycle-rail (Bachand-Marleau et al., 2011) and derived from a study (Flamm & Rivasplata, 2014)
hilly	-	Research for cycling in general (Harms, Bertolini, & te Brömmelstroet, n.d.; Parkin, Wardman, & Page, 2008; Rietveld & Daniel, 2004)
low temperatures	-	Weather was found relevant (Cheng & Liu, 2012)
rainy weather	--	According to (Cheng & Liu, 2012; Molin & Timmermans, 2010; Van Boggelen & Tijssen, 2007) and a research from Bickelbacher in 2001 as described by (Martens, 2004)
Bicycle Journey		
good quality of cycling lanes	+	Attractive route defined by (Krabbenborg, 2015) and explaining bicycle-rail use growth by (Cervero et al., 2013)
high quantity of cycling lanes	+	As derived from studies by (Cervero et al., 2013; Krizek & Stonebraker, 2010; Singleton & Clifton, 2014)
often right of way	+	Mentioned by (Krabbenborg, 2015; Scheltema, 2012)
large number of other cyclists / bicycle lane volume	+	From Dutch survey by (Krabbenborg, 2015) and a study in Singapore (Meng et al., 2016)
direct cycle routes to station (directness)	+	Described as linearity, continuity, right of way to bicyclists, etc. (Scheltema, 2012), with right of way verified by a Dutch survey (Krabbenborg, 2015) and generally tying-in with reliability as important for train users (Brons & Rietveld, 2009)
high bicycle ownership	+	Relevant for the home-station trip part (Keijer & Rietveld, 2000; KiM, 2016a)
good bicycle storage facilities at/near home/office	+	In a discussion on what bicycle-rail requires by (Pucher & Buehler, 2009)
lack of safety	--	A dissatisfier for cycling to a railway station according to (Scheltema, 2012)
Competition other modes		
high level of cycling	++	Higher share of cycling means a larger number of potential bicycle-rail users. Integrated in various bicycle-rail demand modelling studies (Ensor & Slason, 2011; Geurs, La Paix, & Van Weperen, 2016; Krizek & Stonebraker, 2010)
high level of rail use	++	*See "high level of cycling"*
trip distance first/last mile 1 - 3/5 km	++	*See paragraph 3.3.2.*
much congestion for cars	+	Given as reason by survey respondents in the UK (Sherwin & Parkhurst, 2010)
good BTM network	-	In terms of frequency and distance to bus stop (Brons et al., 2009; Meng et al., 2016; Pan, Shen, & Xue, 2010)
available and affordable car parking	-	(Brons et al., 2009; Sherwin & Parkhurst, 2010)
high car ownership	--	(Heinen & Bohte, 2014; Meng et al., 2016; Parkin et al., 2008; Shelat, 2016)
Inexpensive BTM	--	A low price (La Paix Puello & Geurs, 2016) or even free ticket (for students) (Keijer & Rietveld, 2000)

4.4.1 Region's bikeability

There are a number of geographical features that describe bicycle uptake in general and bicycle-rail levels in particular. At a regional and city level some shared characteristics include the weather, hilliness and city size. The influence of weather is considered in various studies and even defined as "main external factor" by a study in Taiwan of Cheng & Liu (2012), although user experience can differ. Weather conditions were defined by rain, wind, and temperature. **Rainy weather** has a "large impact" according to a stated preference survey among rail users in the Netherlands (Molin & Timmermans, 2010) and ranked high as well by Van Boggelen & Tijssen (2007). A small but much quoted empirical research by Bickelbacher in 2001 (found in Martens (2004)) found a decrease in the share of cyclists to a Munich metro station from 16 to 6% on rainy days. **Seasonal differences** indicated a doubling of bicycle-rail use in summertime in the study. The type of users may, however, differ too, as Bachand-Marleau et al. (2011) describe how users cycle more in summer but increase their overall public transport use during the winter - capturing a predictable substitute. Note however that bicycle-rail can also become more attractive on rainy days when compared to cycling the whole way. 33% of cycle-rail users in the US mentioned: "*avoiding bad weather or riding in the dark*" as a reason to chose for the combination (Flamm & Rivasplata, 2014). Note this was posed as one question, making it uncertain what was the reason for people to choose it.

The effect of **hilliness** has been mentioned often in general cycling literature and captures local cycling levels (Harms et al., n.d.; Parkin et al., 2008; Rietveld & Daniel, 2004) but no research has been found that particularly zooms into this aspect for bicycle-rail trips. (Flamm & Rivasplata, 2014) did find in a survey among bicycle-rail users that hilliness may actually increase the use of bicycle-rail compared to bicycle-only trips - arguably trips that else may not have been made at all. Depending on the local routes to/from stations and based on the findings from general cycling literature, we may expect hilliness negatively influences bicycle-rail use.

4.4.2 Bicycle journey

Naturally, good bicycle journeys in general will lead to a good bicycle journey as part of a cycle-rail trip. In this section, the focus is however limited to bicycle-rail literature on the bicycle journey. Two Dutch theses considered the bicycle journey to train stations in particular. Scheltema (2012) designed the pyramid scorecard as shown in Figure 12 below, a variation on Maslow's "pyramid of needs" and related more to the urbanism domain. The two dissatisfiers are captured in the following aspects: **safety** by road division, visibility & lighting and pavement, and **directness** by linearity, continuity, right of way to bicyclists, orientation, fluency, flatness, legibility, transfer distance and bicycle parking capacity. The importance of directness becomes clear when considering that train passengers value for reliability (Brons & Rietveld, 2009), and cycling as an access mode: the cyclist has a train to catch and wishes to have as little traffic lights as possible.

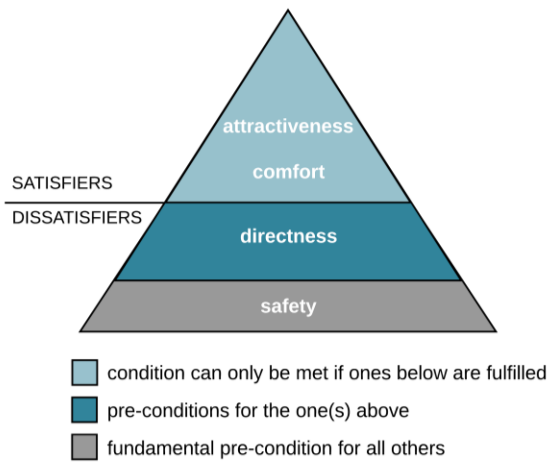

Figure 12 Cyclist's Pyramid of Needs, with safety and directness as "dissatisfiers". From study by Scheltema (2012), based on Traveller's Pyramid of Needs (Peek & Van Hagen, 2002)

The other Dutch study was undertaken by Krabbenborg (2015) verified the aspect "**right of way**" and furthermore indicates that people are willing to cycle further through an attractive environment. An important aspect, suggesting that distance and thus catchment area would increase when routes are more attractive, defined as *"trees, no traffic lights, 50 meters between parking and platform, many people watching or walking on the street and not a crowded bicycle path*". When weighing the various elements, bicycle parking and directness (no traffic lights) came in as most important. Bicycle parking is a bicycle-rail service and thus not included in the list of factors of this chapter. **Vegetation** was found to positively and **crowded bicycle lanes** to negatively influence bicycle-rail use, but both to a lesser extent than the parking and directness. People watching (social safety) was not found to be significant although slightly more important for female research participants. Note the study mentions different weights for different user groups.

Cycling infrastructure has been considered in a number of cycle-rail studies. In a research in San Francisco Bay Area, US (Cervero et al., 2013), the cycling infrastructure (dimensioned in linear km and km/km2 in the surface of the catchment area) was found of significant importance. The researchers describe how "*[a number of infrastructure changes] clearly benefited rail stations (...) in attracting cyclists*". Bicycle infrastructure was even ranked among the top-3 most influential factors when defined in kilometres of bicycle routes in the study by (Krizek & Stonebraker, 2010). In another study, a great under prediction for bicycle-rail use was done in Portland as infrastructure improved so much there (Singleton & Clifton, 2014).

Meng et al., (2016) also found in their survey that **more cyclists along adjacent links** increased the propensity to combine bicycle with rail. It may be assumed that higher shares of cyclists near the station are a consequence of good cycling infrastructure.

Higher **bicycle availability** at the home-bound side, also defined as "*asymmetry in the supply*" (Keijer & Rietveld, 2000) is a main reason for the dominant position of cycling, compared to the activity-end of the trip in the Netherlands (KiM, 2016a). This can probably be captured in general levels of **bicycle ownership**. Another aspect mentioned in the literature are **storage facilities** at the point of origin and destination (Pucher & Buehler, 2009). People wish to store their bicycle safe and dry when not in use, but some homes, workspaces or other destinations lack the space. Folding bicycles may be an option here naturally.

4.4.3 Competition other modes

As the description of bicycle-rail as a competitive choice presented in paragraph 3.3 highlighted: faster, cheaper, more comfortable or convenient alternatives will make the bicycle-rail option relatively less attractive. This applies to both access and egress trips to the train station (competition bicycle) as well as the complete door-to-door journey (competition bicycle-rail). Clearly, when both the **levels of cycling and rail use are high**, the absolute number of bicycle-rail users increases. This logical reasoning is integrated in various bicycle-rail demand modelling studies (Ensor & Slason, 2011; Geurs et al., 2016; Krizek & Stonebraker, 2010).

A main indicator for mode choice is **trip distance**, as was described in detail in chapter 3.3.2. Particularly for the door-to-door journey it becomes clear that the bicycle is the preferred mode of choice in a select range around the station. The distance that people are willing to cycle can vary, depending on station type, geographic characteristics or route directness. Roughly speaking, the bicycle is most popular between 1 to 3, up to 5 kilometre distance. The **individual price** for the alternatives is also a clear indicator of the attractiveness of the alternative modes (La Paix Puello & Geurs, 2016).

For modes of access, as was described in the introduction chapter of this thesis: walking, BTM (bus, tram, metro) and car are competitors of the bicycle. With regards to the car: both negative/push factors like **high parking charges**, **congestion**, dislike of traffic, hassle or low parking availability, as well as positive/pull factors in favour of bicycle-rail were mentioned, such as being able to work on the train or disliking to drive (Sherwin & Parkhurst, 2010). According to (Brons et al., 2009), the **availability of car parking** even plays a larger role than bicycle facilities in the perceived accessibility of train stations by Dutch travellers.

The BTM (bus, tram metro) options can be particularly attractive if their costs are low and connection good. In the Netherlands, a **free public transport card** for students resulted in a sharp decrease of cyclists travelling to the station in the 90's (Keijer & Rietveld, 2000), a logical consequence of the large share of students among bicycle-rail users as the previous paragraph indicated.

Considering the importance of competitiveness, lower BTM costs will lead to a decrease in cycle-rail use. **Good connection**, defined by the number of services and frequency (Brons et al., 2009; Meng et al., 2016) or distance from point of origin to a bus stop (Pan et al., 2010) have also been mentioned. Additionally, particularly those people currently travelling to the station by BTM and/or making transfers during their train ride appear most willing to consider switching to bicycle-rail (80% compared to 63% for average rail-users in this Canadian study) (Bachand-Marleau et al., 2011). This is probably explained by people's low value of time for transfer as described in paragraph 3.2.1.

Upcoming competition for first and last mile travel options may come from developments like car sharing parks, cheaper taxi fares with Uber, automated vehicles or even longboards and Segways, but studies on these modes have not been found.

For the complete door-to-door journey, the car will generally be the main competitor. **Car ownership** among bicycle-rail commuters is slightly lower according to various studies (Heinen & Bohte, 2014; Meng et al., 2016; Shelat, 2016), as among cyclists in general (Parkin et al., 2008) and cyclists in general. Nevertheless, bicycle-rail users often still own a car (Sherwin & Parkhurst, 2010), just like other rail users (Givoni & Rietveld, 2007), indicating they are not 'captive' public transport users per se.

With this final section on the very practical first requirements for bicycle-rail, this literature review comes to an end. The introduction mentioned two main reasons why we should know this context: to help in matching the supply and demand of bicycle-rail services both in terms of quantity and in service type. The focus of this thesis is on the numbers. But for making truly integrated bicycle-rail services, tailoring the services for the specific users is evident. Understanding the context factors helps in choosing the most suitable (combination of) bicycle-rail services. The next chapter will use these findings to find the opportunity for bicycle-rail on station level.

4.5 Reflection on 39 factors

This chapter presented 39 different factors as described in the literature to influence bicycle-rail use. The very formal methodology contrasts with a "group model building"-session held with twelve Dutch practitioners in 2014. Both studies share the same objective: mapping the factors that influence bicycle-rail use. As a form of critical reflection and first step to the more practical approach of this report, the outcomes of the session are briefly compared to the findings of the literature review. Bicycle-rail expert Roland Kager and cycling academic Marco te Brömmelstroet provided additional input for this discussion in open interviews.

The sessions of 2014 lead to an unpublished "causal mapping diagram" which formulates the drivers and relations to explain the growing popularity of bicycle-rail use in the Netherlands (see Appendix D). The purpose of that study was to create a shared language for further discussion, rather than make a perfect model and has thus not been made public. We are not aware of any similar models. Roland Kager provided the diagram and reflected on it as follows:

> *"The conceptual scheme is a tool to give people a sense of the relationships. It shows the complexity and interactions of the bicycle-rail combination, and hence the large number of factors that can change and influence it."*

Roland Kager, Studio Bereikbaar

In total 35 factors are included in the diagram. Five of those offer key (descriptive) indicators that initiate bicycle-rail potential at a system level (shown in grey boxes), all with a positive relationship to bicycle-rail use:

1. Traveller densities at stations of high level / MRT
2. Utility of transit system
3. Degree in which bike-transit acts as a ‘complete’ daily transport system
4. Heterogeneous levels of service in transit system within average cycling reach
5. Actual n[umber] of trip optimisations based on cycling to/from a more distant station

The first two align with the literature review’s findings that “high level of rail use”, “high (service) level of trains” and “high train frequency” make bicycle-rail more attractive. Bluntly put: larger stations are more attractive for cycle-rail use. Roland Kager reflects that this is meant not only in absolute but also relative numbers: the share of access/egress trips by bicycle compared to other modes is expected to increase with station footfall. Some tension in this statement can come from the literature review that indicated BTM can be a large competitor to bicycle-rail, which is typical for higher quality at larger stations. The modal splits of the six-station-typologies in the Netherlands indicate the same competition (see 4.3.3). Kager, however, opposes this by characterizing a good BTM-network as a backup system to bicycle-rail, which adds to the system’s robustness. For example, in the case of a flat tire or spontaneous detour to visit a friend, people can switch to the bus to reach the railway station or arrive home. They are not “bicycle-rail-captives”

The third main variable in the diagram considers the quality of the bicycle-rail combination. We could describe this as a good railway system, a good bicycle system and a good integration of the two. These should all be reflected in their use: the higher the quality, the more users.

In the diagram, “*heterogeneous railway stations within cycling distance*” increase bicycle-rail use. This seems contradictive considering that overlapping catchment areas make stations compete with one another. Marco te Brömmelstroet describes the logic behind this relation: a large heterogeneity between stations (both in train services and facilities) increases the number of travel options. That flexibility itself makes bicycle-rail more competitive to for example the car."

The fifth point is somewhat specific and was probably chosen as it concerns a large but typically Dutch problem: overcrowded bicycle parking at stations. The Dutch are therefore looking for ways to spread the bicycle travel demand over stations.

As a last note on the diagram: a number of factors found in the literature are not included. Hilliness and climate may not have been considered as the Netherlands is flat and the small size limits variations in the weather. Also, the factors cycling levels and infrastructure, the perceptions of various modes and social-demographic factors are not mentioned in the diagram. The variation of these factors could again be smaller in the Netherlands as most people cycle and infrastructure is usually in place. Nevertheless, various Dutch studies did find a clear relationship between demographic factors and varying local cycling levels (Goeverden, 2013; Harms et al., 2014) and even for Dutch cycle-rail users specifically (Shelat, 2016). It is thus assumed that generally these factors are influential.

Considering the various arguments in this section, we may state that on a system-wide level, good public transportation and high-quality cycling infrastructure can provide a reliable and flexible alternative to the car. People are then less reliant on their car. On an individual’s trip choice level, however, there is a competition for the first and last mile between the bicycle and its alternatives to reach or leave a railway station. Then, for bicycle-rail in particular, BTM will work as a competitor. Also, the diagram provides insights of Dutch practitioners on the relationships between the separate factors, which have not been considered in the literature review presented in this chapter. These large correlations and overlap are however evident: good bicycle infrastructure will increase cycling levels and vice versa: high cycling levels will push cycling measures on the agenda. The next chapter will look further into this.

4. POSITIVE PROFIT

Can improving bicycle-rail use be profitable? To be sustainable, a positive financial outcome at the bottom line is also required. Improving and increasing bicycle-rail can make a sound business case for various parties.

First of all, **train operating companies** (TOCs) can benefit financially. Chapter 3 indicated how cycling increases a station's catchment area. Projects and studies showed that improving bicycle-rail services can attract new railway passengers thus ticket sales can increase (Bachand-Marleau et al., 2011; BiTiBi, 2017b). The interest from practice is clear. In Britain for example, the profit-driven TOC's together published a "Cycle-Rail Toolkit" with integration design guidelines.

Secondly, the **bicycle industry** can make money. For example bicycle shops, bike share operators and bicycle producers (including folding bicycles like Brompton) can all increase their revenue directly as the number of bicycle trips and trip kilometres increases.

A group that benefits more indirectly are **local businesses** where cyclists pass by. Studies indicate that cyclists tend to combine their trips with errands like shopping. Additionally, less cars and more bicycles lead to more lively and attractive streets, where also pedestrians like to spend more time - and money (Blue, 2013). For recreational bicycle-rail use in particular (typically BoB), the tourist and hospitality industry can benefit too. Arguably however, those bicycle-rail users formerly walking, may now spend less underway as they pass shops faster.

The last party that profits are the (new) **bicycle-rail travellers** themselves. If the bicycle-rail is chosen for its lower costs, they will have more money left to spend elsewhere. Do note that these resources would previously have been spent on the other transport modes: the car industry, taxi and BTM sector may see a financial loss if bicycle-rail really catches on.

Increasing bicycle-rail use will not happen overnight. Investments are required. Putting in bicycle stands, signs or infrastructure and setting up education or marketing programs come at a costs. Therefore a trade-off must be made to ensure a financially sustainable travel option. Different tools are available to translate the bicycle-rail opportunity into a profitable business case. Examples are a recently published CBA-instrument on walking/cycling-rail integration from New-Zealand and a British study that focuses on bicycle parking in particular (Jones et al., 2015; Wedderburn, 2013).

5 FROM THEORY TO STATION SCANNER

The introduction of this thesis (chapter 1) mentioned the challenges of strategically improving bicycle-rail while bearing in mind local differences. We learned that despite bicycle-rail's theoretical opportunity, it is used limited in practice. Various services and numerous factors that influence bicycle-rail have been described in the previous two chapters. Also, the components that make up a bicycle-rail trip chain were discussed. With these findings and challenges in mind, this chapter aims to answer the fourth sub-question:

4. How can better understanding in bicycle-rail and its influential factors be translated into a practical tool to help find the opportunities for improving bicycle-rail use on station-level?

This question will be answered as follows. First, the main requirements and position of the tool are defined and the "Station Scanner" is introduced (5.1). Next, a number of existing tools are presented to build upon and highlight the added value of the scanner (5.2). Third, the factors are clustered to simplify for analysis and capture overlap. Ten clusters are defined (5.3). We then consider the way in which they can be captured in measurable variables to score and compare the stations (5.4). Finally, a preliminary design of the scanner's interactive dashboards is presented

A prototype Station Scanner was developed for Scotland which is presented and reflected on in chapter 7.

5.1 Framework for Station Scanner

It has become clear that local variation between stations and their surroundings can be large as the concluding paragraph in chapter 3 and many influential factors in chapter 4 highlighted. This means that some stations are more likely to attract bicycle-rail users than others. Also, it is the reason why the exact same bicycle-rail services in one place will perform differently in the next. An analytical tool that helps identify the relevant variations and compare them on a system-wide level is not available, as far as we are aware. When captured for a large set of stations, the relatively high or low chances for successful bicycle-rail integration can be found.

5.1.1 Aims & use of tool

The scanner focuses on a station level, as all bicycle-rail trips involve at least two railway stations, they are clear components in the bicycle-rail trip chain and many bicycle-rail services are implemented at or around station levels, as was described in chapter 3. In this study, a country-wide network of stations is assumed, but this can naturally also be restricted to e.g. the boundaries of a train operating company or regional authority.

The infobox below sums up the three aims of the tool:

Aims of Tool:

1. Provide a **quick-scan** of the potential success of bicycle-rail use at station level.
2. **Compare** (groups of) stations in a system for referencing and strategic planning.
3. **Communicate** bicycle-rail opportunities clearly to various stakeholders (rail and cycling sector).

The tool can help the user to make a quick-scan analysis (aim 1), in an early stage of the strategic decision or design process by comparing stations and knowing where the main opportunities lay (aim 2). Examples of such projects are station development, (public) transport policy or applying for infrastructure funds. The main user and developer of the tool is expected to be an independent consultant, as the tool gives a birds-eye view on the opportunities in a whole railway system. However, all other parties should be able to interpret the outcomes to take part in these early phases of collaboration (aim 3).

There are different parties involved in bicycle-rail projects and similarly able to benefit from seizing the bicycle-rail opportunity: from travellers to train companies and from public authorities to private land development. The initiative to build this scanner can thus lay with various parties. It should be mentioned again that integrated transport can only be truly successful when all stakeholders collaborate.More insight in who can realise these opportunities through action is important in later design phases. The tool does not deal with that to remain clear of political and strategic agendas. These opportunities and stakeholders have been studied for Scotland, with the findings presented in chapter 7.

5.1.2 Station Scanner framework

The aims presented in the previous section can be translated into requirements for a quick-scan tool. Before zooming into its various components in detail, the diagram in Figure 13 below shows the framework for a generic "**Station Scanner**". The Station Scanner is a tool to score and compare stations on 10 clusters that are found to determine the potential success of bicycle-rail use. This can help in deciding where to which bicycle-rail services - both hard and soft. By providing an easy-to-read dashboard, parties from various background can be more actively involved in the improvements.

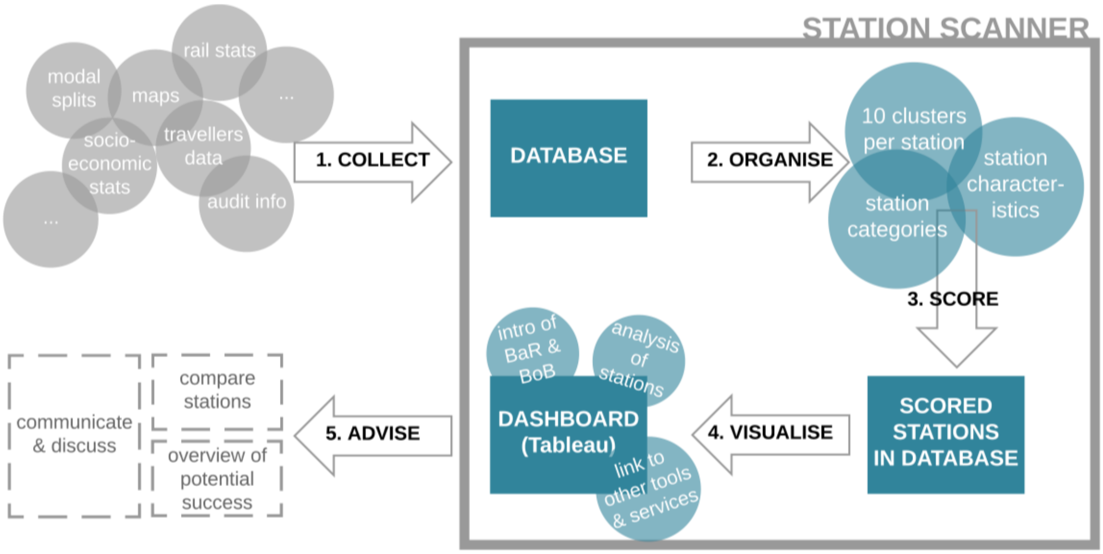

Figure 13 Framework of the Station Scanner. Visualisation by author.

The scanner has three main elements: a database, an overview of scored stations and a dashboard. There are five steps to make and use it: collect data, organise data, score stations, visualise and advise. The last step is an interpretation of the scanner's outcomes and will depend on the question. The elements are introduced briefly after which the various steps are described in detail in the remainder of this paragraph.

5.1.3 Three elements

The scanner has three main elements. The information stored in the **database** contains the characteristics of stations and their surroundings. The data is used to fill ten clusters on station level that help indicate potential bicycle-rail use and map station characteristics. These are based on the factors found in chapter 4 and are discussed in paragraph 5.3. The outcome of this process is an overview of **scored stations**. Combined they reach aims 1 and 2 for the tool: a quick-scan and comparison of stations. The third element is a **dashboard** which ties in directly with the third aim of the tool: "communicate bicycle-rail opportunities clearly". It gives an overview of the various station's potential bicycle-rail use as well as some more background information on bicycle-rail use and references to other existing tools and design guidelines (presented in paragraph 5.2). These aspects are important to consider as bicycle-rail use is still uncommon in most countries and a shared vocabulary is a crucial step in any collaboration. Data visualisation software like Tableau may be used for this third element to enable interactive interfaces.

5.1.4 Five steps

The elements are connected by five steps that the creator of the scanner should undertake. First of all, the database must be filled (**step 1**). The system boundaries must be clearly defined: which stations are included? At which level of detail? To prevent information overload, the organisation of data (**step 2**) should thus be started in parallel. The ten clusters (paragraph 5.3) are matched to the datasets. The more detailed and reliable the data, the better, whilst bearing in mind data availability for all stations. Secondary data is thus probably most suitable. Next, agreement should be reached on how to score the clusters, as is described in paragraph 5.4 (**step 3**). Also the different station categories the dashboards may contain must be decided. To ensure the scanner helps clearly communicate the opportunity, its front-end visualisation dashboard should be attractive, interactive and easy-to-interpret (**step 4**). The proof of the pudding is in the eating. In **step 5**, the scanner can be put to the test to compare the stations, give overviews of potential success and communicate and discuss these findings clearly to the most relevant stakeholders able to influence bicycle-rail use. The more flexible the scanner to take in new information and present relevant information to the stakeholder, the better.

In the framework we assume that the user of the tool will be an objective third-party. Further input on framework requirements came from two Dutch consultants at Witteveen+Bos to ensure its practical use. They agreed that the tool should include a comparison between stations and council areas: between stations to find and share best practices easier and spot the main differences, between councils to spark some competition. This is where the second aim introduced earlier derived from.

To conclude, the element most central to the tool is the scoring of stations. This part is thus described in most detail in this chapter. Paragraph 5.3 discusses the development of ten clusters, paragraph 5.4 describes how to capture and score stations. But first, the existing tools that the scanner builds upon are introduced below.

5.2 Existing tools

Whilst bicycle-rail use and research is limited, a number of tools are available that help practitioners better understand and/or improve bicycle-rail use. The scanner helps as a first indicator and can be used in the early stages of the decision and design process. Building upon, improving or specifying existing tools ensures that it is a unique tool of practical value. A number of them are therefore introduced here before we zoom into the specifications of the scanner in paragraphs 5.3 - 5.5.

The existing tools relevant for this study can be divided into two groups: “scoring tools” and “potential testers”. A detailed overview of the examples for both groups of tools mentioned in the section below can be found in Appendix E. Where possible, British examples were selected to tie-in best with local knowledge for the next chapter. Design guidelines are also tools to improve bicycle-rail and were briefly introduced in paragraph 3.4 and are very useful later in the design process and thus excluded here.

5.2.1 Scoring tools

The first group “**scoring tools**” contains audit instruments or scorecards to help understand a station’s current bicycle friendliness. These may be used for finding the main barriers at station redevelopment, assessing a before and after situation, or checking contractual agreements on accessibility. These tools map and score the current level of bicycle-rail services and integration. Three examples of this type are the “Interchange Audit Toolkit” for Scottish stations, audit guidelines in the RDG Cycle Rail Toolkit 2 as mentioned in paragraph 3.4.2 and the more academic Dutch “Re-Cycle” instrument (Rail Delivery Group, 2016; Scheltema, 2012; Transform Scotland, 2014). The first two examples focus on the station and its direct surroundings, the last on the cycle route from home to stations only. Examples of elements that can be scored include barrier-free entries, route signage, bicycle parking spaces and other cycling infrastructure. These tools typically require first-hand data collection which is then compared to a benchmark, and they consider stations separate from one another.

5.2.2 Potential testers

The second type of tools can be defined as "**potential testers**". These aim to quantify the (potential) share and/or number of cyclists to and from train stations. Some are more academic and based on current shares, like the "CTU-index" by (Krizek & Stonebraker, 2010), others are more pragmatic and predictive, such as the "cycle-rail prediction model" for all British stations, as described by Jones, York, & Ball from TRL consultancy (2015). It will be referred to as TRL-tool in this thesis from now on. These testers find and weight the values of various variables to estimate bicycle-rail use on station-level, with variables similar to the factors presented in chapter 4 of this thesis. This group of tools is very useful to quantify potential success and see where current bicycle-rail practice is most lagging behind from its theoretical potential. It maps the opportunity. The datasets are often secondary and thus less work to collect than for scoring tools. It does typically mean more aggregate numbers are used and simplification will occur. For example, the quality of cycle access to stations (like infrastructure) is now captured in the Census survey response to "Are you willing to cycle?" in the TRL-tool (Jones et al., 2015). This will yield less exact findings than first-hand scoring. More reflections on both types of tools are presented in Appendix E.

5.2.3 Learning from existing tools

Both types of tools have their pros and cons. The station "scoring tools" provide clear current state insight with regards to the level of accessible. However, the data collection is cumbersome - particularly for many stations, and all stations are assumed to have a similar benchmark: the contextual factors that can influence success are left out of scope. Scoring tools that do include those were not found. The "potential estimators" on the other hand provide a quick overview on system level and include station surroundings, but are based on fairly aggregate numbers and assumptions (TRL tool) or hard to make generic as well as practical (CTU-index). Also, the user-friendliness of the interfaces or transparency is limited. We are unaware of tools available so far that aim to combine a station's "as is" state with its "potential use".

Elements of both types of tools discussed above are used to develop the Station Scanner framework. When station characteristics, typically part of scoring tools are known for all stations in the scanner, they may be added. Examples include the current number of bicycle parking spaces or the modal split of first and last mile trips. Whilst potential testers tend to take a far more computed approach, the selection of factors to quantify potential bicycle-rail is an excellent opportunity to shape the clusters. These are used in the development of the ten clusters as presented in the next paragraph. Furthermore, potential testers may have analysed areas where a Station Scanner is also used. Then outputs of these testers can be of large value to benchmark the scanner's findings. For example, the TRL-tool included Scottish stations and are thus integrated in the Scottish Station Scanner as described in chapter 6.

5.3 Ten Clusters to scan for potential demand

Nearly forty factors were identified in the literature review of chapter 4 that influence bicycle-rail use, besides bicycle-rail services presented in paragraph 3.4.2 (see appendix C). If we would analyse and compare each factor for all stations and their potential cyclist's catchment area, a very complex and lengthy analysis is required, with too much detail for the objectives of the tool. A quick-scan should be straightforward to make and use. Considering this and the aforementioned correlations (4.5), the factors are clustered. The clusters are based on overlap (described in 5.3.1 and on theme (described in 5.3.2). Ten clusters have been identified (5.3.3). These clusters combined give a first, rough indication for the relative potential bicycle-rail use on station level. They may be weight different in an analysis as is described in 5.4. As mentioned, existing tools are integrated in the framework: the variables to capture the ten clusters are based on the literature review and the "potential testers" of paragraph 5.2.

The scanner scores each station on these ten clusters. A discussion on the scoring and comparing is presented in paragraph 5.4.

5.3.1 Overlap of Factors

Knowing the overlap between factors makes it possible to leave out those largely correlating. This can be very convenient, for example when information or data is lacking, or when a factor's value is hard to define, such as "attitude towards rail". The many arrows in the causal diagram of Roland Kager and Marco te Brömmelstroet discussed at the end of chapter 4 (see Appendix D) already indicated that there is much correlation between the factors.

Numerous studies as well as basic regression analyses identify such correlations. A higher education is associated with higher income and the number of cars per household, which correlates with household size and more rural living. Often logical combinations, which can be checked for different countries, for example, travel statistics in Scotland, based on the Scottish Household Survey (National Statistics, 2016). These effects create a complex web of relations between different factors, with clusters of effects that strengthen one another ("loops").

These correlations may vary per country or be non-linear. An example includes the relation between income and bicycle use - in the US particularly lower incomes use the bicycle as a mode of transport and the more affluent for leisure, in the Netherlands there is a more direct correlation between higher income and cycling levels (KiM, 2015; Pucher, Buehler, & Seinen, 2011). The framework is generic. As overlap varies from place to place, for now, a practical and convenient interpretation on capturing overlap is used.

5.3.2 Themes of Factors

The tool should "Communicate bicycle-rail opportunities clearly to various stakeholders along the trip chain". Clustering the factors around the trip chain elements like bicycle ride, transit and rail, gives a stronger sense of which services may be effective and who is influential. A similar division was done for factors in chapter 4.

Also, a distinction between factors that are hard to change versus relatively easy to influence can be made. They can be more established, or relatively adjustable. For example, it is easier to improve the bicycle infrastructure or discourage car driving, than to change the weather or location of a city centre. The benefit of clustering for this comes in step 5 of the scanner: advice. At a station that scores high on easy-to-change clusters but very low on more rigid clusters, it will be harder to seize the bicycle-rail opportunity than at a station that scores the other way around.

5.3.3 Ten Clusters

With these thoughts on overlap and themes in mind, ten clusters have been identified to estimate the potential success of bicycle-rail use. The ten clusters are visualised in Figure 14 on the next page.

A first division between the factors is in being adjustable or established. The first five are easier to influence than the last five - a useful division for interpreting the potential to change bicycle-rail use. E.g. if a station scores high on bicycle infrastructure but low on land-use, it will be more difficult (money, time, energy, etc.) to realise the success than the other way around.

The adjustable clusters all involve the current use of the main modes cycling, rail, BTM, and car. The second set of clusters is more diverse. Clusters 6 and 7 ("land-use with potential" and "population with potential") both depend directly on the catchment area around a station. Scanner designers may bear in mind the discussion on its shape and size from paragraph 3.3. Cluster 10 "trip length/hills" includes those factors identified in the literature that could not be captured by any of the other clusters: *hilliness* and *(rail) trips of significant length*. A complete overview of which factors have been included where and a short description per cluster can be found in Appendix F.

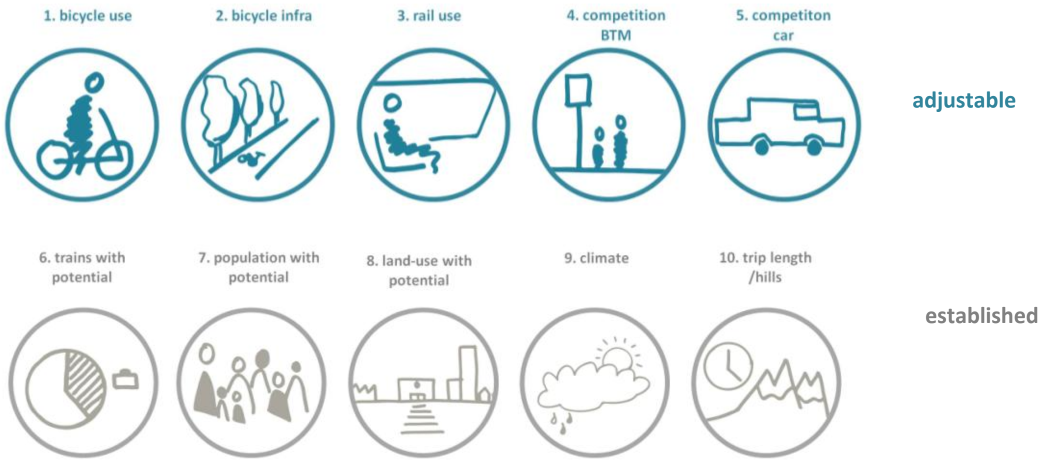

Figure 14 Ten Clusters of Factors to explain bicycle-rail use. The top half are relatively adjustable, the bottom half more established.

The bicycle-rail services as introduced at the end of chapter 3 can be seen as highly flexible factors that can change bicycle-rail use directly. These are captured in the scanner too, under "station characteristics". The influence of the factor "age" was found to vary in influence on bicycle-rail use (relation: "depends"). Additionally, note that the factors *low perception of barriers*, *travel with heavy luggage, wearing smart clothes* and *good bicycle storage facilities at/near home/office* are excluded from the clusters. These are expected to be too difficult to quantify systematically for a large set of stations and have limited influence.

5.4 Capture clusters to score and compare stations

The stations are compared on each cluster to provide a quick-scan of various station's potential success for bicycle-rail. The measurable variables which can capture those clusters are presented in 5.4.1. How they can be translated into relative station scores is described in 5.4.2. To use the scanner for sensible comparisons and bearing in mind the consecutive design steps, some relevant station characteristics should also be included. Possible categories and relevant specs are discussed in 5.4.3.

5.4.1 Variables

Factors are not always directly measurable. Each cluster is therefore linked to a number of possible variables enabling the tool's user to score each cluster. The scanner designer can choose an appropriate variable from the generic overview, this will depend largely on dataset availability: step 1 and 2 of the framework (5.1.4). As a rule of thumb: easily accessible, reliable and on a detailed scale level are good. For example: competition by car may be captured by car ownership or car use. If ownership is known collected via registration systems and known per postal code level, and modal split data is collected every five years via a stated preference survey undertaken and aggregated on council level, the first should be selected to capture the cluster "Competition Car". Alternatively, the (weight) average scores of a number of variables can be taken per cluster. One must beware to check a correct direction with bicycle-rail use (positive or negative). E.g. "direct cycle routes" increase bicycle-rail use, but when this factor is captured by the variable "number of traffic lights", the score should be reversed.

More variables can be added by turning to similar tools as introduced earlier in paragraph 5.1.2. In the CTU-index used in California (Krizek, Stonebraker, & Tribbey, 2011), six different variables were tested to describe bicycle levels to/from 70 selected stations that run the same transit service (therefore variations in rail use is presumably not included). The aforementioned British TRL-tool (Jones et al., 2015) based future demand estimates on seven variables. A third tool we wish to introduce here is the RideScore from the Delaware region in Philadelphia, North-America (DVRPC, 2015). The regional authority scored nearly hundred train stations on bicycle accessibility for ten different elements - combining an audit with comparative scoring. An overview of these tools, their variables and a critical reflection on them can be found in Appendix G.

Combining the variables of literature with those from the existing tools to capture the clusters, yields the results in Table 8 below. Note that these are options. One can choose depending on data availability other variables as well. Furthermore, “large share” can often be replaced by “large number”. Further remarks on their selection are made below.

Table 8 Ten clusters and possible variables

	CLUSTER (relation to bicycle-rail use)	**VARIABLES** (from literature review and existing tools)
ADJUSTABLE	**1. Bicycle use (+)**	high share of cycling use; large absolute number of cyclists; high bicycle ownership; many frequent cyclists; large % willing to cycle
	2. Cycling infrastructure (+)	many kilometres of (dedicated) bicycle infrastructure per km2; many cycling routes connected to station; many roads of max. 20mph or 30km/h connecting to station; low number of cycling accidents
	3. Rail use (+)	high share of rail use; large station footfall; high train frequency; high rail network directness
	4. Competition BTM (-)	high share of BTM use; large number of BTM users; high frequency of BTM from station stop; large time frame of BTM departure; low BTM ticket fees (relative to other modes)
	5. Competition car (-)	high share of car use; large number of car users; high occupation of car parking at station; cheap car parking at station; limited congestion delay for cars; high levels of car ownership
ESTABLISHED	**6. Trains with potential (+)**	large share/number of commuters; large number of season ticket holders; much rail use among commuters
	7. Land-use with potential (+)	high population density near station; density of dwellings nearby; attractions nearby (e.g. university, offices, shopping areas, parks); share of first/last mile journeys 1 - 5 km
	8. Population with potential (+)	large share of students; large share of population is employed; large number of people employed and willing to cycle to work; household income; economic growth (regional GDP); large share or number of males; highly educated population*;* % population aged 20-39 *(relation depends!)*
	9. Climate (-)	few hours of daylight; low average temperature throughout year; many days with rainfall; much rainfall (in mm)
	10. Trip length/Hills (non-correlated; +)	limited slopes of roads connected to station; large share of (rail) journeys >20minutes / >10/15km

A number of factors from the literature review have been excluded from the cluster’s variables: *positive attitude towards cycling; positive attitude towards rail; low perception of barriers, car as a status symbol* and *good storage facilities at/near home* are expected to be too hard to capture for a large number of stations. Also, these indirect factors may be assumed to translate into the current choice for transport modes, reflected in the clusters 1, 3, 4 and 5. Besides being hard to capture, the factors *travel with heavy luggage* and *wearing smart clothes* will only be relevant for a select number of travellers and were thus also excluded.

Additionally, the age of bicycle-rail users was debated in the literature and thus its influential direction has been marked as “depends”. If the variable age is used to capture cluster 7, then this relation should first be assessed for the system by the scanner’s designer.

Despite the discussion on BTM as a back-up on a system level at the end of chapter 4, cluster 4 “Competition BTM” has been assigned a negative relation to bicycle-rail use. This decision was taken as the scanner focuses on the smaller station-level, where bus, tram and metro compete with the bicycle. This decision also reflects that particularly large city-centre stations and urban stations without parking attracted fewer cyclists (Cervero et al., 2013; Van Hagen & Exel, 2014), as was discussed in paragraph 4.3.3. Considering that these also tend to have best overall public transport connection, the competition between bicycle and BTM is convincing.

The variables make it possible to use datasets and capture the station's clusters. Secondary datasets are increasingly publically available (OpenStreet maps, national surveys, etcetera) and easy to access via online statistic portals. Considering that bicycle-rail is particularly interesting for the railway industry, train operating companies and the like may be expected to be initiating and supporting the development of a Station Scanner. They may be able to provide additional station-level data. Finally, research institutes can help to retrieve and choose the most reliable datasets. If all datasets are collected for all stations, a complete database can be made for example in excel. This makes it easier to compare the stations as will be described in the next section.

5.4.2 Score & Compare Stations

Each station can be scanned on the previously introduced ten clusters. However, most of the variables have a relative value. Therefore a benchmark is required to indicate whether their effect on bicycle-rail use is **relatively** positive or negative. For example a "high frequency of trains", "large share of cyclists" or "steep slope of the roads" is meaningless without defining what high, large or steep means. One can consider the mean or median, statistical quartiles or decimals (grouping the stations in "buckets" of 25 or 10% respectively), or some threshold value per factor.

Furthermore, the clusters may be given different weights, according to the user's needs and wishes. Besides these relative numbers, absolute numbers of existing or even potential bicycle-rail users are an interesting benchmark to compare with. For absolute potential indicators, caution should be taken in making this reliable, as the existing "potential testers" tend to highlight themselves (5.2.2). First of all, because the knowledge on the exact influence of the factors is very limited and many factors influence mode choice. Estimating current modal splits of stations is difficult, estimating the potential is even harder. Second, the level of influence of different factors seems to differ from city to city and country to country. Thus, for a generic framework, only rough bandwidths may be relevant. For a specific scanner, local research and estimations can add value when limitations are stated clearly. Finally, as this study's scope is limited, and to prevent users of the framework from spending unjustly time and energy on estimating these exact numbers, we refer to the existing "prediction tools" given as examples in Appendix E and early in this chapter (5.2.2) as a source of inspiration.

The difference of this tool compared to an audit or scorecard ("scoring tools") is that it compares a whole set of stations within a system rather than audit a few. This comparison is the added value as it helps make strategic decisions: not all bicycle-rail services can be implemented everywhere as space and money are limited. Naturally, the comparisons can be done with all stations considered in the tool's database, but alternatively only for a smaller set of stations, defined here as a "station category", as the next section introduces.

5.4.3 Station Categories & Characteristics

It will be more interesting to compare a large city's main railway station to a similar-sized station in another council, rather than the rural station two nodes down the line. Alternatively, if a council wishes to find out how to allocate bicycle parking, they are only concerned with stations within their council. A more advanced scanner should enable to score station to an alternative sets than the whole. This again is a choice that the scanner builders should make and depends on the tools' use and purpose.

The categories can be based on standard categories or station characteristics. Additionally, to integrate well with existing tools - particularly design guidelines, also existing bicycle-rail services may be included. Considering the importance of the transfer in a traveller's experience as we learned in chapter 3, more general station information like staff availability, current facilities or vacant space may also be added. This can help in the next planning and design phases of matching bicycle-rail services to stations. This thesis does not consider what kind of characteristics match best with which services. Further reflections on how a scanner may improve can be found in the discussion in chapter 8 of this report.

5.5 Dashboard of Scanner

This chapter's final paragraph maps out the potential composition of user interfaces to enable clear communication, as was defined as the third main aim in the beginning of this chapter: "*Communicate bicycle-rail opportunities clearly to various stakeholders along the trip chain (both rail and cycling sector).".* The outcome of an iterative design process leads to the development of five conceptual dashboards. Additional inspiration came from the web-based RideScore (DVRPC, 2015). There are different types of elements in each dashboard, some are static (e.g. text boxes and description of the scanner), some are interactive (the map with stations, the scores) and others can be used to filter the data (drop-down menus).

From the top left corner clockwise, we see in Figure 15 on the next page:

1. Introduction dashboard: A brief introduction to what bicycle-rail is and why it should improve.
2. Country dashboard: Here one can select a council, a station category or a particular station.
3a. Council dashboard: As local authorities often have local transport budgets, it can be useful to compare different stations within a council.
3b. Type dashboard: the stations can be categorised according to the model builder wishes (e.g. on footfall, minimum % cyclists in region, current n of bike parking, etc.) and compared.
4. Station dashboard: each station is analysed in one dashboard overview. The map shows relevant information in a 1, 3 and 5 kilometre radius to highlight the potential cyclist's catchment area.

These sketches are for indicative purposes only, the outcomes of the dashboards from the Station Scanner prototype built for Scotland (chapter 6) can be found in Appendix I. Whichever software, screen layout and storyline suits the user's demand best, should be selected.

This chapter clustered the factors from the literature review into a practical quick-scan framework which should enable users to easily analyse and compare a station's potential for bicycle-rail use. The next chapter presents the practical development and reflections on a prototype Station Scanner for Scotland.

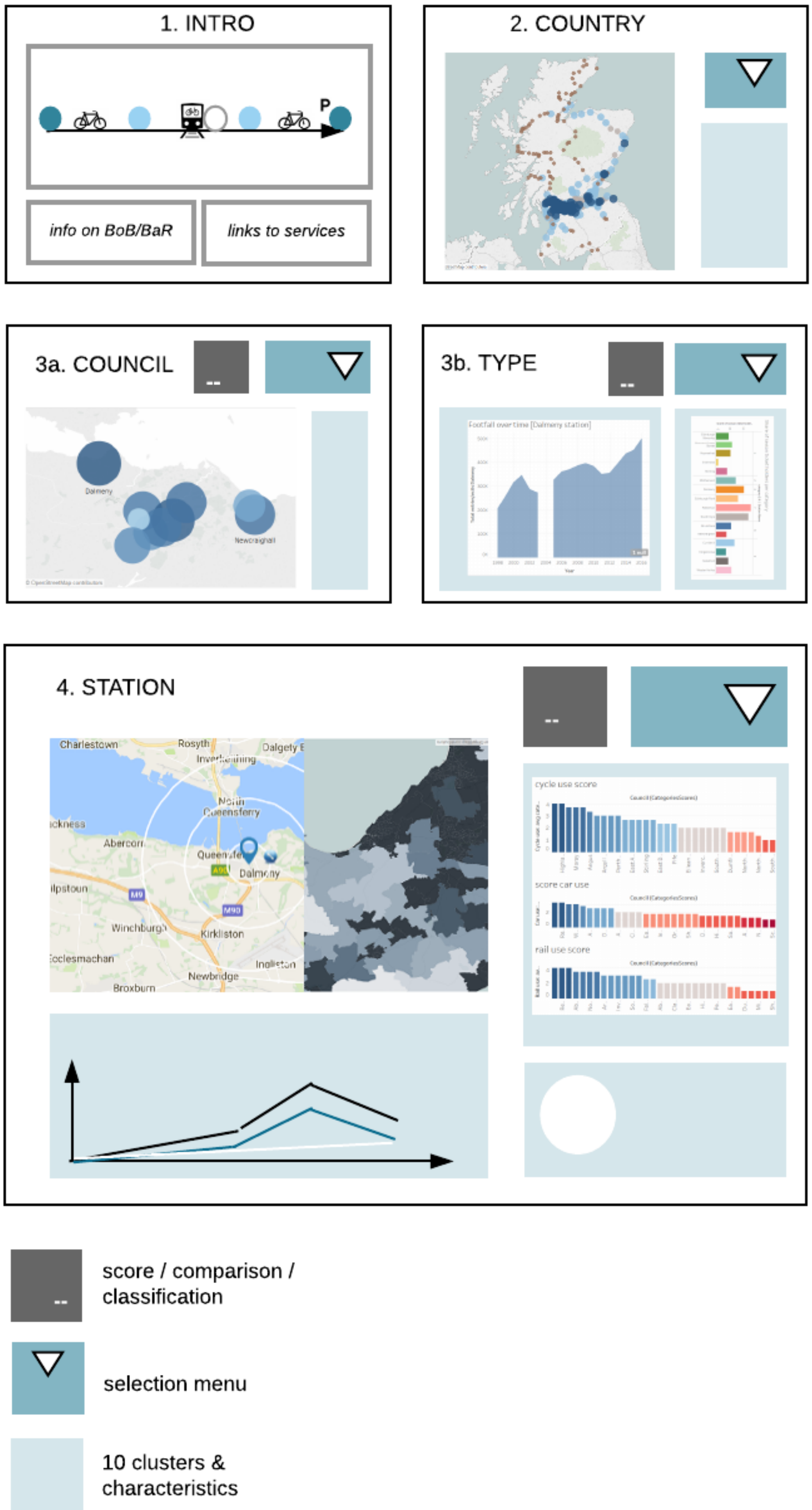

Figure 15 Five conceptual dashboards for a Station Scanner

6 SCOTTISH CONTEXT & STATION SCANNER

This report so far considered international research and generic frameworks to describe and capture the various factors that influence bicycle-rail use to help advice. The remainder of this report will zoom into Scotland. Scotland is selected for this study because of the cycling ambitions of its government (10% of daily trips by 2020), the pro-cycling transport operating company currently running the ScotRail franchise, and the large variation between stations in both service levels (from 20 trains per hour to 2 trains per day) and locations (from highly urbanised to extremely rural). This makes Scotland an interesting case to proof the concept of a Station Scanner. In this chapter Scotland is first introduced and next, the development of the "Scottish Station Scanner" described.

The sub-question answered in this chapter is:

5. How can a "Station Scanner" be created for Scotland?

Before answering this question in paragraph 6.2. a brief introduction of Scotland, its passenger transport in general and bicycle-rail use in particular is presented in paragraph 6.1. The chapter concludes with screenshots of the prototype. The consecutive chapter 7 will expand in detailed on the Scottish stakeholder's playing field and opportunities.

6.1 Scotland-wide context

Whilst many factors are locally dependent, the regions and stations in Scotland share a number of characteristics. As an introduction to the country, some key numbers and statistics are given in this paragraph. Where applicable, they are compared to the EU-28 average and the Netherlands, considering the expected readers of this report. The last sections consider current bicycle-rail use and typical users in Scotland, to check consistency with the scanner's framework presented in the consecutive paragraph.

6.1.1 Introduction to Scotland

Scotland forms together with the countries England and Wales the unitary state United Kingdom (UK), and Great Britain when including Northern Ireland. Great Britain consists of one large island and the north-eastern corner of Ireland, with hundreds of smaller islands around it (see Figure 16 below). Scotland is located in the northern part of the larger island.

Figure 16 Scotland (orange), as part of Great Britain (yellow), located in the north-west of Europe. Image from maplist.com.

Scotland has a surface of 78,700 km^2, nearly twice the size of the Netherlands. It has over 790 islands and only one on-land neighbour: England to the south, which is thus naturally the only country it connected via railway.

With a population of 5.4 million, Scotland's population density comes down to 69 inhabitants per km^2. This is far lower than the Dutch average population density of 501 inhabitants and almost half the EU-average (117 inhabitants/km^2) (Eurostat, 2016b; Office for National Statistics, 2016). The population densities, however, differ greatly throughout the country, with particular high-density areas in the region between the two main cities Edinburgh and Glasgow, both of around half a million inhabitants, located on respectively the east and west coast. This naturally reflects in both the transport infrastructure and its use.

6.1.2 Passenger transport

Considering the opportunity and potential for bicycle-rail use, it is interesting to look at the current shares of passenger transport as well as trends in time. Scotland's National Transport Strategy describes how rail use has increased over the last years. Between 2006 and 2014, the number of ScotRail passengers increased by 29%. Meanwhile, bus travel decreased by 12%, ferry use by 7% and the number of air passengers remained fairly stable. Overall, 17% of public transport journeys in 2014 were undertaken by train. The number of vehicle kilometres by car and car ownership have remained fairly stable. Of all modes, cycling levels have increased most the last decade in Scotland: 30% more kilometres, rising to 339 million km in 2014 (Transport Scotland, 2016). This is in line with EU averages (Eurostat, 2016a).

When looking at the modal share of all journeys of the past decade, both rail and cycling use are limited. Rail fluctuates around 1.5% and cycling around 1% of trips (data from the Scottish Household Survey 2014, published by (Transport Scotland, 2014). Yet, among commuters, train use is four times as high. Considering its speed, it is also worth noting that 5.6% of total passenger kilometres undertaken in 2015 were by rail (Hart, 2015; Transport Scotland, 2014). As particularly commuters appear attracted to bicycle-rail (chapter 4 indicated), there is a fair share of current rail users that may be attracted to bicycle-rail.

Currently, 66% of commuter journeys are made by car (see Figure 17 below). As bicycle-rail is mainly competitive on journeys too far to walk or go by bus, those trips are not competitive. Car users are thus the most interesting (and largest) group from both a railway sector view (new passengers) and government (fewer cars on the road). A point of remark is the popularity of the car for short distances too. The majority of trips below 1 kilometre are undertaken by foot, for 26% of those a car is chosen (National Statistics, 2016, p. 10). These perhaps surprisingly high numbers align with research from Aldred & Jungnickel (2014) who describe the UK car culture as "*dominant, with lifestyles built around the assumption of car ownership and use (cultural normalisation) rather than car use being actively chosen*".

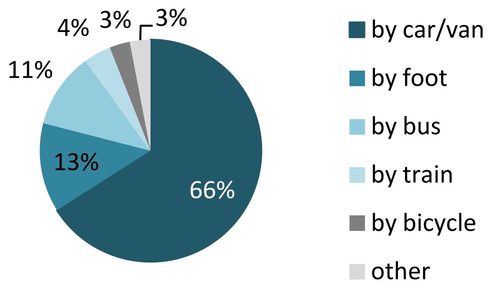

Figure 17 Modal share of commuter journeys in Scotland in 2013 (Transport Scotland, 2014)

The presented statistics also show low numbers of bicycle use. It also appears these are undertaken by a small portion of society only: in Scotland 88% of people indicated that they did not ride a bicycle in the last month, and 65% of English people cycle less than once a year or never (Cycling Scotland, 2017; National Travel Survey England, 2014). This barrier should be born in mind when studying bicycle-rail opportunities.

6.1.3 Bicycle and rail system and stakeholders

In chapter 7, a detailed description of the Scottish stakeholders and (in)formal collaborations is presented. Some background information required for the Station Scanner is introduced here.

Scotland has a railway network of 356 stations on the mainland, connected to England by various routes in the south. Network Rail owns these stations, the train operating company Abellio manages all besides the two largest: Edinburgh Waverley and Glasgow Central. A map of the stations is shown in Figure 18 later in this chapter. Governments have an array of instruments to influence transport networks and choice. Like most countries, Scotland has transport policy on different levels. As part of their strategy for 10% of daily trips by bicycle, all 32 local councils of Scotland are required to write and execute a local active travel plan (Transport Scotland, 2017). The local governments are in charge of local roads - where bicycle infrastructure may be expected most. In collaboration with TOC Abellio and other parties, various bicycle-rail services are rolled out in the country, with some of the most common secure bicycle parking, bike hubs and bike sharing systems (Bike&Go type).

6.1.4 Bicycle-rail usage numbers

Information on bicycle-rail use is very limited. We therefore look at aggregate numbers for the whole of the UK. In 2015, around **50 million bicycle-rail trips** were made in the UK. This is an increase of 40% in five years time, the Rail Delivery Group announced during the annual Cycle-Rail awards (2016). With a total of 1.65 rail journeys in 2015, this should translate to **roughly 3% of rail journeys begin or end by bicycle** (Rail Executive, 2015). In the Netherlands in comparison, this share is 42% on the home-bound trip, and 13% on the activity-end and increasing (KiM, 2016a).

Noteworthy for particularly Dutch readers will be the **significant high share of BoB**: roughly half, of which 1/3rd is folding bicycles. This share does seem to decrease relatively (Haigh, 2017). At the two stations researched in-depth in Bristol, far lower levels of 15% for BoB was found of which half foldable bicycles, indicating these numbers may be very station dependent (Sherwin & Parkhurst, 2010).

As was described in detail in paragraph 3.3.2 the influence of first/last mile distance on bicycle-rail's competitiveness is clear. Different studies in the UK consider this distance. According to a survey on projects in England, the **British cycle slightly further to the train station** than may be assumed from the literature review in chapter 3. Just over sixty percent of bicycle-rail travellers stated cycling up to 2 miles (3.2km), 16% cycled 2 to 4 miles (3.2 - 6.4 km) and the remaining 20% cycled even further (>6.4km) (Wilson & Le Masurier, 2011). These surveys were part of a before/after-intervention study and found that particularly the share of those travelling less than 1 mile (1.6 km) increased most (with 14%), which indicates that the trade-off with walking is also made on shorter distances. We may recall here that the Scots also use the car much for short distances so the competition with various modes can be entered. A different study by (Jones et al., 2015) found that British bicycle-rail users on average cycle 3km, with the 90th percentile at 4.6 kilometres. No studies for Scotland specifically have been found.

6.1.5 Bicycle-rail users

Many factors from chapter 4 relate to user characteristics as an indicator for the potential use of bicycle-rail. The (typical) travellers who combine bicycle and rail use can differ per country. Three reports are found that consider these groups in the UK and are discussed in this paragraph. We are unaware of any publications on this topic focusing on Scotland in particular.

As part of the evaluation of bicycle-rail interventions at 120 stations in 2011, the Rail Delivery Group (RDG) compared bicycle-rail users on the frequency of travel, attitude, and awareness of cycle facilities and socio-economic profile to general rail users (Wilson & Le Masurier, 2011). The study found they are **mostly weekday travellers**, who **make the trip frequently**: before the interventions, 47% of bicycle-rail users travelled over 5x a week, which further increased to 57% after the intervention. Most other bicycle-rail users travelled 3 or 4x a week. Comparing age and gender, the RDG study found that roughly 2/3rd of cycle-rail travellers was **male**, which increased to 3/4th after the interventions. There were slightly more men aged 31-59 than <31, and vice versa for females but this may be coincidence, the study mentions and the age ranges are wide. A second report comes from traffic consultants TRL, for the RDG (then called ATOC) and found that **91% of bicycle-rail users are commuters**, compared to 68% of non-cycling train passengers (Jones et al., 2015). This is so far in line with findings from the literature review of chapter 4. In a third, smaller (and unpublished) study by the Cycle-Rail Working Group (part of the RDG), **60% of cycle-rail trips were for leisure purpose** and three-quarters of the people took their bicycle on board (Dosanjh, 2016). This study was undertaken among 5629 respondents, mostly via National Rail and a touring club. The latter could be a reason for the far higher share of recreational bicycle-rail trips.

Nevertheless, some stations or service lines may be particularly well-suited for very different off-peak recreational travel. Attracting these passengers to use the bicycle-rail combination for their e.g. mountain bike trip in the Highlands can bring additional revenue for the TOC, particularly when the trains run at overcapacity (Rail Delivery Group, 2016).

For the Station Scanner, one factor was identified to vary particularly much per country or region: the relationships of age on bicycle-rail use. Whilst both published studies discuss the age of their respondents, they do not pose any conclusions on bicycle-rail usage and age (Jones et al., 2015; Wilson & Le Masurier, 2011). Considering the quick-scan approach of the scanner, this has not been considered in detail. Therefore, age should for be excluded from the scanner prototype.

6.2 Scanner for Scotland

Chapter 5 described how a "Station Scanner" can help tailoring bicycle-rail services. This section looks into what it entails to create such a tool for Scotland. First, we take a look at the current bicycle-rail tools readily available in Scotland (6.1), to find out what may be integrated into the scanner. Next, as a proof of concept, the framework of the scanner is used to create a prototype scanner for Scotland, see Figure 13 in 5.1.2. The five steps are followed: collect data, organise data, score stations, visualise findings and give advice. Considering limited time for this research, the last step has not been tested and only a limited number of stations are scored fully. The main actions taken and reflections for the generic framework are presented per step in the paragraphs 6.2.2 to 6.2.7.

6.2.1 Existing tools and cycle-rail Analyses

As mentioned, there are various tools available to help improve bicycle-rail. For Scotland, the British **Cycle-Rail Toolkit 2** is an excellent handbook (Rail Delivery Group, 2016). It contains design and audit guidelines: collecting information on the current status and comparing that to a certain benchmark. Furthermore, an audit tool developed particularly for the integration of public transport and cycling in Scotland is the **Interchange Audit Toolkit** (Transform Scotland, 2014). The scanner may refer to these two documents were applicable.

Additionally, the findings from the aforementioned **Cycle-Rail parking tool** - dubbed TRL-tool in this thesis - can be perfectly integrated into the scanner. This tool was developed by TRL consulting, and financed by the Rail Delivery Group (RDG) and Rail Safety and Standards Board (RSSB) for the railway industry in 2014, and has been updated a number of times since. For each British station, an estimation for potential bicycle use and bicycle parking requirements is calculated. These numbers are readily available to any TOC and we are graceful that they have been made available for this research. They provide an excellent benchmark apart from the scanner's relative score.

With the Scottish context as described in paragraph 6.1 and these existing tools in mind, the five steps of the scanner are described and reflected upon here.

6.2.2 Step 1: Data collection

Datasets are required to capture the clusters and characteristics of each station and its catchment area. The sources were found with help from Marta Nicolson from the Urban Big Data Centre and Neil Ferguson from Strathclyde University, and via online search engines. The data portal “Statistics.gov.uk” is helpful in this process. For the clusters, in total four mostly open data sources containing various useful sets are selected: the data warehouse from Census 2011, the travel diary information collected from the Scottish Household Survey from 2014, and ORR’s annual estimates of station usage and weather statistics from Met Office. The scanner is a prototype and a limited number of stations are scored in detail as a proof of concept. Note that other datasets are considered and the final selection of datasets is based on their assumed match with the clusters as described in the next paragraph. Appendix H shows an overview of the considered (and in step 2 selected) datasets.

Additional data sets are used to describe the station’s characteristics and categories. The ScotRail Local Station Strategy (LSS) form and TRL-tool have been made available for the development of the prototype in this study and are not publically accessible as such. Additional station information via the ScotRail website is referred to with a link in the scanner.

For the prototype, three scale levels are selected: “Small Area 2001 Data Zone”, station and council. These are chosen as many (recently published) datasets are available Scotland-wide. Figure 18 below maps their locations and boundaries in Scotland. There are over 6,000+ zones, 350+ stations and 32 councils in Scotland.

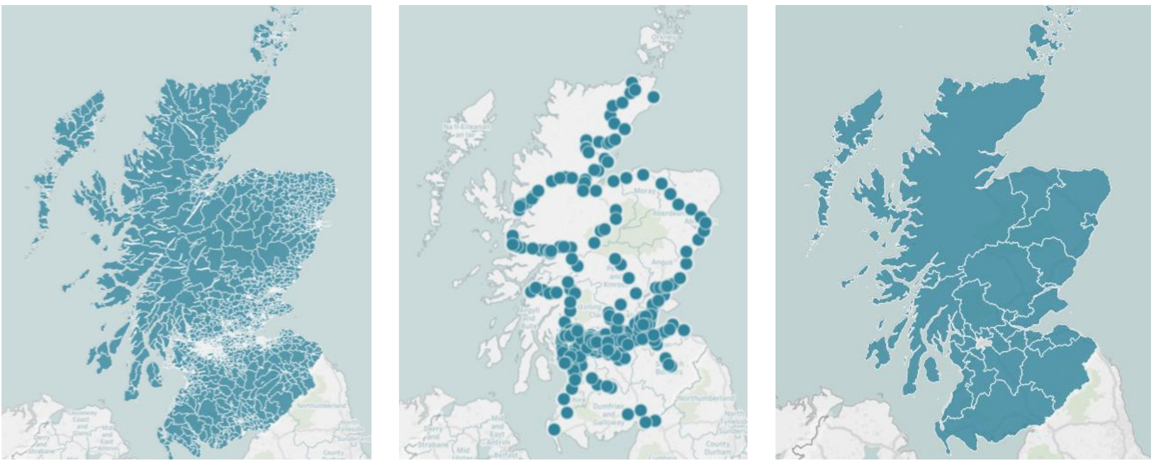

Figure 18 Three data zone levels: a) **zone 2001** b) **stations** c) **council. Visualisation by author.**

Three different dataset spreadsheets are created, one for each scale level. These are connected in step 2.

6.2.3 Step 2: Data organisation

Parallel to the data collection, considerations must be made to link to the ten clusters for scoring the potential success, the categories for analysis and the station characteristics for later design decisions. To get out flaws and outliers, also some basic data treatment is required. The datasets are matched to the ten clusters as Table 9 below shows. Some main reflections on this step are given after the table.

Table 9 Overview draft combining factors to datasets in Scotland

	CLUSTER (relation to bicycle-rail use)	DATASET	SOURCE	SCALE
ADJUSTABLE	**1. Bicycle use (+)**	Three datasets: % of trips by bicycle, % of commuters by bicycle and bicycle ownership.	Census (2011), SHS travel diary (2014)	council
	2. Cycling infrastructure (+)	*none found on a system-wide level*	-	-
	3. Rail use (+)	Two datasets: % of trips by rail and % of commuters by rail.	Census (2011), SHS travel diary (2014)	council
	4. Competition BTM (-)	One dataset: % of trips by bus	SHS travel diary (2014)	council
	5. Competition car (-)	Three datasets: % of trips by car; % of commuters by car (both passengers and drivers), and car ownership	Census (2011), SHS travel diary (2014)	council
ESTABLISHED	**6. Trains with potential (+)**	One dataset: % of season ticket holders	ORR	station
	7. Land-use with potential (+)	Two datasets: dwellings and population per hectare	National Rail Statistics (NRS)	zone 2001
	8. Population with potential (+)	Two datasets combined: share population of working age, and weekly household income	Census 2011, SHS 2014	zone 2001
	9. Climate (-)	One dataset: average yearly number of days with rainfall for last ten years.	Met Office	council (higher district region)
	10. Trip length/Hills (non-correlated; +)	One dataset: average distance to place of study/work in kilometres	Census (2011)	zone 2001

Various remarks are in place, the main ones are discussed here. Considering data on **#1: bicycle use**. The SHS Travel Diary dataset from 2014 is based on a sample of 19,930 people, with some councils' observations based on less than 450 respondents (e.g. West Lothian, Orkney Islands, Midlothian Dumfries & Galloway). Considering the small role of current cycle use this is not very robust. To try to balance these effects out, where possible datasets are combined, thus also for this cluster. More details on how the stations are scored are given in paragraph 6.2.4. For cluster **#2: bicycle infrastructure** there is an evident lack of standardised data. Whilst some councils monitor dedicated cycling infrastructure, there is no standardised way of keeping track of this. A Sustrans representative suggests that as an alternative one may consider investments on cycling per inhabitant per council. These statistics were not available yet for this study. Options to collect this data may be local audits (if the set of stations is limited) or interpreting data from e.g. Ordnance Survey maps.

Clusters **#3 rail use** and **#5 competition car** are straightforward. Both modal splits of all trips and of commuter trips only are known on council level. High car ownership is added as an additional variable to capture the competition of car. **#4 competition BTM** was found to mainly be of interest for the access or egress trip component (chapter 3). Ideally, the frequency of buses departing per railway stations would be used, but such datasets were not available, therefore again council-wide modal share is chosen.

For the second group of five, more established clusters, data on a more detailed scale level is found. **# 7 Land-use with potential, #8. Population with potential** and **#10 Trip length/Hills** could all be captured on a detailed level. Do note this posed difficulties in later data treatment as described later. Again, datasets were combined. An excellent dataset comes from the Office of Rail and Road, who estimate the percentage of season ticket holders per station. These are typically frequent trip makers and capture **#6 Trains with potential**. Scotland has dozens of weather terminals, with data made available via Met Office. Upon request, the number of days of rain observed at a selected number of terminals was shared. However, considering the required system-wide level, the (highly) aggregate "higher district regions" of north, east and west Scotland are used for the prototype to capture **#9 Climate**.

Besides the clusters, the scanner also requires station characteristics and some categories to select sets of stations. An overview of the selected datasets for these is shown in Table 10 below.

Table 10 Datasets for station categories and characteristics for prototype Scottish Scanner

STATION SPECIFICATIONS	DATASET	SOURCE
CATEGORY		
Station authorities	All stations lay within the boundaries of a council and are managed by a TOC (see chapter 7 for more information). These boundaries can be relevant for the influence of local power and funding. All stations are thus matched with their respective local authority.	ORR (open access)
Station type / footfall	A categorisation by type, used by Network Rail and the RSSB ranges from A-F (national hub to small unstaffed).	TRL tool (via TRL)
Cycle-rail potential	An excellent benchmark for the stations in Scotland is the cycle-rail tool. It estimates an absolute number of potential cyclists to/from any railway station in Scotland.	TRL tool (via TRL)
CHARACTERISTICS		
Available services	Station information: number and type of car parking, staff, ticket office, waiting room, toilets.	Local Station Strategy forms (via ScotRail)
Available bicycle-rail services	Station information: bicycle parking, bicycle hub, bicycle sharing available.	TRL tool (via TRL)

Considering the use of different sources and large amount of information, some **data treatment** is required. We share two examples here to illustrate what actions are undertaken. First of all, **station names**. Not all datasets use the same names, which is required to link the sheets. It was decided to use the ORR names. For the ScotRail audit data, for example, this required changing 27 names (e.g. Balloch Central to Balloch). The second example of data treatment are the **coordinates**. To increase the readability of the scanner, the various stations are plotted on a map. Coordinate points are added to each station. A first search for them is done via railwaycodes.org.uk. They are plotted and those off the map of Scotland retrieved manually via the website latlong.net.

The final step of the data organisation is combining the data on three scale levels into one scale level: station plus catchment area. Figure 19 below shows the 2001 data zones of Inverness compared to a 5km catchment area. Paragraph 3.3.3 described the difficulty of defining a station's catchment area size and shape. For convenience and considering the scope of this research, a manual 5km circle is drawn around the stations using Tableau software. The average scores of these zones is used to define the score. Note that these scores are based on all the zones in Scotland, rather than only those around stations, and that the differing area sizes of zones are not considered. Additionally, Figure 19 shows the discrepancy between the borders of the catchment area and the zones.

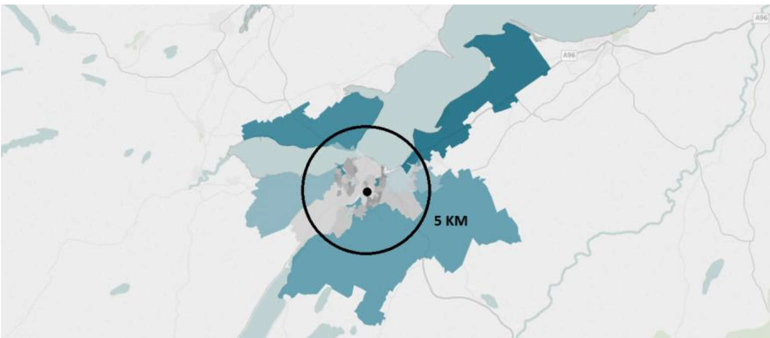

Figure 19 Difference boundaries of data zone and circular catchment area around Inverness railway station in prototype Station Scanner for Scotland

A more automated method should be considered for large sets of stations. This may involve combining the coordinates of the stations with the geographical zones of the dataets. As the prototype is a proof of concept, only a few stations have been found manually based on the zone 2001 data. To still provide a benchmark, the aggregate council-wide averages of the data 2001 zones are used.

6.2.4 Step 3: Score stations

After the data is collected per station, it is time to score them. Chapter 5 describes how stations can be scored compared to the complete set of stations. For the prototype, we select a score of 1 to 10, as this is an easy-to-communicate score which will be understood quickly by the users. A score above 5 indicates that the station scores above average on bicycle-rail attractiveness for that particular cluster.

This "interdecimal range" scoring works as follows. The range limits of each score value are defined, for all ten clusters, so that each score value contains 10% of the stations. As Scotland has nearly 360 stations, there are 36 stations per score. Assuming a normal division for most values, this means that the outer scores typically have a wider range. When the values are exactly on one of the range limits, it was classified into the higher category.

Table 11 below gives the different range limits for the cluster "car use" in Scotland to illustrate the method. When different datasets are combined, the datasets are first scored individually and the averages of these scores are again ranked to find the final score for cluster 5. All datasets are thus weighted equally. Only integer scores are used in the scanner. Note that some ranges are ordered in reverse to capture their direction. For example, the dataset "percentage of trips delayed due to congestion" to partially describe "cluster 5: car use" is reversed. More congestion will make bicycle-rail more attractive, so higher values receive a lower score.

Table 11 Range limits of score values for the three datasets that combined score cluster 5: Car Use for the prototype of the Scottish Station Scanner

CLUSTER 5: CAR USE	1	2	3	4	5	6	7	8	9	10
CarCommute (% commuter trips)	79,4-81,9	77,7-79,4	76,4-77,7	75-76,4	74,2-75	72,8-74,2	72,4-72,8	70,1-72,4	66-70,1	46,4-66
CarMainMode (% all trips)	73,4-78,5	70,7-73,4	69,3-70,7	67,8-69,3	65,1-67,8	64-65,1	61,7-64	61-61,7	58,6-61	39,7-58,6
CarOwners (% households 0 cars)	15-17,9	17,9-20,8	20,8-22,3	22,3-23,7	23,7-25,2	25,2-26,9	26,9-28,2	28,2-30,5	30,5-41,5	41,5-49,1

The description of the previous step 2: "Data Organisation" (paragraph 6.2.3) indicated that the datasets for car use have only been found on the council scale. Although local variations will be large and differ from one station to the next, all stations within a council are scored the same.

This results in each station being scored 1 to 10 on all clusters. Similarly, rather than comparing each station with the total set of all stations, a selection of stations can be made. The categorisations mentioned earlier in Table 10 may be used to define other sets: by the local authority, station footfall, station type or its cycle-rail potential as found in the TRL-tool. Note that this last element is possibly unique for the countries in the UK.

There are many points of improvement in both the dataset matching and the scoring. Knowledge on what influences (potential) bicycle-rail use is still in its pioneering phases. We like to point out again the explorative nature of this research. The scanner is a tool to assist its user in giving advice. Detailed reflections on the limitations and main points of improvements for the scanner are presented in paragraph 8.2 of the Discussion chapter of this thesis.

6.2.5 Step 4: Visualisation

The interactive dashboards of the prototype are made with Tableau software. An interactive storyline is chosen, to ensure the user understands the scanner's added-value and limitations and use it accordingly The storyline also provides the wider context of bicycle-rail in an orderly manner. Sliders and selection bars are added to navigate through the information and compare stations interactively. Where possible, direct hyperlinks to other tools or reference projects are made. The scanner framework of chapter 5 identified the difference between "established" clusters and more "adjustable" clusters. These are thus grouped together.

Figure 20 below shows a picture of the third dashboard where station scores can be compared. Grey scores are below average, blue scores are above average. The brighter blue, the better.

The grey colours indicate below average (scores 0-5), the blue colours above (5-10). The deeper the colour the stronger this relation. Instructions on how to navigate the dashboards are made orange to guide the user. Some of the ten clusters, category selection and station characteristics described, may be better presented in a map or table than in a score. The two categories tested are "council" and "station footfall" - the latter following the UK standard guidelines on station type A-F.

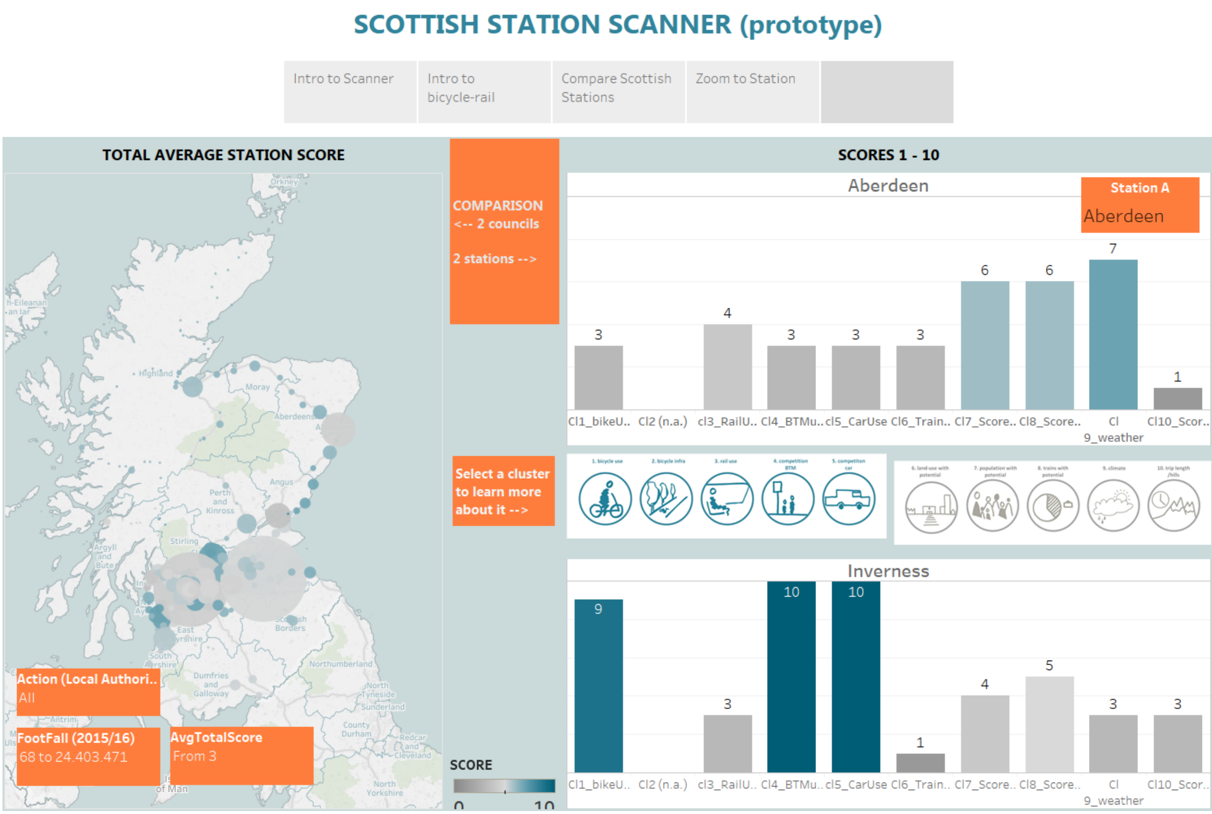

Figure 20 Prototype Station Scanner: Dashboard for comparison

Larger images of all four dashboards can be found in Appendix I.

6.2.6 Step 5: Advise

The output of the scanner can be interpreted by advisors to help relevant stakeholders improve bicycle-rail use. Naturally, the quality of the advice depends on the user and many more factors than a station's comparative score for bicycle-rail use and characteristics are required to make a strategy. As mentioned before, due to limitations in time for this study, this final step is not tested.

6.2.7 Satisfaction of the three aims of the scanner

The framework for the scanner as introduced in the previous chapter has three aims: a quick-scan of the potential success of stations, a comparison between the stations and an attractive communication to various parties involved in improving bicycle-rail use.

The first aim is ambitious. Assessing potential demand for any form of transport is a matter of prediction and requires precaution. In bicycle-rail, a niche with limited research and practical experience this is even more the case. However, bearing these limitations in mind, the aim of making a "quick-scan", in a field where currently much work is done based on trial-and-error, may be considered a step forward.

The prototype scanner can compare stations not only on bicycle-rail potential but also other aspects like managing train operating company (TOC), passenger footfall or number of current bicycle spaces. Particularly in countries (thus sets of stations) where more than one TOC are operating, such information can be helpful to ensure collaboration among all parties. England could be an interesting follow-up case for testing the framework, where over twenty TOC's manage stations across the country.

The final aim of the scanner is an attractive outcome to clearly communicate opportunities. The prototype was built in Tableau, a program which may also take over part of the data analysis. Its attractiveness will be subjective and depends on the user's wishes and demands. To adhere better to those, more input should be asked. The main builder and user are recommended to be an independent consultant, nevertheless, as the scanner combines railway statistics with socio-demographic data, we may expect the outcome and interactive dashboards can appeal to a range of stakeholders.

Further recommendations for and reflections on the scanner can be found in paragraph 8.1.

How can bicycle-rail use be improved sustainably? From the previous Green Boxes the net effect of more bicycle-rail on the triple bottom line (or 3P's) is positive. But how about the process to get there? To realise the transition to more sustainable and active travel, including bicycle-rail a combination of hard and soft measures is required (Chapman, 2007). Hardware services often use primary resources.

Engineering consultants Witteveen+Bos have much experience in the design and execution of particularly "hard measures", including station areas and cycling infrastructure. They use seven sustainable design principles to safeguard sustainable designs which are depicted and described in Table 12 below. For each, some examples for sustainable bicycle-rail services are given.

Table 12 Seven Witteveen+Bos design principles with examples on how to sustainably improve bicycle-rail.

PRINCIPLE	DESCRIPTION	EXAMPLES SUSTAINABLE BICYCLE-RAIL SERVICES
1. Nature-based design	*Build with nature by making use of natural processes*	use passive ventilation, grey water and day light in bike hubs or cycle parking buildings
2. TRIAS	*Get the most from resources by restraining the need for and optimise consumption of energy and resources*	choose materials for cycle roads and racks with limited footprint; run lockers, bike share stations; bicycle park lighting and (better even) trains on renewable energy
3. Circular design	*Close energy and material cycles within project and surroundings*	lease rather than buy cycle racks or bicycle sharing programs from organisations that consider the full life cycle; produce racks locally to limit transportation; choose for recyclable materials
4. Multi-functional design	*Fulfil multiple (also unsolicited) functions in one design*	cycling and walking share similar design needs so integrate their wishes; a bicycle hub can be integrated with flexible desks, a day-care centre, information office, park & ride, etc.
5. Flexible design	*Make a design that can adapt in the future to meet change in needs and circumstances*	use modular bicycle parking racks and bike sharing stations so they can be used elsewhere if demand changes; integrate bicycle-rail service design with general station refurbishment or new roads.
6. Participatory design	*Include all stakeholders in working together on designing and improving our living environment*	include all parties along the (complex) bicycle-rail trip chain in the design process and tailor for their needs: find the best match of services and situation
7. Societal design	*Combining technical and societal measures to achieve the goals of a project.*	consider a mix of "soft" and "hard" bicycle-rail services to limit the use of resources; tie-in with the wider active and sustainable travel agenda and goals of the stakeholder

These seven principles can be combined and considered at each phase of the design process. Principles like this can help to guide and inspire practitioners. The "Station Scanner" introduced in this thesis for example aligns with the 6th design principle of Witteveen+Bos. Also, it can help advice where bicycle-rail services will not be needed and thus limit the use of resources (principle 2) at a later design stage.

7 SCOTTISH STAKEHOLDERS AND OPPORTUNITIES

The thesis so far helped us to understand more about what bicycle-rail is, and which services are typically available to improve it. The literature review and Station Scanner combined gave us some first insights in what influences the potential demand for bicycle-rail use and how the potential demand may be found at station level. In this chapter the supply side of bicycle-rail policy and practice is considered for Scotland.

The focus will be on the stakeholders and particularly those parties able (and potentially willing) to influence bicycle-rail, to give an impressionistic image of the playing field. The importance (and challenge) of good collaboration has been mentioned various times in this report, this chapter thus provides a starting point for strengthening existing bicycle-rail collaborations in Scotland. The sub-questions answered in this chapter are:

6. Which Scottish parties can influence bicycle-rail use and how?
7. When does the opportunity for Scottish stakeholders to improve bicycle-rail use arise?

The first sub-question helps us to better understand the playing field of stakeholders and their (in)formal relations and objectives. It is answered using a combination of desk work and open interviews. The second sub-question involves organising reflections of stakeholders collected by semi-structured interviews on the current bicycle-rail situation. It gives an idea of who could implement the bicycle-rail services (as presented in chapter 3) change the influential factors (chapter 4), or possibly realise the opportunities at station-level found from a tool like the Station Scanner (chapter 6). It is also mentioned “when” these may be seized.

This chapter is structured around three paragraphs. First, an overview of the Scottish stakeholders (7.1), then their reflections presented per theme (7.2), and finally a concluding overview of when and where the opportunities for bicycle-rail use in Scotland arise (7.3).

7.1 Stakeholders in Scotland: an overview

This paragraph gives an overview of the various stakeholders in Scotland and their individual objectives and levels of influence. They are first introduced along the trip chain and in general (paragraphs 7.1.1 - 7.1.3). Second, the background information on the various parties is presented per sector: first the rail sector (paragraph 7.1.4), where Network Rail, Abellio (Group), ScotRail and the RDG are particularly highlighted. Then the cycle sector is described, led by public authorities and action groups (paragraph 7.1.5). Next, the overlapping bicycle-rail “sector” is discussed to provide a complete picture of the various parties’ objectives and levels of influence (paragraph 7.1.6). At the end of this paragraph, Table 14 gives an overview of the main parties, their publications and formal objectives relevant for this study, and their associated influences and interests (7.1.7).

7.1.1 Stakeholders in Scotland in the trip chain

To directly see the complexity of increasing and improving multimodal travel, the parties are mapped along the trip chain from a traveller’s perspective as was formulated in chapter 3, see Figure 21 on the next page. The place of influence is reflected in the location of the party’s textbox. This diagram shows how councils can achieve more in the public space (e.g. station integrated in the cycling network), whilst train operating companies and Network Rail are very influential in the integration of the two modes at train stations. A number of bicycle-rail services are described in the circles at their respective position in the chain. The level of influence is reflected by the colour of the boxes: the darker, the more influential. As a main takeaway from the diagram: places of influence overlap, thus collaboration is required to ensure a good door-to-door bicycle-rail journey. An overview of the different levels and types of influence of the various parties can be found in Table 14 in paragraph 7.1.7 at the end of this section. The consecutive paragraphs describe their roles and relations in detail.

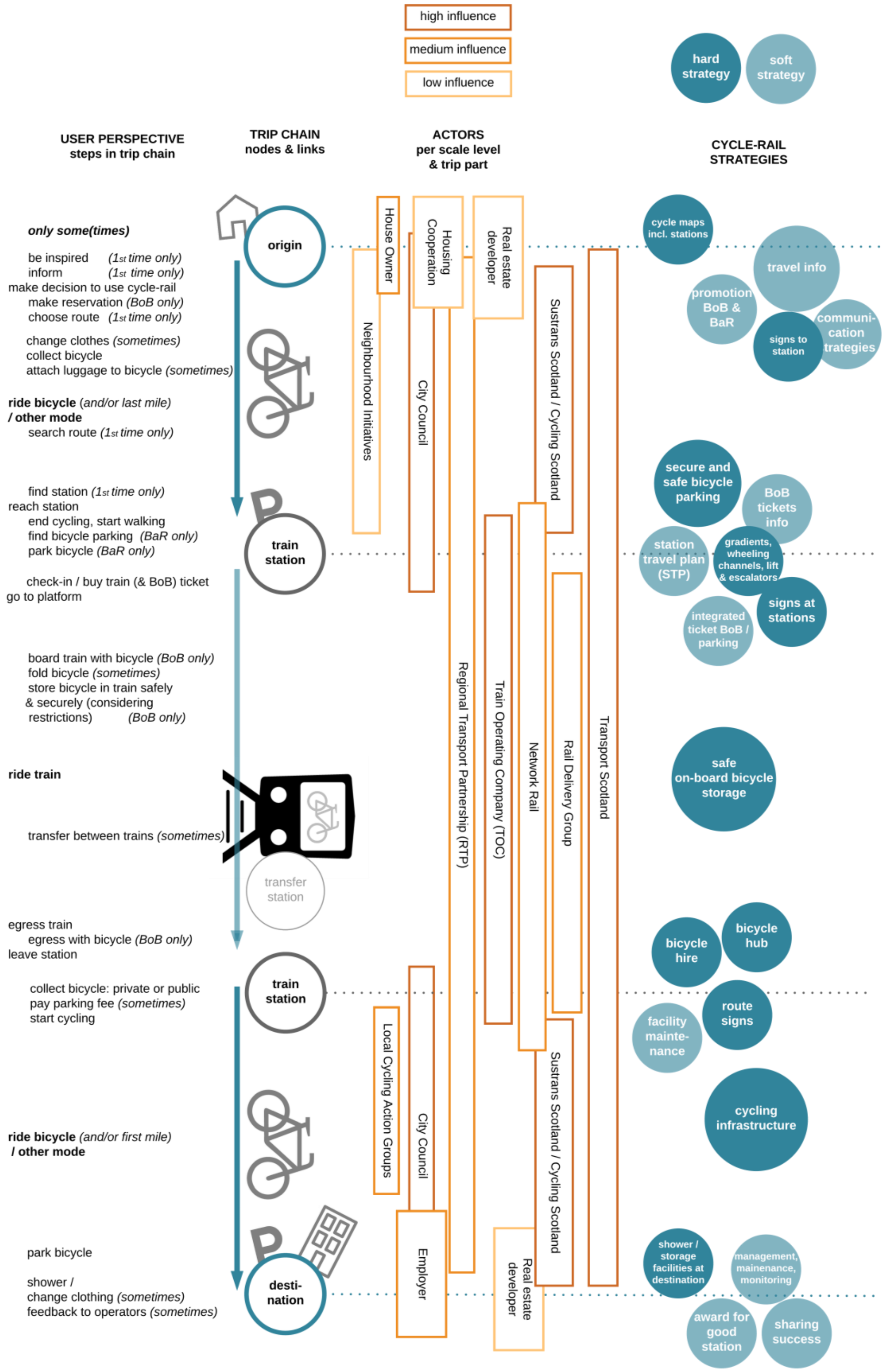

Figure 21 User-perspective Trip Chain Components & Stakeholders influence. Dark borders indicate more active involvement than light ones. Visualisation made by author.

7.1.2 Stakeholder types

An initial list of stakeholders is made from the overview of "potential parties" recommended by the Cycle Rail Toolkit 2 for TOC's (Train Operating Companies), and the regional transport partnerships added from Glasgow's bicycle strategy (Rail Delivery Group, 2016; Sustrans, 2015). This list is reduced to the main parties in Table 13 below as more information became available. After a description of the national authorities, the parties are described per sector later in this paragraph.

Scotland is part of the United Kingdom but has its own "devolved" government, which means that apart from cross-border topics like environment, legislation, and defence, the **Scottish Government** can make independent decisions on many other aspects such as health, education and transportation. As in most countries, public parties are in charge of the construction and maintenance of road and rail infrastructure, and to some extend the public transportation services that use the infrastructure. **Transport Scotland** is the government department of most relevance for this research. It collaborates with the **Department for Transport** (DfT), in charge of transport in England and to some extent in Wales and Northern Ireland where required.

Table 13 Overview of stakeholders in Scotland for bicycle-rail use

TYPE OF PARTY	SCOTTISH STAKEHOLDER
GOVERNMENT & PUBLIC SECTOR	
central government	Scottish Government
government department	Transport Scotland
executive non-departmental public body (supervised by Department for Transport)	Network Rail[1]
UK government agency	Office of Rail and Road[1] (ORR)
Regional Transport Partnership (RTP)	7 RTP's in Scotland, e.g. Strathclyde Partnership for Transport (SPT) which considers 12 local authorities
local authority	32 in Scotland, e.g. Glasgow City Council
departments of local council	e.g. Land & Environmental Services (Glasgow)
UNION / COMMUNITY ORGANISATIONS	
cross industry working group	Cycle Rail Working Group[1]
association of companies	Rail Delivery Group[1] (RDG, former ATOC)
forum (recurring meetings with various groups)	e.g. Cycling Forum; Cycle-rail Forum; CAPS delivery forum
national cycling charity / action group	Cycling Scotland (former CTC); Sustrans Scotland
local cycling charities / action groups	e.g. Glasgow Cycle Forum; Freewheel North
community rail partnerships (RCP)	e.g. Borders RC, to organise communities and railway line players.
PRIVATE SECTOR	
Train Operating Company (TOC)	32 in total, Abellio ScotRail is currently the main TOC in Scotland (previously First ScotRail)
public transport operator	e.g. Abellio, currently running the franchise of ScotRail; First Group
bicycle-rail service providers	e.g. Nextbike (bicycle share); Falco (parking); bike shops
supporting services for TOC's	e.g. Rolling Stock Operating Company (ROSCO) (Eversholt Rail Group for ScotRail); travel information software developers, etc.
real estate developers	any working within cycling distance to/from train station
employers	any working within cycling distance to/from train station

Note that the UK only has national and local authorities. Remainders of the *regional* governments (abolished in 1996) are the regional transport partnerships (RTP's, for example Strathclyde Partnership for Transport, in the area around Glasgow) who are supervised by Transport Scotland.

1 These parties work UK-wide, excluding Northern Ireland, where the situation is different. There NI Railways, a state-owned company, is in charge of both ownership and operation of the railways. It is therefore left out of this research.

7.1.3 Introduction to relations

The stakeholders have different relationships, of which the main are visualised in Figure 22 below. This diagram summarises the main parties to function as a point of reference while reading the chapter, and will therefore not be explained in more detail here. The diagram differentiates between public and private parties. Sustrans Scotland takes a special role as cycling charity in this overview, which is explained in more detail in paragraph 7.1.5. The diagram has been checked on validity with Kathryn MacKay (cycling manager at ScotRail Abellio), Karen Furey (cycling policy maker of Transport Scotland) and Dave Holladay (independent transport specialist in Scotland) in individual interviews. It is a large simplification of reality, with the purpose to help describe the various parties and relations in this report.

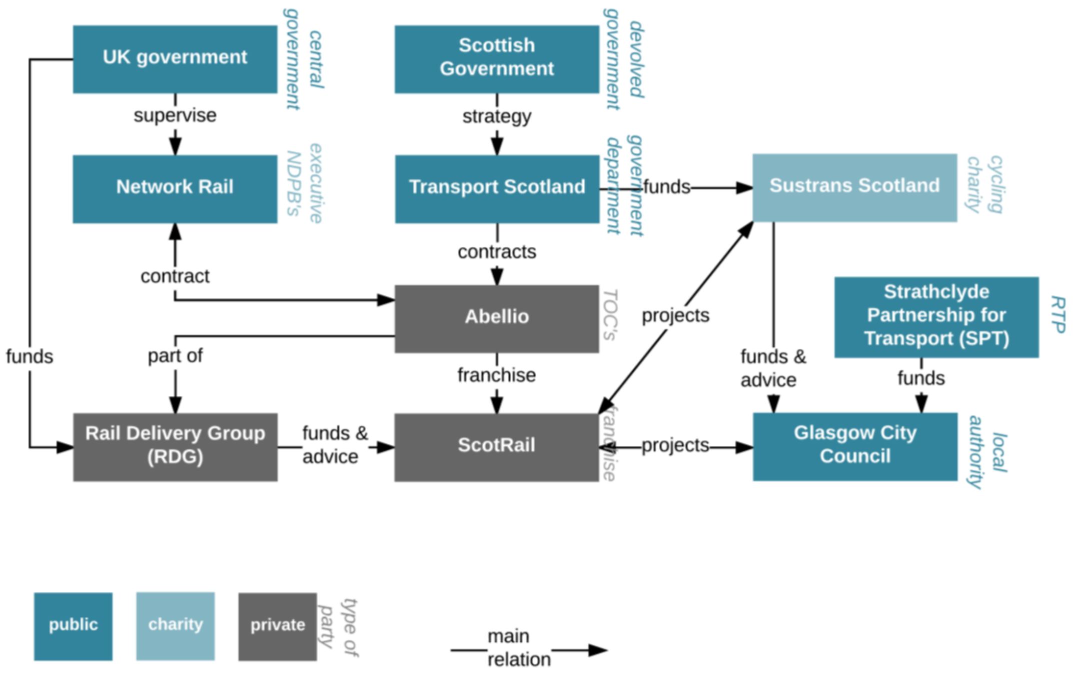

Figure 22 Diagram of main stakeholders and their relations in the Scottish bicycle-rail "sector". Made by the author.

7.1.4 The rail sector

The rail sector works on British rather than Scottish level. Ownership, maintenance, and operation of rail used to be in the hands of the state, under the name of British Rail. The sector became partially privatised under the Railways Act 1993, and the government reorganised passenger services into 25 different units and offered them for sale as separate franchises (Butcher, 2016). Currently, a range of different actors is in charge of different parts of the network. **Public transport operators** such as First Group or Abellio, (the international branch of the Dutch Railways: Nederlandse Spoorwegen (NS)) can make a bid to win the franchise in a region. If they win, they set up privately owned **Train Operating Companies** (23 "TOC's" in total, e.g. Abellio ScotRail[2]). These TOC's hire the staff, operate the trains, manage most of the stations and typically lease their rolling stock from **ROSCO**s. Those are private parties, who are less regulated by the authorities.

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[2] For the sake of convenience, "ScotRail Abellio" will be referred to as "ScotRail", and "Abellio Group" as "Abellio" in this thesis. Abellio is used only to refer to the public transport operator and its representatives. It is currently also running the franchises Abellio Greater Anglia and Merseyrail in partnership.

Network Rail is an executive body of the transport departments and in charge of the rail infrastructure and owns most of the 2500+ railway stations in the UK and manages nineteen of the largest ones, of which two in Scotland. In Scotland, it is also under various levels of control by public bodies and part of the franchise agreement with the train operating company. Matt Stacey from Abellio gave the following rule of thumb concerning the two main parties' responsibilities at station level:

"Everything below the platforms and from the wires and ceiling up, is the responsibility of Network Rail, everything in between is run by ScotRail."

Matt Stacey, Abellio

The map in Figure 23 below shows who is in charge of which station's facilities in the UK and Scotland. The size of the circles on the map of Scotland represent the annual passenger footfall of each station. The TOC's operate regionally, within their "concession area". ScotRail has a unique position, with only a limited number of stations where they share train services. It runs nearly all of over 350 stations in Scotland. ScotRail is the second biggest franchise agreement of the UK in terms of passenger kilometres travelled. The two stations operated by Network Rail are Glasgow Central and Edinburgh Waverley (serving 30 and 21.7 million passengers per year respectively), indicated by the orange circles in Figure 23 below (ORR, 2015). The large relative size of these numbers is clear from the circle diameter. More on the concession areas and franchise agreements is described in paragraph 7.2.1.

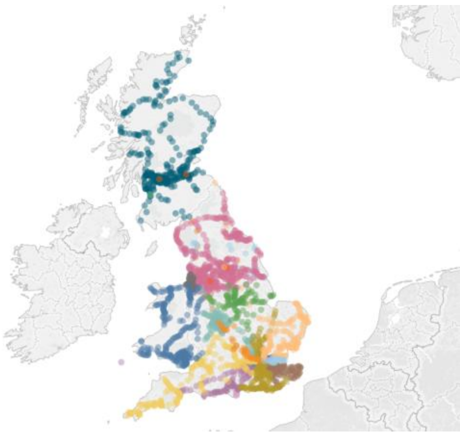
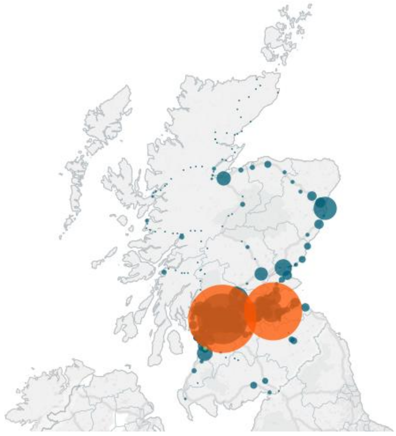

Figure 23 Left) **Railway stations in the UK. Each colour represents a different station facility manager.** Right) **Railway stations in Scotland, the circle size represents relative footfall. Data from ORR, coordinates from railwaycodes.org, visualisation by the author.**

The TOC's are collectively organised in the **Rail Delivery Group** (**RDG**, former ATOC), where they collaborate on themes such as ticket fares, train schedules, travel information and accessibility of stations for the UK. The **Office of Rail and Road** (**ORR**) is in general an independent regulation (under government control) working on rail in Scotland, Wales, and England to "*protect the interest of rail and road users and improve the safety, value and performance of railways and roads, today and in the future*. For example, it regulates Network Rail, by checking its contracts with the TOC's to ensure fairness for both parties (ORR, 2016).

Whilst there are locally individuals involved in the rail industry (e.g. via **community rail partnerships**), none have been identified to target cycling-rail particularly. Nevertheless, they could play a role in the future.

7.1.5 The cycling sector

Considering the cycling part of a bicycle-rail trip, different parties emerge. The road infrastructure in the United Kingdom is planned, constructed and maintained by the four independent countries. The major roads (trunk roads) are funded by the central governments and managed by the respective highway agencies. Local authorities are in charge of the local roads. Naturally, considering regulations, limited travel distances and the speed of bicycles, local roads are of more interest for improving bicycle-rail.

In 2013, **Transport Scotland** published the first Cycling Action Plan for Scotland (CAPS) with a high ambition: 10% of trips by bicycle in 2020, described in paragraph 7.1.7 in detail. All 32 **local authorities** are required to write an Active Travel Plan to help realise these ambitions. Fifteen out of 32 local authorities had an active travel plan or strategy in place according to Karen Furey from Transport Scotland when the latest CAPS was published in January 2017. Twan van Duivenbooden from Sustrans Scotland mentioned that the realisation of the CAPS goal depends strongly on the councils, with large variation in their capacity to achieve these goals. The **Regional Transport Partnerships** have limited policy influence but are mostly concerned with regional transportation matters where councils need to cooperate, for example on cross-council-boundary bus lines or integrated tickets. They make regional strategies and can provide funding to realise them. For the development of cycling networks and general cross-council collaborations they are valuable public partners.

Sustrans Scotland is a cycling charity that operates nationally. It is in charge of allocating a large part of the government's cycling budget. A second established cycling organisations is **Cycling Scotland**. They push cycling in various manners and are in charge of publishing the annual Cycling Monitoring report. Parties such as **recreational cycling groups** or initiatives like **cycling forums** (often set up by local councils) can also provide relevant input on bicycle(-rail) plans or policy. Besides infrastructure, many soft measures may increase cycling shares. For the execution of those programs, a whole range of stakeholders like action groups, bike shops, recreational cycling groups, schools or companies may be involved.

7.1.6 The bicycle-rail "sector"

The slowly upcoming interest in bicycle-rail cannot be described as a sector exactly, but rather takes shape in the form of (project-based) collaborations between the various partners. In 2007, as a result from the White Paper published by the British government, the **Cycle Rail Working Group** was found. This cross-industry working group "*encourages implementation and best practice development of strategic policy in relation to the delivery of cycle-rail integration.*" (Rail Deliver Group, 2016). Parties it includes are the RDG, Sustrans, Transport for London and even English Heritage, as many British stations are protected. According to Conrad Haigh, integrated transport manager of the RDG:

> *"The Cycle Rail Working Group was the key to improving bicycle-rail in the UK"*
>
> (Conrad Haigh, RDG, speaking at the BiTiBi conference, 2017)

Other stakeholders that play a crucial role in the bicycle-rail trip are naturally the **bicycle-rail travellers** themselves. They can advocate for better or more integrated transportation. However, we are not aware of any (formally) organised bicycle-rail user action group.

Chapter 3 highlighted that every journey begins at an origin and ends at a destination. Those are usually not stations. Stakeholders such as **house owners, employers** or **developers** within cycling distance from stations, may therefore also have a large (long-)term effect in travel times (e.g. bicycle parking at homes and offices) and alternatives like bicycle-rail (e.g. develop an active-travel neighbourhood). The SPT representatives described how transport and land-use integration in Scotland are promoted through for example the Scottish Planning Policy and Local Development Plans. Section 75 agreements and planning conditions can be used as a mechanism to require developers to deliver or fund improvements to ensure good access for all. This can include the requirement to develop and deliver a travel plan which outlines measures to encourage sustainable and active travel and ensure good access to the development by sustainable modes. As was mentioned, these land-use factors (cluster 6 from the scanner described in chapter 5) are harder to change. However, for a more ambitious transition to sustainable transportation modes like bicycle-rail, also these may be considered. Some bicycle-rail services implemented at the origin or final destination of a journey like secured cycle parking on the street or bicycle sharing stations at a company's front door, highlight the role those stakeholders may take. As a large variation in interests among these groups of stakeholders may be expected and considering the scope of this research, they are not considered in more detail in this study.

7.1.7 Overview: objectives, publications, influences & interests

The first part of this paragraph introduced the main stakeholders in Scotland. The parties identified as most relevant are mapped in the network diagram introduced earlier (Figure 22). The stakeholders' formal objectives and related publications (e.g. policy document, strategic plans, etc.) are presented in Table 14, per scale-level of their influence: national, regional, local. Besides the Cycle Rail Working Group, no party is formally focusing on larger numbers or greater satisfaction of bicycle-rail use solemnly. Their more general goals and objectives do however reflect their (potential) interest for better or more bicycle-rail use. For more detail, this study refers to the actual publications of the various strategy documents and policies.

Table 14 Overview of stakeholders, objectives, and publications (table continues on next page)

SCOTLAND STAKEHOLDER	FORMAL CYCLING and/or RAIL RELATED OBJECTIVES; PUBLICATIONS	INFLUENCE CYCLING-RAIL
NATIONAL		
Scottish Government	mobility for economy and equity; healthy population; "public services fit for the future"	Legislative authority, strategies, and funding.
Transport Scotland	more sustainable and active travel; *"10% of trips by bicycle in 2020"; "increase in sustained funding (...) towards a 10% allocation of national and council transport budgets"; "Improve integration with public transport, through partnership working with ScotRail, bus/coach operators and Regional Transport Partnerships and provide secure cycle storage at key destinations including transport interchanges"* from: Cycling Action Plan for Scotland (CAPS) (2017)	Provide funding (40 million pounds/year for cycling only), have strategies for mobility and transportation (both system level and per mode), create partnerships and apply for e.g. development of active travel hubs (with European Regional Development Funding). They formulate & check the rail franchise agreement with the train operating company at the time. Plan on giving out "Cycling City Award" in the future.
Network Rail	No formal strategy in place. Do facilitate for cyclists when required; typically following demand. Collin Peters, Network Rail: "*We also do customer surveys and if our customers are unhappy we get a lower score. If we have a community of people that are unhappy we need to facilitate this.*"	Own all stations ground and property, and in charge of the 19 main ones. In Scotland: Edinburgh Waverley and Glasgow Central
Rail Delivery Group (RDG, former ATOC)	more rail passengers; accessible stations	They represent all TOC's and can thus do much knowledge sharing or cooperate in research. Also lead party in the Cycle Rail Working group
Cycle Rail Working Group (part of RDG)	*"encourages implementation and best practice development of strategic policy in relation to the delivery of cycle-rail integration";* Cycle-Rail Toolkit (number 2 was published in 2016);	Allocate the Cycle Rail fund (from UK government), share knowledge and organise the annual Cycle Rail Awards (sponsored by Cyclepods).
Sustrans Scotland	*"Sustrans makes smarter travel choices possible, desirable and inevitable. We're a leading UK charity enabling people to travel by foot, bike or public transport for more of the journeys we make every day.";* Published design guidelines (Sustrans Design Manual Chapter 9) (2014);	Allocate cycling funding of Transport Scotland and develop the National Cycle Network; advocate for cyclists.

REGIONAL		
Regional Transport Partnership (e.g. SPT)	*"SPT has, with our partner councils, invested over £2m in cycling improvements over the last 3 years"*	Write Regional Transport Strategy (RTS) Walking and Cycling Action Plan and stimulate and facilitate collaboration between different councils and organisations. They also have funds available.
Abellio (runs ScotRail)	*"During the period of the new ScotRail franchise we will target a 10% increase in sustainable access to and egress from the rail network"; "Our duty to our customers will span the entire journey"* Published Abellio ScotRail Cycle Innovation Plan (CIP) (2015)	The CIP includes opening hubs called Cyclepoints, more CCTV, Bike&Go bicycle rental and the 'Cycling is Smart' campaign. Also agreed upon delivery of e.g. 3500 bicycle parking spots by March 2017 and having a Bicycle Manager.
LOCAL		
Local Authority (e.g. Glasgow City Council)	*"To create a vibrant Cycling City where cycling is accessible, safe and attractive for all"*; *"We will work with public transport operators to improve integration between cycling and public transport". Published a Local CAPS: Glasgow's Strategic Plan for Cycling 2016 - 2025 (2015);*	local CAPS includes Glasgow Cycle Hire Scheme (Nextbike), cycle network expansion, assessing the feasibility of cycling hubs. Funding for measures.

7.2 Processes & reflections

The previous paragraph introduced the formal framework that the different Scottish parties operate in. To understand how the opportunity for bicycle-rail use is currently seized, this section is structured in a number of themes around which the interviewees remarks are clustered. Considering the explorative nature of this research, the aim is to get an impression of the context. A statement by a single individual can give a crystal clear picture of a certain situation. Therefore quotes of interviewees are used in combination with descriptive texts, for each of the four main themes that were found to be of value for improving bicycle-rail use.

The themes are discussed in the following order:

- Rail franchise contracts paragraph 7.2.1
- Deciding on bicycle-rail services 7.2.2
- Financing bicycle-rail services 7.2.3
- Thinking out of the boundaries 7.2.4

These themes' relevance in terms of opportunity for bicycle-rail will unfold during the storyline and is summarized at the end of each paragraph and presented in an overview at the end of this chapter (7.3: Cycle-Rail Opportunities). The final paragraph summarizes the moments and places of opportunity.

7.2.1 Rail Franchise Contracts

A first aspect to consider are the franchising agreements in place in the UK, between the government and respective train operating company (TOC). The infobox below introduces them.

FRANCHISE AGREEMENTS IN THE BRITISH RAIL SECTOR

The operation of the majority of train services for passengers is organised by private parties through franchising. Via a competitive tendering system, TOC's can run specified services within a specified area, for a specified period of time as set out by the government. Typically the time period lays between seven and fifteen years (Butcher, 2016). Companies write a bid for the right to operate a franchise.

SCOTRAIL FRANCHISE AGREEMENT

The franchise authority in Scotland is Transport Scotland. In 2014, Abellio won the bid for ScotRail formalised in a ten-year contract. During the contracting period, it must adhere to a certain level of performance and service quality as set by the government. The first is an assessment based on the reliability and punctuality of train services. The second focuses on equipment and stations, under the Service Quality Incentive Regime (SQUIRE) (Transport Scotland, 2013). This includes 4-weekly audits of stations and trains. There are strict agreements in place that must ensure companies deliver as promised. Network Rail is also involved in the franchise agreement.

The principal advantage of railway franchising is preserving an integrated network of services, possibly combined with subsidy but having a competitive market too (European Conference of Ministers of Transport., 2007). However, franchising is not always ideal, perhaps particularly so for new, upcoming opportunities. Bicycle-rail use challenges conventional single modal thinking and strict agreements now might limit flexibility later. Some statements of the interviewees formulated below discuss some downsides.

"There is an ongoing discussion on what the best length for a contract is. (...) a short term contract can lead to short-term vision, and investments need to pay back."

Iain Docherty, University of Glasgow

"Yes, many TOC'S now have an integrated transport manager, but only because they have to write that in the bid. (...) the most basic requirements are met simply to agree to the concession (...) Generally speaking: what is asked, is delivered."

Kaj Mook, Abellio/NS

As there must be a profitable business case for the transport operator after each cycle of contracting periods, plans can become safe and pragmatic, rather than challenge the status quo. In the UK, the main responsibility of the formulation of the so-called franchise agreement lays with the government. Gordon MacLeod from Transport Scotland reflected on the origin of the requirements for the latest ScotRail franchise. With an intensive public consultation, based on 1400 responses, a rather new approach was taken. The wishes of the public were translated into bidding requirements, leading to bidding choice criteria for price/quality at a 60/40 ratio - a high focus on quality service for British standards:

"Our franchise agreement was 60% costs and 40% quality.
Abellio wasn't the cheapest but it was the highest quality. This was really fairly new."

Gordon MacLeod, Transport Scotland

With its bid for the ScotRail franchise, Abellio proved that some changes are underway. Matt Stacey from Abellio even described how the Cycle Innovation Plan was "*crucial to winning the bid*".

Gordon MacLeod who oversaw the sustainability aspects of the bidding reflects largely positively on the process and outcomes of the franchise agreement. The government largely put in the right incentives and the mechanism to check performance is working well and is flexible enough to make their investments wisely. However, reflections that the franchise agreement may work too rigid also arose. Including one from another Transport Scotland representative on financing more ambitious bicycle-rail targets than formally agreed upon:

"We can improve on the agreed commitments in the franchise by working with TOCs and investing in more ambitious facilities, over and above the franchise commitments."

Karen Furey, Transport Scotland

As a concrete example of limiting ambition concerns Bike&Go, a bike share based at British railway stations:

"The initial idea of Bike&Go was to make an operator independent, UK-wide system. However, the pragmatism of the English railway sector kicked in, and Merseyrail was to take the lead."

Kaj Mook, Abellio/NS

Karen Furey explained that ScotRail must deliver exactly what is in the contract, even if the context alters or new insights arise, as flexibility is limited. Good bicycle-rail solutions can then still be delivered but must be organised creatively. Further reflections on the formulated targets and potentially wrong incentives were also given, first of all by a representative from the regional transportation partnership of the southwest of Scotland:

"At some stations – for example Patterton – there is limited evidence of any current high demand and the former facility was not well used. However, and regardless of this, a new, higher capacity facility has now been installed, as the physical space is there and the franchise agreement seeks to provide more spaces. This provision seems to be more opportunistic rather than based on any evidence of suppressed demand or potential future growth."

Allan Comrie, Strathclyde Partnership for Transport

His statement indicates that a more evidence-based selection to match stations with services may pay off. Abellio's former integrated transport manager mentioned the following related to contract incentives:

"Energy is sometimes put in the wrong things, for example: discussions with the board of directors were often about managing risks (e.g. of not living up to the bidding promises), rather than focusing on how to genuinely make things better."

Kaj Mook, Abellio/NS

He also gave an example of how the limitations from a contract can spark creativity and push bicycle-rail services. At Mersyrail, a TOC in the southwest of England, the capacity for bicycles on board (BoB) was getting tight. However, no restrictions for BoB could be made according to the contract. Therefore, the TOC did not only improve bicycle parking but also actively pushed the bicycle sharing service Bike&Go to encourage BaR. Kaj Mook summarised that in a train-journey-focused railway industry like the UK, it is very helpful if stimulating cycle-rail solves an operational problem.

This section discussed the opportunities for particularly TOC's and national governments to improve bicycle-rail through franchise agreements. A focus on the exact delivery the contract may limit creativity and long-term investments if the wrong incentives are in place. Bidding TOC's will ensure to write a bid with promises they are sure they can deliver, thus the government has a responsibility to define targets that stimulate their creativity and ambition, or make the contracts flexible enough to improve where required. When used well,

the franchise agreement can be a very effective tool for public authorities to reflect and help deliver their sustainable and active travel strategies.

7.2.2 Deciding on Bicycle-Rail Services

The previous section discussed the franchise contracts in Scotland, with obligations, agreements, and regulations. We now look at the various actions to provide bicycle-rail services. As the very varying roles, responsibilities and resources of the parties presented in paragraph 7.1 already indicate, their individual influence on different components along the trip chain and/or bicycle-rail services also differ. In this section, various examples of how and by whom bicycle-rail services are implemented is discussed.

All parties have their own ways. Transport Scotland formulates the franchise agreement requirements, Sustrans and the Cycle Rail Workgroup write criteria to allocate funding wisely (see paragraph 7.2.3 on financing), whilst TOC's, developers or Network Rail have the bear a complete business case in mind when considering bicycle-rail services. Depending on the party, situation and possible solutions at hand, other trade-offs are made. As an example, the way in which ScotRail's franchise requirements on bicycle-rail are translated into deliverables is presented in the infobox below.

BICYCLE-RAIL STRATEGY & INVESTMENT OF SCOTRAIL

ScotRail executes a Cycle Innovation Plan which "*contains the main bones for all the active travel decision that ScotRail is taking*" (Matt Stacey). Besides a number of clearly defined deliverables as mentioned in the plan - including bicycle parking spaces, cycle point facilities and Bike&Go services - ScotRail Abellio has a number of strategic commitments. To help deliver the ambitions of the Scottish Government's CAPS, ScotRail looks to support cycling through the following strategic commitments:

- Investment in cycling infrastructure and facilities at stations in Scotland
- Working with Stakeholders and other organisations
- Promotion of cycling to encourage journeys to/from stations by bike

Kathryn MacKay is currently the cycling manager at ScotRail and in an interview describes the following three points of analysis before bicycle parking investments are made:

1. What bicycle parking is currently available and how is it used?
2. What space is available at the station for additional bicycle parking?
3. What interventions is the local authority doing, in and around the station area?"

She mentions that the working knowledge of her team on both the rail network and local cycling-related interventions is vital in taking bicycle-rail related decisions.

The different parties' plans are delivered according to the formal agreements they make. ScotRail's Cycle Innovation Plan mentioned in the infobox above contains clear formulations. There are a number of potential challenges concerned with ensuring the right (number of) bicycle-rail services are chosen for the right locations. Three are described here. First of all, the novelty of bicycle-rail services and what type to choose. Gordon MacLeod described that bicycle-rail is in an "*infant state*" in Scotland, therefore it is still often searching where to improve things. Kathryn MacKay from ScotRail mentioned the importance of repeating why cycle-rail services are put in place, to get enough support. An example of the search is reflected in the following statements:

"A challenge when targeting the cycling market is competing wishes: the elite lycra cyclists are different from the mountain bikers, who vary from commuters with functional bicycles or kids getting to school. These lead to competing requirements."

Gordon MacLeod, Transport Scotland

A Network Rail representative describes bicycle-rail services at nineteen large British railway stations and how these require different services:

"It depends on a lot of factors what [bicycle-rail services] we put in. How much space there is, how much demand there is. Different stations will have different levels of demand. (...) We mostly use double-decker facilities so you can maximise the number of cycles that you are able to securely store. (...) Some of our facilities have basic toolkits like pumps, keys and that sort of thing. But again, that depends on the station."

Peter Collins, Network Rail

A second challenge may be indicated the other way around: a party knows it will place a service but not yet where. This might be particularly important in Scotland. Gordon Macleod from Transport Scotland mentioned Scotland is very diverse: it has both extremely rural area, where trains only go once every three or four hours, as well as urban regions like Glasgow or Edinburgh. The following was stated on bicycle parking:

"We mainly let us be advised on putting in bicycle parking (...) and used station footfall as a main indicator."

Joost Mortier, Abellio

Another practical example is the roll-out of the Bike&Go system by Merseyrail, a partially-Abellio-owned TOC. After funding was secured, the main question was where to place the system.

"The station choice of the Bike&Go system was pretty straightforward: those with a high footfall, the opening of a cyclehub and much leisure attraction were considered. (...) It was very flexible, after a piloting phase we moved some bikes from Stirling to Edinburgh and that was that."

Matt Stacey, Abellio

A trial and error approach worked well for such a flexible service can function well. For larger investments like a bicycle hub, barrier-free station or double-decker bicycle parking, this may not be ideal.

The previous chapter highlighted the growing numbers of both BoB and BaR use in Scotland. The third challenge for improving bicycle-rail is found here. Considering capacity limitations of trains, particularly BaR, rather than BoB should be stimulated, as the Merseyrail example indicated. This may proof difficult:

"If we were to ban bicycles on trains in Scotland, there would be a backlash. Some train operators, including Abellio Greater Anglia do use such strategies in England at peak hours."

Matt Stacey, Abellio

"Some users have quite 'rose-tinted spectacles' concerning bike-on-board."

Gordon MacLeod, Transport Scotland

“Cycling bodies are well organised and have taken a fairly strong bond on bicycle-on-board (BoB) policy. Therefore it is currently mainly encouraged to do bike-and-ride (BaR), as trains are designed to carry people rather than bikes.”

Joost Mortier, Abellio

Particularly this last critical contextual difference must be kept in mind when comparing the bicycle-rail success of the Dutch practice to the Scottish potential, where BoB use is restricted and thus less common.

The examples so far concerned hardware bicycle-rail services. When considering the currently low bicycle-rail usage and realising that this transport alternative requires some introduction, the need for some additional “soft” measures is evident. “Positive communication” was already mentioned as one of the six building blocks for bicycle-rail improvements by the EU-commissioned BiTiBi project in chapter 3. The importance of these softer measures was stated well by a member of the bidding team of Abellio:

“Build it, communicate it and thèn they will come.”

Irvine Piczenik, Abellio

Bicycle-rail services should be a mix of hardware and software, as described in detail in 3.3. A regional transport partnership representative reflected that this is not always common practice yet:

“There is a lack of any widespread or local marketing, or raising of public awareness, associated with the installation of new [bicycle-rail] facilities.”

Allan Comrie, Strathclyde Partnership for Transport

This section introduced some examples to describe how bicycle-rail services are currently implemented in Scotland. As it is still a fairly new practice in Scotland and wishes of bicycle-rail users differ, both the decision of service-type and next its location is often trial and error and based on working knowledge or estimates. A thought for the future may be to push bike-and-ride in particular, concerning the limited train capacity.

7.2.3 Financing Bicycle-Rail Services

Funding for direct bicycle-rail investments comes from various sources. More funds are probably available, but considering the scope of this research and impressionistic approach of this section, only those mentioned by the interviewees have been listed here. The stakeholder diagram presented in Figure 22 at the start of this paragraph may be useful to keep in mind here.

Most straightforward, funding for direct bicycle-rail services comes from the Train Operating Company (TOC) or authorities to reach their transport strategy targets. The business case for enlarging a station's catchment area by good bicycle-rail solutions is clear, as we learned from the ScotRail bid by Abellio and its cycling innovation plan. A TOC’S own resources thus provide a first fund, but there are other places to consider. In England, there is even a National Cycle Rail Fund. Considering knowledge sharing and the Britain-wide bidding of for example Abellio, this fund is explained in more detail in the infobox below.

THE NATIONAL CYCLE RAIL FUND

In 2007, a White Paper was published by the British government, pushing integrated transport in the rail industry. One of the outcomes was funding, managed and allocated by the Cycle Rail Working Group. The cycle-rail fund has been invested in various improvements at 350 stations across the UK, including the opening of 42 cyclehubs. This fund comes from the Department for Transport.

Various parties can bid for funding from the national cycle-rail fund. The fund is allocated to a TOC. As part of the legal requirements, they are required to co-invest a minimum of 10% and collaborate with city councils, said Conrad Haigh from the RDG. In 2015-2016, nearly 14.3 million pounds were projected, in projects with a total value of 16.7 million (DfT, 2015a). The allocated budget between 2012 and 2014 was 14.5 million GBP in total - an increase probably associated with the positive findings from the RSSB evaluation report (Jones et al., 2015).

An example of a project funded by the national cycle-rail fund is the Bike&Go system, also available at Scottish stations:

"The second round of biddings for the Cycle Rail Fund made us apply for the Bike&Go System. It was at the time unique that the 1.65 million pounds we received for a project went to more than hardware alone, in a period of four years."

Kaj Mook, Abellio/NS

He did mention that as it is typically one-off funding, maintenance or promotion must come from other budgets. To show the Dutch alternative: typically the railway sector is in charge of bicycle parking security, (local) governments finance the construction and maintenance, and a partnership of the two, run the overall management and conservation (BiTiBi, 2017b, p. 10). Irvine Piczenik from Abellio noted that the end of a financial year can push bicycle-rail solutions from a TOC's point of view. As bicycle parking can be put in very quickly, it can be a perfect way to spend the remaining of a fund you have been assigned. There may, however, be other services required for that particular station or the parking spaces located at an easy-to-place but inconvenient-to-use spot.

Regional funding can come from regional transport partnerships like Strathclyde Partnership for Transport (SPT). Their capital programme funding is available to the 12 councils in their respective region to support the aims and objectives of the regional transport strategy. Representative Clare Strain mentioned that First ScotRail (before the Abellio franchise) once used funds to purchase and install bicycle parking facilities at a number of stations. Local funding can come from the Local Sustainable Transport Fund (LSTF), which councils can spend according to their own objectives. Councils can also apply for funding from Transport Scotland, which are allocated by Sustrans. For specific bicycle-rail interventions such as a station-to-station bicycle sharing service, universities or employers may (co-)finance, as was the case with the Nextbike system in Bath.

Considering EU funding, the following has been noted. As part of the aforementioned BiTiBi project from the EU, four pilot projects in Italy, Spain, Belgium and England, Merseyrail received funding for a communications and marketing project to push Bike&Go. Collin Little from Glasgow City Council mentioned that a number of bike hubs have also been constructed with funds from the European Union. For future policies, Brexit is fairly likely to change this, although an independent Scotland remaining in the EU also seems a plausible outcome at the moment of writing. That this may not always be used is reflected in the following statement:

"Most parties seem quite reluctant for EU funding. I'm not sure why, it could be because they're simply too busy with their own work"

Collin Little, Glasgow City Council

Collin Little did note that others will be more aware of the EU funding landscape. Considering particularly funding from public budgets for cycling-related investments, the following may be noted. Both a representative from the Dutch embassy in the UK and the cycling manager from Transport Scotland pointed out the importance of considering that cycling is a politically sensitive topic in the United Kingdom. Especially during election times, even the labour party who typically support cycling (and thus it may be assumed cycling-rail), will be less eager to make large or risky decisions. Depending on who is in charge, this naturally varies locally. Similarly, Joost Mortier from Abellio described how a council's civil servant was once threatened on the street for building cycling infrastructure and Twan van Duivenbooden from Sustrans described aggressive sticky notes on where to "execute" the responsible council staff at a consultation event in East Dunbartonshire (also mentioned in newspaper article via Evening Times, 2016). In this last example, the loss of car parking space was a design trade-off.

Before the benefits can be reaped, someone will have to invest in bicycle-rail. This section described the funding availability and use for improving bicycle-rail Scotland. Findings from this exploratory research indicated most funding comes from public parties or ScotRail. Most funding is one-off and focused on hardware, where an overall practical and easy-to-implement approach seems to be the norm. As much funding is earmarked whilst bicycle-rail needs a trip-wide approach, collaborations may occur. The next paragraph considers these both in physical and organisational terms.

7.2.4 Thinking out of the boundaries

This paragraph considers various boundaries relevant to improving bicycle-rail use and implementing services or a strategy. The trip chain aligned with the parties as Figure 22 at the introduction of this chapter showed. The various levels of influence of the parties directly show some potential physical boundaries. Each trip chain component has its own, often overlapping part with influence. The particular difficulty at stations is highlighted in the infobox below.

BUSINESS AT BOUNDARIES

Making changes in station areas is particularly difficult. There are many stakeholders with varying, possibly conflicting objectives and limited space. This is the same in many countries, including the Netherlands.

Consider for example the situation at Stirling station in the south of Scotland. Network Rail owns the station building, but ScotRail is in charge for the ten-year contract period, whilst Virgin Trains East Coast and Caledonian Sleeper also run train services. The station's platforms and buildings are both listed as A-category, thus Historic Scotland supervises their heritage state. The land and buildings surrounding the station are owned by various parties, where e.g. shop owners rent space. Car parking is leased by ScotRail, surrounding street furniture and cycle paths connecting the station are managed by Stirling City Council.

Various action can be undertaken to improve bicycle-rail as chapter 3.4 highlighted. Hardware services require physical space which is limited by definition. That this can lead to conflicts is shown in the following statements:

"Space is very valuable. So there are many competing demands for space. If you run a station and you have a choice between cycle racks and a retailer, one is going to cost you money, the other is going to give you money. The same competing demands can occur with car parking spaces for example."

Peter Collins, Network Rail

"It is always a fight for space, and retail could bring in more revenue than bicycle facilities."

Joost Mortier, Abellio

That this is very location dependent becomes clear from for example a reflection of Gordon MacLeod, describing how many Scottish station buildings are vacant and various parties glad to find a good purpose for them. Many of them are official heritage sites, with attractive buildings and often unused rooms and space. These are gradually turning into destinations like museums or cafés, but also bicycle hubs like in Stirling. Conrad Haigh (RDG) also mentioned space issues. He described how building the first bicycle parking facilities at stations in the UK was fairly cheap and easy but as space is getting more limited, the future ones will require more effort.

Car parking owned by private parties can also hypothetically pose issues of interest. For example, if the number of parking spots is decreased to open up space for bicycle services. A loss of revenue from car parking charges is however currently not an issue in Scotland as this is free of charge and the official sites are owned by ScotRail or local authorities. Part of Transport Scotland's Park & Ride strategy is that the number of car parking stays at least the same, to encourage people to switch from car to "car-rail" for their complete journey. This can, however, work as a push factor that compromises the relative attractiveness of cycling to a station, as was described in the previous chapter 4 on factors.

Whilst working on your own land does make it easier and quicker to implement changes, there are downsides, both in terms of delivering the best possible integration and optimise costs, as reflected in the following two quotes:

"The TOC's typically take a "my power stops at station boundaries" approach. Which is good because it gives much power within that boundary. Which is bad as it means integration is hard"

Conrad Haigh, Rail Delivery Group (at BiTiBi conference)

"You do have to bear in mind that putting in cycle parking facilities on platforms or in the station is often far more expensive than for example in a park, as a result of safety regulations because of cables and such."

Matt Stacey, Abellio

Another challenge can arise from the aforementioned funding, which is typically earmarked for a location. Local funding must be used on publically accessible land, Collin Little from Glasgow City Council describes and similarly Kaj Mook points out how the Cycle Rail Fund may only be used for projects on the station's ground. That this may lead to suboptimal solutions is clear - with for example empty bicycle racks at a station side entrance, and full ones at the other, along the main road on council land. An ideal location for parking may not be available and compromises must be made, Clare Strain from SPT mentioned. She said that Partick interchange station is a very popular destination for cyclists and demand for bike parking frequently exceeds supply. A convenient and ideal location for improved bike parking is being sought to provide improved bike parking facilities there. Kathryn MacKay from ScotRail mentioned that collaborations with local councils can often be an option.

Besides the physical boundaries, there are also less visible ones. Collaboration requires working beyond the own scope and seeing the benefits for the system and stakeholders combined. Various guidelines mentioned the importance of collaboration to deliver good bicycle-rail integration (BiTiBi, 2014; Rail Delivery Group, 2016). Various interviewees described how project-based collaboration is fairly common (e.g. to apply for a local fund), but more strategic long-term planning seems to happen less. Particularly when compared to the Netherlands, as particularly the various Dutch interviewees mentioned:

"The British are very good in delivering pragmatic solutions fast and on the spot. (...) but for a larger change there is no pragmatic solution, that needs time and patience.

Joost Mortier, Abellio

"In the Netherlands, collaboration with the municipality is sought often, creating a larger benefit. It must be borne in mind however that in the UK the local councils have no money, expertise nor ambition to make it perfect. There is no party that tries to push better integration or a broader look. (...) On the other side, in the Netherlands, we sometimes stay in the idealistic world and forget the economical model."

Kaj Mook, Abellio/NS

These statements do raise the question how realistic an overarching bicycle-rail strategy is when the context and system are typically more pragmatic. Bicycle-rail opportunities may then be more successful on a small scale or pushed by one party, or the system may require other values. A Dutch Sustrans representative did mention the overall development of cycling policy and strategy:

"A larger vision [on what is good cycling infrastructure] still needs to be shaped, but ideas from abroad are being picked up [in Scotland]: the standard is improving and there is a better understanding of the type of facilities required for everyday cycling."

Twan van Duivenbooden, Sustrans Scotland

An illustrative example of how particularly bicycle-rail use developed came from Peter Collins from Network Rail who explained why for example at London Waterloo station bicycle parking increased from 20 to 400 in five years and noted:

"Cycling is generally more at the front of people's mind. (...) It's about giving people the tools and facilities to make that difference. That's the challenge. "

Peter Collins, Network Rail

Another concrete bicycle-rail example is the current feasibility study undertaken by the regional transport partnership HITRANS (Highlands and Islands Transport Partnership) to improve bicycle-rail services and tie-in with the highland cycleway between Macharioch, via Fort Williams to Inverness.

It was also noted how within the transport and rail sector, not all departments or individuals are in favour of bicycle-rail:

"There can be a lack of awareness within the rail industry of what we're trying to achieve with cycle-rail. That is because it is quite a new concept to people (...) You're asking people to think beyond trains. To think about another part of the journey"

Kathryn MacKay, ScotRail

"According to the marketing departments, the role of the TOC's is not the first and last mile. They literally don't look beyond the front door of the stations. (...) You have to realise that also within TOC there can be scepticism towards the bicycle-rail opportunity."

Kaj Mook, Abellio/NS

That this can change and a positive vibe can even be built around bicycle-rail in an organisation was beautifully phrased by the following example:

"There is also one person from the front-line [railway] staff part of the Cycle Forum. (...) Now the staff is actually bragging that they were able to get 15 bikes on board!"

Dave Holladay, British transport specialist

These examples and the remarks about how politicized the topic of cycling has become show how both the railway's and public opinion is not always in favour of cycling, despite its evident advantages. Upon asking about any opponents to bicycle-rail directly, interviewees described how occasionally conflict occur on-board of trains. Particularly during rush hour when capacity is fully reached, some arguments can occur.

On a longer term, it may be noted that if the bicycle is increasingly successful in shifting more and more people from either car or BTM, more opponents may arise. For example from private parties that make a profit from car parking nearby railway stations, frustrated non-BoB passengers or bus operators losing many customers on certain services. Everything combined, it appears that as the opportunity for bicycle-rail is dawning upon more parties, collaboration improves.

Finally, a reflection on the view on cycling in general in the UK is in place. Cycling numbers are low and there are a relatively large number of people that never ride a bicycle. That cycling matters are politicised was mentioned by various interviewees. Or, as one of the interviewees framed it:

"We must keep the position in the middle of the room and keep the conversation going"

Dave Holladay, British transport specialist

7.3 Cycle-rail opportunities

The introduction of this thesis (chapter 1) described strategy and collaboration as one of the main challenges. In this chapter, an effort was made to understand how the current strategies and collaborations work in Scotland and consecutively find the main barriers as well as opportunities. They are summarised in Table 15, structured along the four main themes of section 7.2.

Table 15 Overview of main opportunities for better bicycle-rail use in Scotland

	Theme	Overview of opportunities
1	**Rail Franchise contracts**	- ScotRail franchise contract is set by Transport Scotland. It is followed strictly by the winning TOC. If the targets and agreements reflect stimulating bicycle-rail use this can be a great push. However, strict regulations can limit creativity and cooperation. Once every ten years a new franchise period begins (next one: 2024) - Scotland is ahead of the curve in setting high ambitions, which shows in its approach of asking for a combination of a good price and high-quality service to the TOC.
2	**Deciding on bicycle-rail services**	- Each party can influence a different factor, often overlapping. One party can, therefore, make a difference, using its own skills and resources. However, ensuring the complete bicycle-rail trip improves and particularly good integration at overlapping points is hard. - The local authorities are not involved in the rail franchise contracts but can play a large role, for example in station area development. Both the characteristics of and cycle-related ambitions among the 32 Scottish councils vary. - Some interventions are pushed and only a location must be sought (e.g. Bike&Go), or because the book year ends (e.g. easy to implement bicycle parking). In other opportunities, say station area development or a new local active travel plan, bicycle-rail can be an afterthought.
3	**Financing bicycle-rail services**	- All funds require a business case. Note that the British transportation system is more commercialised than the Dutch. The financial benefits of bicycle-rail must therefore always be clearly pointed to. - There are a (growing) number of funds available to invest in cycle-rail. Most

		importantly from a TOC as part of the franchise agreement. - When funding comes available, this is a clear trigger for various parties to write a bid. Also, complementary funding to existing cycle-rail projects is available.
4	**Thinking out of the borders**	- Physical ownership of land can be problematic, also considering the relatively short term of the contracts: who pays for infrastructure on the station land, owned by Network Rail, operated by a TOC? The direct surroundings may be from the council or private parties. Trade-offs must be made for space: retail, cycling infrastructure, car parking, etcetera. - Typically stakeholders tend to "work on islands" and collaborate per case rather than on a strategic level. - Funding is often earmarked to be spent on a particular piece of ground or topic, by looking for collaborations it can be secured most optimal.
5	**Strategies & Opponents**	- In the UK in general, parties work ad hoc and pragmatic, making quick interventions possible. Whether these are most ideal is often the question. More strategic work can improve this. - In the railway sector in general and also within parties themselves, the benefits of bicycle-rail are not clear to everyone. Many people in the UK never cycle, making the perceived barriers for cycle-rail larger. - Bike-on-Board is increasingly posing challenges for both staff and passengers when trains are crowded. This can lead to negative imagery, but may also be a chance to inspire people to try bicycle-rail in general.

6. IS CYCLE-RAIL SUSTAINABLE?

Is bicycle-rail a sustainable opportunity? Let us reflect. The previous five Green Boxes considered the triple bottom line (or 3P's) of bicycle-rail. These appear positive and are thus in line with the common notion of bicycle-rail as a sustainable mode. When considering particularly hardware bicycle-rail services, the use of resources are required. An active use of sustainable design principles can help limit the environmental impact. Note that all types of transportation require investments which come at a (sustainable) cost and more bicycle-rail can lead to lower demand for car use and with that its dedicated infrastructure.

In a more long-term mindset, the need for a transition to more active and sustainable modes of transport is clear. Note that most environmental benefits ("Planet") come from shifting away from the car. As the use of electric cars is increasing, these relative benefits can decrease over time. Nonetheless, trains may - and should - also become more energy efficient. The value of particularly cycling in terms of exercise and lively streets for people's individual benefits and the economic spin-off effects will likely remain valid. Bicycle-rail has the potential to attract a new type of bike-users and these first rides might just lead to overall increasing levels of cycling, with additional indirect positive effects when a cycling culture is established.

Taking a broader scope to consider the current reality: the transportation sector is responsible for 26% of GHG emissions and one of the few industrial sectors where emissions are still growing (Chapman, 2007). Mobility is vital for both our individual needs as well as communities and economies, thus alternatives are required to meet demand. Bicycle-rail is an opportunity to "(...) *meet the needs of the present without compromising the ability of future generations to meet their own needs*", as sustainable development has been typically defined (World Commission on Environment and Development, 1987).

8 DISCUSSION & CONCLUSIONS

In this final chapter, the methods and results are discussed, with recommendations for the future. First of all the research methods (8.1) and Station Scanner (8.2) are reflected upon. Then, we zoom out to discuss the recommendations and meaning of the study's findings for science and society (8.3 and 8.4)

This thesis deals with a multimodal travel option which has been researched to a limited extent and is only marginally used in most countries, including Scotland. The risks of such a research is a lack of reliable information and data and thus of generalising too quickly. This made it inevitable that assumptions had to be made and we like to highlight again the explorative nature of the research. Despite these limitations, the findings of this study can help to better understand bicycle-rail and with that, help practitioners to facilitate its use where and when most required and scholars to focus their research effectively.

8.1 Reflections on research methods

A multitude of methods was used to collect, analyse and interpret both primary and secondary data. This flexibility enabled the selection of choosing the most suitable methods. There are some reflections on various methods, listed below in chronological order:

- Academic literature was used to describe both the trip chain and the influential factors. As was noted, however, the **literature is scarce** thus also bicycle-transit (other than the train) was included. This likely resulted in generalisations to bicycle-rail so assumptions had to be made. Furthermore, only literature in the English or Dutch language was selected, possibly excluding relevant sources.
- For the description of the factor's influences on bicycle-rail, a basic description ranging from "very negative / --" to "very positive / ++" was used. This is a **large simplification** of reality which must be carefully communicated. It did enable us to translate the factors into a practical and accessible framework. As **local variation** of their influence, overlap, and weight appears large, much more studies are required to assess the various factors correctly. Additional expert group model building session, similar to the Dutch one mentioned in chapter 4, or user surveys could help to improve the reliability.
- The development of the scanner was highly iterative and inspired by existing tools and comments from various Scottish stakeholders and Dutch consultants. It's form and aims will reflect their opinions, which we have tried to make as transparent as possible. Nevertheless, **other input will have resulted in another outcome** and it is hard to say whether the scanner is the optimum solution. More detailed reflection on the scanner's added value, it's limitations as well as possible improvements are presented in section 8.2.
- In general, all qualitative methods used are **limited in their repeatability**. Considering the Dutch background of both researcher and supervisors, a (positively) **biased view on bicycle-rail from own experience** may have lead to a coloured picture of particularly the Scottish situation. Elements in the trip-chain or stakeholder's organisation that stand out for the Dutch may not be as striking to non-Dutch researchers or practitioners, which may have resulted in other areas of focus. However, it could be an advantage: elements known as potential barriers in the Netherlands may have been noted sooner. Examples include parking spaces on the platform and limited BoB capacity.

8.2 Recommendations for Station Scanner

As a practical product to answer part of the sub-question: "how to (...) help advice", the framework for a Station Scanner was tested in Scotland in chapter 6. Below we discuss the lessons learned for the generic scanner framework as presented in chapter 5 by describing it's added value, limitations and the main points of improvement. Considering the scope of this research, it was not possible to integrate them all in the prototype. The recommendations are listed from most to less important.

8.2.1 Added value of a Station Scanner

- Bicycle-rail use and research are very limited. Considering that this tool is the first of its kind, it is already valuable. In informal contact with developers of the TRL-tool and RideScore the **novelty of a Station Scanner** was clear.
- A strategic scanner can assist in **thinking beyond the typical boundaries** of a station or council, as well as beyond the single mode paradigm. These larger scopes are vital to realise a transition to increased mobility and sustainable travel alternatives. Integral design of bicycle-rail at all trip chain components is a first step to better-integrated travel.
- A practical tool like a scanner can **help in sharing the story** of bicycle-rail as an attractive travel option with a wider audience. It can open up conversation and introduce bicycle-rail which is a benefit in itself.
- With many parties and varying demands of travellers on such little space, the **high complexity of stations** is a fact. The station is, however, crucial for both good integration and travel time experience of multimodal trips as chapter 3 highlighted. The scanner takes this **complex element as a starting point**, thus ensuring potential difficulties at stations are considered in the first phases of a design and decision process.
- The scanner can **integrate with existing tools**. This enlarges the toolbox of practitioners and may spark more collaborations.

8.2.2 Limitations of a scanner

- The main limitation of the scanner lays in the **reliability of the estimation of a station's potential demand**. Both research and monitoring of bicycle-rail use in practice is very limited. The quick-scan character must thus be clearly communicated. However, scoring runs the risk of being interpreted as a hard fact, whilst any model is a simplification of reality.
- Assumptions were required to definite ten clusters. Similarly, a pragmatic **selection of variables** was inevitable, but these do affect reliability. However given limited knowledge on this topic more than a comparative score would give off an unrealistically detailed message.
- As described in detail in chapter 6, the **exact matching of available zone data to station's catchment area**s is near to impossible as zone boundaries will vary. Particularly for large data zones stretching way beyond a realistic cycling distance, this decreases the reliability of the scores and requires more advanced data processing techniques.
- The scanner is useful when seeking bicycle-rail opportunities among a set of stations. For other purposes, e.g. the development of one particular station area, audit instruments and guidebooks are far more suitable. This **limited applicability** must be clearly formulated to ensure effective use.
- The scanner does not differentiate in the **type of bicycle-rail use** a station attracts, whilst these may require other services.

8.2.3 Improvements for the Scanner

Chapter 5 of this thesis presented the framework for a generic scanner. It should always be tailored to suit the needs of the users and stakeholders. The list below includes only some of the many ways to improve a specific Station Scanner.

- A main improvement is **adding weights** to the various clusters and selected variables. Different studies have made an effort by discussing factors (see chapter 4) but variations appear large between transit systems and countries. This should thus be done to the specific scanner. Considering that even in the Netherlands the full potential of bicycle-rail has not been reached (as usage number still grow), more research is required, as described in more detail in paragraph 8.3. This may lead to certain clusters being found "insignificant" and removed from the scanner. For example, in the Netherlands, due to limited variation, cluster 2 (bicycle infrastructure) and cluster 9 (weather) may proof redundant.
- This research tested the scanner framework in one place. **Further reflection** with stakeholders and making **prototypes in other places** will improve the general applicability of the scanner's framework.

We may suggest England, as much of the datasets have already been organised for this study, and with over twenty separate TOC's operating the stations, a birds-eye view may be helpful.

- Although **more sophisticated scoring methods** are possible, this study describes how stations can be compared to one another. The scores are thus relative to the whole set of stations. This may limit ambition: a score benchmarked against e.g. the mature Dutch system may stimulate more daring action to realise the full potential of bicycle-rail. Also, rather than comparing against the whole set, additional sets of e.g. station type may be added.
- **More interactive dashboards** may stimulate the use of the scanner. One could imagine adding sliders to the scanner's dashboard to show the effect of interventions like increasing train frequency or building cycling infrastructure on the station's scores. Similarly, an additional dashboard could show the **business case for various bicycle-rail services**, by building further upon existing tools like the CBA-integration tool for New Zealand (Wedderburn, 2013). Particularly the rail industry may benefit as various Scottish representatives mentioned the economic mind shift and the need for "hard" arguments.
- In the framework, the database and dashboard are two separate elements. Finding a way to **link the two elements** directly (perhaps by using different software) could make it easier to improve detailed data (e.g. modal splits per station when known) or enable users to e.g. benchmark station sets with one another on the spot.
- Rather than a scanner only available to some, it could be **published online** like the "Propensity to Cycle" to help spread the bicycle-rail concept. Considering the novelty of this mode this may spark some inspiration among both the public and practitioners. Building on that, it may enable anyone to add information on stations. For example by asking travellers to fill in a standard audit scorecard like the one from Transform Scotland or local authorities to update scores for bicycle use and infrastructure.
- Despite the discussion of catchment areas size and shape in paragraph 3.3.3 of this study, for practical reasons the scanner assumes a circular area of 5km. Using **isochrones maps** based on actual travel time by bicycle will increase reliability, assuming the aforementioned difficulties with data set boundaries are overcome.
- There are many ways imaginable in which the scanner could **link more directly to bicycle-rail service**s, e.g. via pictures of case studies or suggestions based on the station score and characteristics. It should be borne in mind here that tailoring is always required. As a suggestion, theories on levels of integration by Preston (2012) may be of help here.

These reflections imply that user's of the scanner shall be aware that the validity of the station scores depends on the selection of datasets, and the overlap and weight of their variables. Professional insight is required to translate the scores into advice for practitioners and misinterpretation and false expectations should be prevented. The scanner as a tool to help develop a shared language and bring different parties around the table is worthwhile on its own. Generally, the scanner can be further improved as more (empirical) studies on influential factors and bicycle-rail interventions are published and insights from practical experience develop. More recommendations on these wider aspects are given in the remainder of this chapter.

8.3 Recommendations for further research

The explorative research presented in this thesis provides many possible connections for further research. Some suggestions with regards to the scanner were already made in the previous paragraph. The more generic bicycle-rail related recommendations are summed up below.

- Insight in the **different factor's independent influence** on bicycle-rail and their correlations with one another would offer valuable insights in bicycle-rail use. A **distinction between user groups trip type** (BoB vs. BaR) would be interesting here. Note the factor's weights are expected to vary from place to place. Different (often Dutch) studies have looked into this but typically to explain current rather than potential bicycle-rail demand. The TRL tool and CTU-index may be starting points for such a study.

Possibly, the Dutch situation could be used to benchmark against as a "mature" system. It may be noted that this was the initial set-up for this thesis, but as reliable knowledge on the weights is still very limited and not per se what practitioners require now in these pioneering phases of bicycle-rail practice, the concept for a scanner developed, with the TRL-tool's output used as a benchmark.

- It is suggested to **focus on the factors land-use and catchment area shape and size**, as literature indicates that these are most influential on first or last mile trip choice station's potential demand. For door-to-door trips, studies on the competitiveness of bicycle-rail to particularly the car may be of interest.
- **Information on current bicycle-rail use** (e.g. from monitoring data) **and users** (e.g. from surveys) is limited. The detailed trip chain (Figure 6 in paragraph 3.2.2) and associated services may be further developed by adding more bicycle-rail users experiences. Generally speaking, the availability of reliable data on particularly bicycle use and infrastructure is improving, but nevertheless, with low overall cycling numbers, these are often highly aggregate or inaccurate. User and usage statistics may become increasingly available as Smartphone tracking data and user statistics from bicycle sharing systems improve. Privacy issues should be considered. As bicycle infrastructure is often managed by local authorities, the type and quality of information collected on available bicycle roads differ greatly. More standardised monitoring methods would help compare and share best practice. Generally, good monitoring of bicycle levels in before and after situations of bicycle-rail interventions can help ensure effective solutions are chosen.
- More qualitative research that looks into **why people (start to) use bicycle-rail** can also shed some more light. For example Dave Holladay mentioned that the current large number of cyclists arriving at Waterloo station in London is the result of to a temporary close-down of the subway. This made people try the bicycle, discovered its benefits and have stuck to the bicycle-rail habit even after the subway was opened again.
- This thesis focuses on the train as the only transit mode. However, the **similarities with BRT or metro systems** are obvious. Bearing in mind that both catchment area size will be smaller and user groups differ, we may assume the findings of this study on particularly trip chain and scanner framework may be of use there too.

8.4 Recommendations for practice

Considering the large local differences, it is difficult to make generically applicable recommendations for practice. Some of the findings presented in this thesis about Scotland will be recognised by practitioners from other countries, others will not. The recommendations below are the result of insights gained from the literature review, development of the scanner and the interviews with Scottish and Dutch practitioners.

- The importance of **collaboration** has been discussed much in this research. The initiative must however be taken. We learned that in Scotland some developments are underway with a transport department that ensured the railway franchise contract included quality besides price, and a transport operating company which was dedicated to think beyond the train-leg of the journey. Considering that typically the railway sector sees the most direct benefit in the form of increased ridership, the initiative to push bicycle-rail on a system-wide level may be expected to come from them. At local levels, councils can also push action around railway stations. Particularly at stations in congested areas or where car parking is always full, bicycle-rail can greatly increase their accessibility. It is worth noting here the differences between already a Dutch "polder" model where collaboration and long-term planning is the norm and the Anglo-Saxon where action and more pragmatic working styles prevail. Different strategies are required. For the UK in particular, Network Rail could push bicycle-rail more actively and have a large influence, considering their station ownership and management of the largest ones.
- Bicycle-rail is in theory an appealing option for users. This study indicated however that it will only prove an attractive alternative at certain places and among certain groups of people. More specifically: for those

trips with their origin or destination up to five kilometres distance to a railway station, and for those people willing and able to ride a bicycle and board a train. When we assume land-use as a given, we may wish to focus our energy on this second part. Changing people's travel behaviour is hard. **Influencing the travel choice of individuals requires long-term visions and actions**. Even with all factors perfect in place, it may take a while for travellers to discover the bike-transit combination, as the aforementioned MaxSem study indicated (Carreno et al., 2009). This ranges from pre-contemplation to maintaining new behaviour.

- Looking at current trends in bicycle-rail use in Britain and considering lessons learned from the Dutch practice, the **focus of bicycle-rail services should arguably be on bike-and-ride** (BaR): e.g. facilitate good bicycle parking at stations and bike share, to prevent that bike-on-board (BoB) travel in crowded trains makes bicycle-rail use inconvenient and give it a bad image among other rail users. Also, particularly at crowded train services, the focus may be on improving the door-to-door journey of existing railway passengers by improving the bicycle-rail alternative, rather than attracting new customers. The advantages of e.g. less car parking and shorter travel times are benefits already.
- **Active travel agendas** are currently being pushed by various parties on local and national levels. Tying in wisely with those by promoting also walk-rail and cycling on its own will likely have spin-off effects on all sides.
- The **scanner's framework is a concrete practical output** of this research. The prototype for Scotland can be finished, possibly adding some of the improvements discussed above. This can help a party like Witteveen+Bos to advice Scottish stakeholders on actually seizing the opportunity for bicycle-rail use. These experts have trained skills for what "off-the-shelf-doesn't-work" means as well as the first-hand experience of Dutch practice.

This study is part of a growing body of research undertaken in bicycle-rail travel. Nevertheless, change can only happen through action. It depends on influential stakeholders to make a difference and actively stimulate a better integration of bicycle-rail. Only then bicycle-rail can grow to its full potential.

8.5 Conclusions

The research presented in this thesis aspires to help bridge the gap between theoretic knowledge and everyday practice of improving bicycle-rail use. Whilst a convenient, competitive, healthy and sustainable travel option in theory, it occurs little in practice. However, the context for seizing the opportunity is receptive. Two challenges were introduced in the beginning of this report: satisfying the (potential) demand for bicycle-rail use with a suitable supply of services, and good collaboration among relevant stakeholders of both the rail and bicycle sector. The following research questions were formulated:

Which factors influence the combined use of bicycle and train, and how can these findings be applied to help advise (Scottish) stakeholders improve bicycle-rail use?

1. What is bicycle-rail?
2. Why do people choose to use bicycle-rail and how can it be made more attractive?
3. Which factors influence the use of bicycle-rail?
4. How can better understanding in bicycle-rail use and its influential factors be translated into a practical tool to help find the opportunities for improving bicycle-rail use on station level?
5. How can a "Station Scanner" be created for Scotland?
6. Which Scottish parties can influence bicycle-rail use and how?
7. When does the opportunity for Scottish stakeholders to improve bicycle-rail use arise?

The findings to the seven sub-questions discussed in this report synergize to answer the main question in this final paragraph.

The bicycle-rail trip chain provides a shared understanding of what bicycle-rail is (chapter 3). There are two types of trips: bike-on-board (BoB) and bike-and-ride (BaR). These trip chains both have many elements (and thus potential barriers) to be considered by the individual traveller and a variety of stakeholders. **An array of different bicycle-rail services can influence the trip chain elements directly**, examples including bicycle parking, bike share, union of bicycle and train organisations, integrated payment systems, positive communication and safe bicycle infrastructure to stations. There is, however, no one-size-fits-all solution to improve bicycle-rail use.

The subsequent literature review in chapter 4 makes clear that many other factors apart from these services summed-up above can influence the number of cyclists to or from railway stations. The literature review indicates that the **most influential factors are access/egress trip length (people will cycle <5km), current bicycle and rail use, competition of other modes, safe and high-quality bicycle routes to/from the station, share of commuters among railway passengers and number of rainy days**. The total of 39 factors from the literature can be grouped in the three categories *context*, *rail journey* and *first/last mile journey* to align with the trip chain components. These findings answer the first part of the main question and give a clear overview of the factors and current bicycle-rail literature. Further research is required to capture the factors' overlap and levels of influence in more detail, while accounting for both local differences and user type preferences.

The findings related to subquestions 4 till 7 synergize to answer the second half of the main research question: how can they "be applied to help advise (Scottish) stakeholders improve bicycle-rail use?". We assume a currently unmet, but potential demand for bicycle-rail use. To find out where this demand is largest, **the influential factors are incorporated into the framework of a "Station Scanner" to provide a relative score on a station's potential to attract cyclists**. This tool can help in the first strategic design and decision phases to improve bicycle-rail use (presented in chapter 5). Figure 24 below shows the scanner's main components and steps. As far as we are aware, such a "scanner" is unique both in its aims and form.

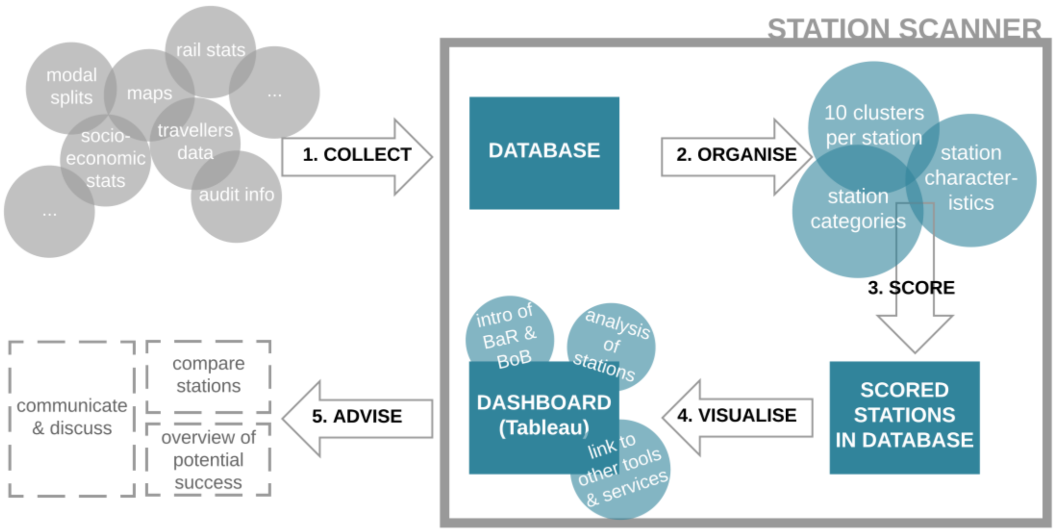

Figure 24 Station Scanner for Scotland

Various recommendations for the scanner are pointed out earlier in this chapter (paragraph 8.2) Many originated from the prototype creation for Scotland. Most important are more sophisticated scoring methods as bicycle-rail research increases, matching reliable and detailed datasets with all stations in a set and better integration with best-practice bicycle-rail services.

The scanner is part of a growing toolkit for improving bicycle-rail, which also includes design guidelines and station audit tools. Whichever tool is most suitable should be selected. Particularly in countries like England, where over twenty train operating companies are in charge of nearly two-thousand stations, an objective birds-eye view could lead to **more strategic improvements in bicycle-rail use and with that a better balance between (potential) demand and supply**.

The last three sub-questions of this thesis zoom into Scotland to test the practical validity of the findings. The explorative stakeholder analysis in Scotland (chapter 7) identifies that many parties may (and do) influence bicycle-rail use, at different locations in the trip chain. Project-based collaboration and pragmatic solutions is the norm. Windows of opportunity in Scotland include renewal of the 10-yearly ScotRail franchise agreement and station development projects. For bicycle-rail to take off, a shared consideration for the user's door-to-door travel experience and current obstacles is required. Any party that thinks beyond its formal boundaries and collaborates strategically is therefore an excellent opportunity: good integration requires collaboration.

Bicycle-rail can proof an attractive option for passengers, transport operators, and governments alike. As the trip chain is complex there are many potential barriers to ensure a seamless journey. However, as both the levels of cycling and rail are increasing and pushed to ensure liveable and accessible cities, the synergy will be discovered by more people. Chances are that bicycle-rail will thus shift from a theoretic opportunity to an everyday mode of transport around the globe.

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The table below shows the different interviewees in alphabetical order, with the party they represent, their bicycle-rail related role and the location and date of the interview.

REPRESENTATIVE	PARTY	ROLE	LOCATION & DATE OF INTERVIEW
Allan Comrie	Strathclyde Partnership for Transport (SPT)	Senior Transport Planner	Glasgow, 12-1-2017
Clare Strain	Strathclyde Partnership for Transport (SPT)	Travel Planner	Glasgow, 12-1-2017
Collin Little	City Council Glasgow	Sustainability Officer	Glasgow, 9-1-2017; 16-3-2017
Conrad Haigh	Rail Delivery Group (RDG)	Head of Integrated Transport	London, 7-1-2017
Dave Holladay	Tramsol consultancy	Independent Transport Specialist	Glasgow, 15-3-2017
Gordon MacLeod	Transport Scotland	Rail Stakeholder and Sustainability Manager	Glasgow, 13-3-2017
Iain Docherty	University of Glasgow	Professor of Public Policy and Governance	Glasgow, 11-1-2017
Joost Mortier	ScotRail at Abellio Group	Project Director Transport Integration	Glasgow, 12-1-2017
Kaj Mook	former Abellio, current NS	former director NS fiets and OV-fiets, and Bike&Go Director; current: Business Development Director NS International	Utrecht, 20-1-2017
Karen Furey	Transport Scotland	National Cycling Policy Manager (Transport)	Edinburgh, 15-3-2017
Kathryn MacKay	ScotRail at Abellio Group	Cycling Manager	Glasgow, 10-1-2017; 14-3-2017
Marco te Brömmelstroet	Universiteit van Amsterdam	Associate Professor Urban Planning / Academic Director of the Urban Cycling Institute	Amsterdam, 23-3-2017
Matt Stacey	Abellio Group	Operations Development Manager	Glasgow, 13-1-2017
Peter Collins	Network Rail	Operations development manager	(Skype call) 31-3-2017
Roland Kager	Studio Bereikbaar, former UvA	Transport advisor and publicist on cycling-inclusive transit	Amsterdam, 23-3-2017
Stefan de Graaf	Goudappel Coffeng	advisor / project leader traffic studies	Deventer, 2-12-2017
Tessel van Essen	Dutch Embassy	Senior Commercial Attaché, cycling portfolio holder	London, 6-1-2017
Twan van Duivenbooden	Sustrans Scotland	Strategic Project Officer in regional transport partnership 'SPT' (on active travel network)"	Glasgow, 12-1-2017

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APPENDIX A: Interview questions

As mentioned, all interviews were tailored to the party interviewed and the researcher's knowledge at that moment in time - for example, once the relationships between stakeholders were mapped, more detailed questions on certain projects could be asked. Roughly however, the following structure was followed:

NAME I PARTY I date

- Is recording ok?
- introduction study (background, goal)
- describe structure of the interview

PART 1: ROLE OF STAKEHOLDER

- What does [PARTY] do?
- What is your role at [PARTY]?

Influence of [PARTY] on bicycle-rail. Mention publications. Ask about practice

- What role does the [PARTY] take in this?
- Where and how does the party use its influence?
- Examples?

Collaboration with other parties

- Is there collaboration? Where? What scale level?
- Which parties?

PART 2: STRATEGY

- How does the decision process look like? The design process?
- Could you describe them? Example?
- How do you currently estimate demand? Potential demand?
- What stations score high? Why do you think that is the case?

PART 3: DATA COLLECTION SCANNER

- For the analysis of both "as is" state and "influential factors", different input data is required.
- How could [party] help? What quality, when? Suggestions other parties I should reach out to?
-

APPENDIX B: Bicycle-rail services

Four guidelines were selected to describe how to best design and implement a whole range of bicycle-rail services: three British, one based on Dutch practice, for EU-wide use. They are introduce first in Table 16 below and examples per solution given in Table 17.

Table 16 Guidelines on bicycle-rail services

	title	publisher	document content	n of pages
1	**BiTiBi** **Guidelines**	EU-funded pilot projects on bicycle-rail integration.	These guidelines built upon the first five building blocks (number 6 was only added recently). The guide uses many pictures and takes Dutch experience as a best practive. The focus is on parking and the station plus its direct area. The target group is presumably the rail industry.	59
2	**RDG** **Cycle-Rail Toolkit 2**	RDG (former ATOC): the umbrella organisation of all British train operating companies.	Detailed handbook with do's and don'ts for the British context. Includes clear instructions, mostly UK case studies and pictures, following different parts of the journey. Particularly bicycle hire and parking are described in more detail. It is written for train operating companies	81
3	**Sustrans** **Cycle and Rail Integration Design Manual**	Sustrans is a cycling charity that aims to make cycling accessible for all ages and abilities	As part of the general design guidelines for cycling, this document gives a concise overview of aspects to bear in mind when designing for cycle-rail. The focus is more on hard factors (cycling infrastructure, parking) and the guide intended for local authorities and station developers.	11
4	**ScotRail Abellio** **Cycle Innovation Plan**	Abellio is a public transport operating company and this plan was part of the contract	A plan that sums-up very to the point the various interventions that Abellio is making in Scotland to improve bicycle-rail integration. Particularly cycle hubs, parking, promotion/communication and bicycle sharing with Bike&Go receive much attention	20

Table 17 Overview of bicycle-rail services

SOLUTION	DESCRIPTION	EXAMPLES / DESIGN VARIATIONS / ADVICE	FURTHER INFO
AT ORIGIN/DESTINATION			
Employer bike scheme	Via co-funding from employer people can get a bicycle, possible tax benefits	e.g. funding, champion scheme, etc.	1, 4
O/D facilities	Additional to parking, other facilities may be of added value (for cycling in general).	Cyclehub; dressing room; showers at workspace, etc.	1
O/D parking	Place to store bike securely at point of origin/destination, in- or outdoor, collective or individual. Possibly collaboration with employers, universities, etc. (for cycling in general).	CycleHoop Bike Hangar; employers initiatives; folding bikes for those short of space; bike shed is a building requirement by law (since 2012 in NL)	1
BICYCLE JOURNEY TO/FROM STATION			

Cycling crossings	Roadcrossings with considerations for the cyclist	not required to dismount or make significant diversion	3
Cycle route maps	Maps with cycling routes, make it signed and marked	On paper or online, ensure stations and facilities are clearly marked.	2
Cycling paths	Dedicated lanes on the road for cyclists. Should be safe, convenient and direct	safe, convenient and direct routes (3-5miles, Sustrans)	3
Signposting surroundings	Signs from/to the train stations	connecting to local routes; give distance / travel time to station; ideally show both entrances and bicycle parking (for BoB and BaR users)	2, 3
STATION ENTRANCE/EXIT			
Bicycle hub	building of varying size at the station, with typically a bike shop, tools to borrow, secure parking spots and information point combined	Advantage can be e.g. Stirling Cycle Hub; Abellio's Cyclepoints and Cycleparks+	2, 4
Bicycle sharing	Last-mile solution of public bicycles. It can be back-to-one (B21), where people return the bike to the point of collection, or back-to-many (B2M) with stations. Development is dockless via e.g. bluetooth. Can be seen more as service than profit making activity.	B21: Bike&Go (UK only), OV-fiets (Netherlands), Blue Bike (Belgium(or B2M:Nextbike (worldwide), Brompton Bike Hire (UK only), with more distribution costs but may collaborate with authorities. All require maintenance team (e.g. local bike shop). Requires good communication and support system.	1, 2, 4
Last half mile to/from station	Particular attention to last half mile to or from station, as high density of all modes causes potential conflicts.	e.g. forecourts clear of barriers, all entrances accessible, remove small obstacles from route (e.g. kerbs, doors, steps)	3
Seamless station access	Smooth access to and inside the station (for BoB or on-platform bicycle parking) with a bicycle	e.g. ramps (5% gradient, well-placed), wheeling channels/ramps, lifts, escalators	2, 3
AT STATION			
Bicycle parking location	A good location concerning both cycling routes and entrances to the station and platforms, where people feel safe and the bike is secure. BiTiBi describes "location as the absolute priority" for good parking	Near to platform (max 50 meters from entrance) and at all entrances e.g. on the platform (Glasgow Central), in a vacant building (Stirling) or underground if space is limited (Delft)	1, 4
Bicycle parking quality	Covered and where no damage to bike can be done. Ensure parking is visible	e.g. able to lock up well, sheltered, modern stands (no wheel benders), good access, lighting, sockets for e-bikes. Considering space limitations, two-tier racks can be considered. Convenience wise: numbered spaces to retrieve bike quickly; also consider special bikes (e.g. cargo, e-bike)	1, 2, 3
Bicycle parking quantity	Good estimation for the number of bicycle parking spots to prevend over- or undercapacity. Roughly 20% more racks than bikes, beware of snowballing effect (able to expand). Beware to remove abondened bikes.	e.g. RDG estimation tool available to councils and train operating companies (e.g. ScotRail, Greater Anglia, etc.) to estimate the number of bicycle parking spots (from RDG toolkit, used in this thesis); method of monitoring and calculating (from BiTiBi); consider future demand	1, 2

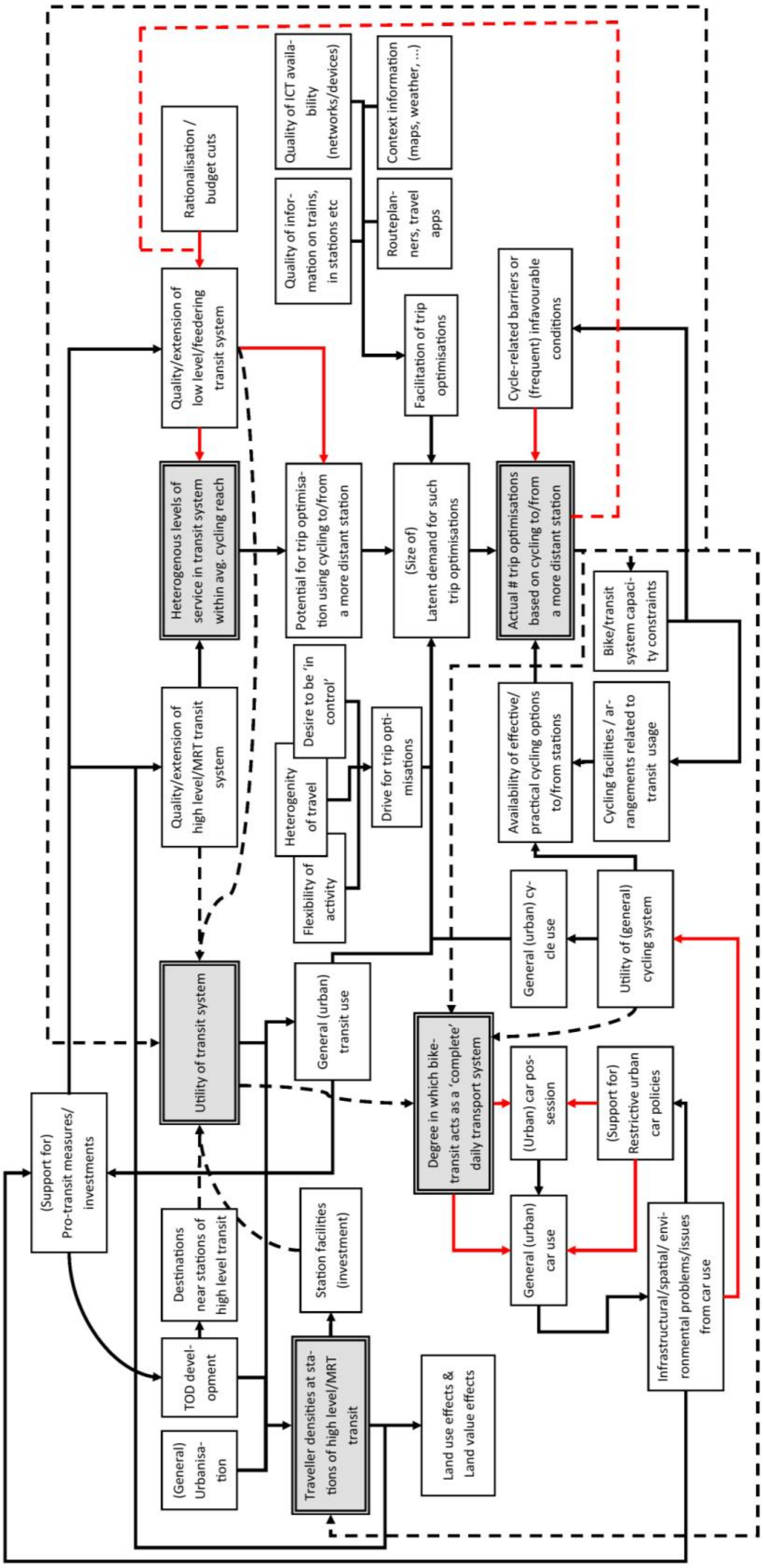
Bicycle parking security	Ways to ensure that bicycles can be parked securely at the station	CCTV surveillance, safe location, lighting, secure facility, lockers (consider counter terrorism regulations), in view of houses, human guarded. Can differentiate between guarded and non-guarded and charge (e.g. Netherlands). Give instructions on how to lock securely to cyclists. Campaigns against thieves. Cooperate with police for registration of bikes.	1, 2, 3
Signposting at station	Make parking visible, for 1st time users and non-users. Also directions to bicycle hire	e..g directly along walking route in station, lit up signs, markings on the floor, posters, information screen train departure times and ticket machine next to bicycle parking (Sheffield hub)	2, 3
TRAIN JOURNEY BoB			
BoB cycling carriage	Various ways to board and store bicycles securely and conveniently.	Flexible for other purposes; ensure safety; give instructions; e.g. bikes can be standing in a rail or vertical on a hook; special folding bicycles compartments (London) ; signs on doors where to store. Possibility of forwarding bicycles to destination station (e.g. Caledonian sleeper). Carriage signage where to board with a bicycle and wide doors (Denmark); wide enough access gates; able to buy ticket at machine / counter and keep eye on bicycle	2, 3
BoB regulation	Regulations to cap use of BoB, concerning capacity limits.	max capacity on train vehicles; charge a fee; off-peak only (Netherlands); use booking on popular lines (Germany; ScotRail); max. wheel diameter for folding bicycles	2
THROUGHOUT TRIP CHAIN			
Award	Giving a price to motivate and inspire staff and gain publicity to put cycle-rail on the map	e.g. bicycle-rail award from the Cycle Rail Work Group; Cycle-friendly station of the Year award	2, 4
Facility maintenance and management	Both bicycle (parking) infrastructure and information systems (e.g. websites) need maintenance	e.g. service team that monthly cleans bicycle parking spot and take out abandoned bikes (which are first labelled with a warning). Also consider cyclists when building works are being done.	2
Information supply	Off- or online, and off and on station site information on BaR and/or BoB facilities and regulations	PlusBike website RDG; well-informed staff; posters; dedicated page at councils / TOC / tourism websites, containing e.g. station services, terms and conditions BoB and BaR, etc. Real time information for onward journey (via owns smartphone or monitors)	1, 2, 3, 4
Integrated ticket	High level of integration, for easy payment systems, processes, fares	e.g. Oyster Card (London), OV-chipkaart (Netherlands)	1
Monitor bicycle-rail use	Monitoring before and after cycling use when improving bicycle-rail services to find effects	e.g. count occupation of bicycle parking spots; n of bike-users on roads to station, ask feedback from users	2, 4
Promotion	Targeted positive communication for cycling related topics	e.g. discounted rail travel to cycling related events; support/sponsor cycling events; leisure programme at cycling destinations	2, 4
Trial days	Removing barriers by introducing rail travellers to using a bicycle	e.g. organise free trials of bicycle sharing or lockers	2, 4

APPENDIX C: Overview of influential bicycle-rail factors

CONTEXT FACTORS	influence on cycle-rail use
Culture & Attitude	
positive attitude towards cycling	+
positive attitude towards rail	+
low perception of barriers	+
car as status symbol	-
User Characteristics	
high number of commuters	++
high number of students	+
full-time employment	+
share of mid/higher income	+
economic growth	+
high number of frequent rail travellers	+
high share of males	+
higher level of education	+
many 20-39 year olds	depends
travel with heavy luggage	-
wearing smart clothes	-
RAIL RELATED FACTORS	**influence on cycle-rail use**
Rail System	
direct routes (no transfers required)	+
high train service levels	+
Rail Journey	
(rail) trip of significant length (min. 10-15km)	+
Station Typology	
station at small or medium-sized city's centre, out of town or urban areas with parking	+
urbanised areas (e.g. population density and jobs in zone)	+
FIRST/LAST-MILE FACTORS	**influence on cycle-rail use**
Regions bike ability	
long summers / many hours of daylight	+
hilly	-
low temperatures	-
rainy weather	--
Bicycle Journey	
good quality of cycling lanes	+
high quantity of cycling lanes	+
often right of way	+
large number of other cyclists / bicycle lane volume	+
direct cycle routes to station (directness)	+
high bicycle ownership	+
good bicycle storage facilities at/near home/office	+
lack of safety	--
Competition other modes	
high level of cycling	++
high level of rail use	++
trip distance first/last mile 1 - 3.5 km	++
much congestion for cars	+
good BTM network	-
available and affordable car parking	-
high car ownership	--
Inexpensive BTM	--

APPENDIX D: Conceptual scheme bicycle-transit use

Via Roland Kager, not published.



APPENDIX E: Overview of existing tools

There are different existing tools introduced in the thesis that can help improve bicycle-rail use. The scoring tools are described in more detail below, the potential testers include an overview of the variables used and reflections on the tool used to ensure a unique Station Scanner. Sources of the tools are included in the list of references.

Scoring Tools

1. Interchange Audit Toolkit by Transform Scotland

Work field publisher: transport consultant, assignment of Transport Scotland, **location**: Scotland, **radius**: post code area of station or 8km radius

Publication: (Transform Scotland, 2014)

Description: A toolkit for doing audits at public transport stations (including rail, bus and ferry) created for Scotland particularly and tested on a number of case studies. Users of the tool may also be private persons.

2. Cycle-Rail Toolkit 2 by Rail Delivery Group

Work field publisher: umbrella organisation of all TOC's in the UK, **location**: UK, **radius**: post code area of station or 8km radius

Publication: (Rail Delivery Group, 2016)

Description: An extended guide (81 pages) aimed at TOC's in particular and any bicycle-rail advocate in general, including research references, detailed designs and rules of thumb. An audit and checklist for bicycle parking are included: appendices C and F respectively.

3. Re-Cycle Instrument by Scheltema

Work field publisher: umbrella organisation of all TOC's in the UK, **location**: UK, **radius**: post code area of station or 8km radius

Publication: (Scheltema, 2012)

Description: The tool can help analyse various cycling routes to/from train stations. At its core is a pyramid of need, with safety and directness as dissatisfiers: if not in place, people will not make a bicycle-rail trip. Attractiveness and comfort are satisfiers which can increase and improve bicycle-rail use.

Potential Testers

1. UK cycle rail parking tool / TRL tool by TRL consultants

Work field publisher: rail industry, **location**: UK, **radius**: post code area of station or 8km radius

Publication: not publically available, shared for this study via TRL

Researcher's comment: Includes all stations, highly detailed, (too?) large radius, good benchmark, unattractive excel-document

- % commuters
- % willing to cycle
- % trips to station by season ticket holders
- % employed and willing to cycle to work
- % trips to work within postcode of station by walking
- % trips to work within postcode of station by bus
- ratio trips to stations within 8km of station

2. CTU-index by (Krizek & Stonebraker, 2010)

Work field publisher: research, **location:** California, US, **radius:** 2 miles (=3.2 km)
publication: (Krizek & Stonebraker, 2010)
Researcher's comment: All compared stations have the same characteristics. Variables may be hard to measure, academically sound but less practical.

- household income
- population aged 20-39
- density (dwelling units/acre)
- percent transit (commuting 3x/week<)
- percent cycling (commuting 3x/week<)
- bicycle facilities (km of bike routes)

3. RideScore by DVRPC

Work field publisher: regional authority, **location**: Delaware region, US, **radius:** 1 mile (=1.6km)
Source: http://www.dvrpc.org/webmaps/ridescore/
Researcher's comment: impressive visualisation, very easy to use for practitioners, potentially large overlap, small radius.

- transit vehicle volumes (n of BTM within 500ft of station)
- connectivity score (number of intersections)
- cultural (n of civic/cultural resources within ½ mile of station)
- circuit proximity (distance to dedicated cycling infrastructure)
- outdoor destinations (distance to outdoor destinations, e.g. parks, cemeteries)
- retail district (distance to "walkable commercial corridor")
- near bicycle facilities (within ¼-mile of on-road bicycle facilities: yes/no)
- population (n of inhabitants within 1 mile radius)
- employees (n of employees within 1-mile radius)
- non-parking boards (share not arriving by car)

APPENDIX F: Factors per cluster

Note that the relations of the factors are not per se in line with the cluster. This is corrected when the clusters are matched with the variables underlying the factors (appendix G).

	CLUSTER	FACTORS FROM REVIEW CHAPTER 4	DESCRIPTION
ADJUSTABLE	**1. Bicycle use (+)**	positive attitude towards cycling; high level of cycling; large number of other cyclists / bicycle lane volume; high bicycle ownership	Many cyclists indicates more people are familiar with cycling as a mode of transport, know how to ride a bicycle and own a bicycle. They will thus consider bicycle-rail use quicker too.
	2. Cycling infrastructure (+)	good quality of cycling lanes; high quantity of cycling lanes; often right of way; direct cycle routes to station (directness); lack of safety	The cycling infrastructure in the station's catchment area has a direct influence on travel time and attractiveness. Direct and safe (segregated) cycle paths that connect the station to (existing) bicycle network improves bicycle-rail use.
	3. Rail use (+)	positive attitude towards rail; high level of rail use; high train service levels; direct routes (no transfers required)	The more people travel by rail, the larger the absolute number of bicycle-rail users can be. It also indicates the general competitiveness of rail compared to other travel mode options.
	4. Competition BTM (-)	good BTM network; inexpensive BTM	Overall, after the discussion at the end of chapter 4, good and inexpensive BTM services will be competing with the bicycle as a first or last mile solution to bicycle-rail.
	5. Competition car (-)	car as status symbol; much congestion for cars; available and affordable car parking; high car ownership	The car is a competitor both as first-/last mile and door-to-door alternative to bicycle-rail. We assume that much congestion makes cycling more attractive, as does low car ownership and expensive car parking.
ESTABLISHED	**6. Trains with potential (+)**	high n of frequent rail travellers	Research on bicycle-rail clearly showed that the more recurring a trip, the more attractive bicycle-rail becomes.
	7. Land-use with potential (+)	station at small or medium-sized city's centre, out of town or urban areas with parking; urbanised areas (e.g. population density and jobs in zone); trip distance first/last mile 1 - 3/5 km	The more points of origin or destination in a station's catchment area, the more attractive cycling as a first or last mile choice for transport. Several factors fit in this cluster.
	8. Population with potential (+)	high number of students; high number of commuters; full-time employment; share of mid/higher income; economic growth; high share of males; higher level of education; many 20-39 year olds	A particular part of the population within these catchment areas will be more appealed to travel by bicycle-rail. Whilst correlation between these factors is limited, they do appear clear indicators for bicycle-rail use.
	9. Climate (-)	long summers / many hours of daylight; low temperatures; rainy weather;	Long, dry, not too cold (or warm, probably) days positively influence the use of bicycle-rail. Note that if this aspect scores low, services can be tailored, e.g. good lighting along cycle paths and sheltered bike parking facilities.
	10. Trip length/Hills (non-correlated; +)	hilly; (rail) trip of significant length (min. 10-15km)	Two remaining factors that are not correlated but are considered measurable are placed in this last cluster. Long trips and flat roads increase bicycle-rail use.

Excluded from the clusters are the factors low perception of barriers, travel with heavy luggage, wearing smart clothes and good bicycle storage facilities at/near home/office. These were deemed too difficult to quantify systematically for a large set of stations.

APPENDIX G: Variables of potential testers in ten clusters

Apart from the variables from the literature review, also variables used by the studied potential testers are included. They are divided over the clusters as shown in the table below.

	CLUSTER	RideScore Delaware	CTU score	TRL Tool
1	**Bicycle use**		percent cycling (commuting 3x/week<)	% willing to cycle
2	**Cycling infrastructure**	connectivity score (number of intersections), circuit proximity (distance to dedicated cycling infrastructure); near bicycle facilities (within ¼-mile of on-road bicycle facilities: yes/no)	bicycle facilities (km of bike routes)	
3	**Rail use**			
4	**Competition BTM**	transit vehicle volumes (n of BTM within 500ft of station)		% trips to work within postcode of station by bus
5	**Competition car**	non-car arrivals		
6	**Trains with potential**		percent transit (commuting 3x/week<)	% commuters; % trips to station by season ticket holders
7	**Land-use with potential**	cultural (n of civic/cultural resources within ½ mile of station); outdoor destinations (distance to outdoor destinations, e.g. parks, cemeteries); retail district (distance to "walkable commercial corridor"); population (n of inhabitants within 1 mile radius); employees (n of employees within 1-mile radius)	density (dwelling units/acre)	
8	**Population with potential**		household income; population aged 20-39	% employed and willing to cycle to work; ratio trips to stations within 8km of station
9	**Climate**			
10	**Trip length/Hills**			% trips to work within postcode of station by walking

APPENDIX H: Considered and selected datasets for Scanner Scotland

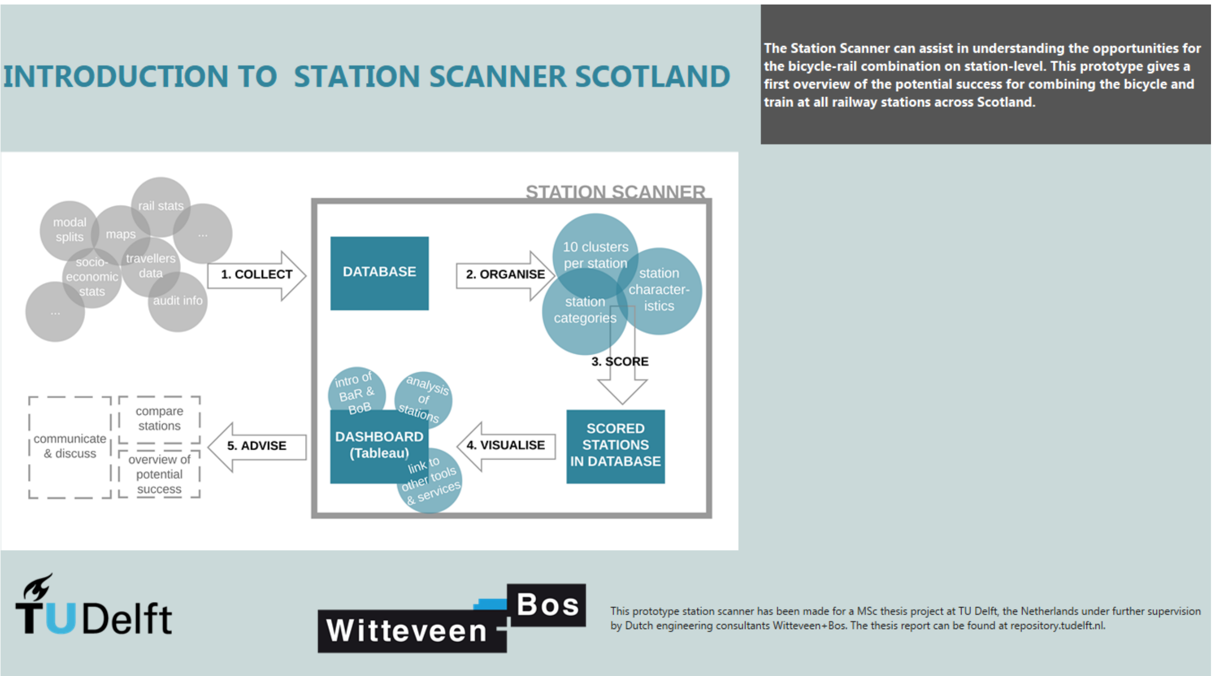
The table below gives an overview of the various datasets considered for this study. It functions as an indication for possible variables to capture the ten clusters of the scanner, as well as the station characteristics and categorisations. They are grouped accordingly.

Those selected for the clusters in the scanner are marked **bold**.

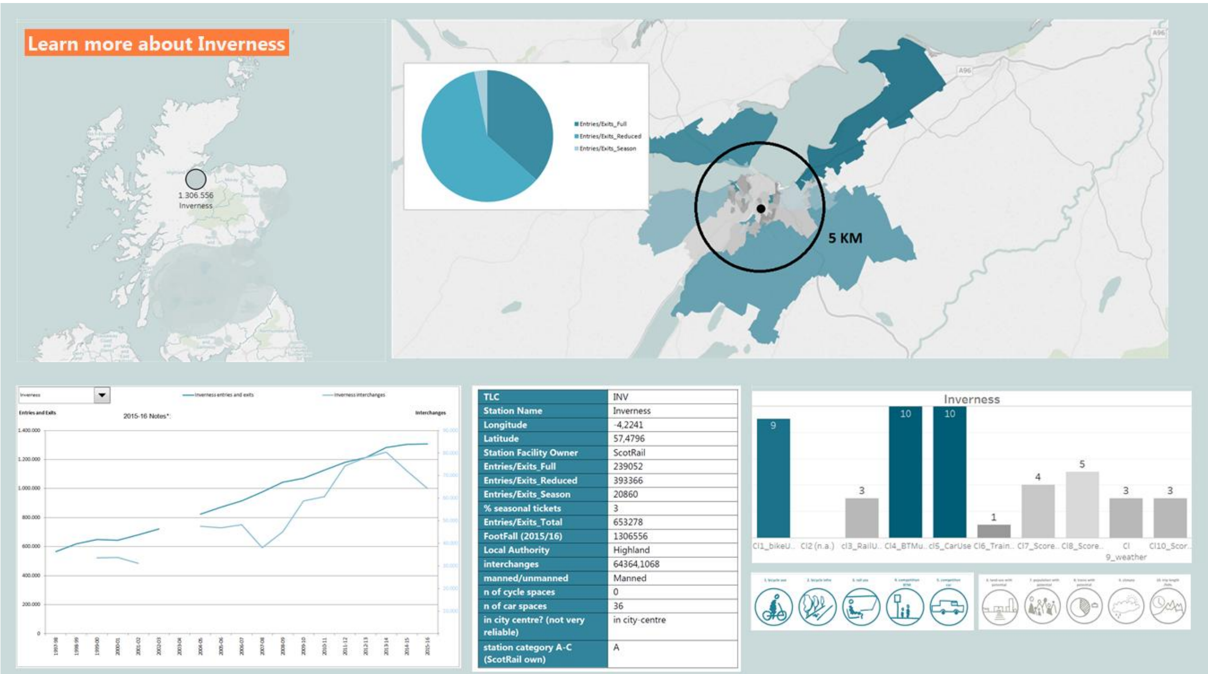
DATASOURCE	DATASET	CONTENT	SCALE LEVEL
TEN CLUSTERS			
National Records of Scotland (NRS)	various	**population**	**2001 data zone**
open data		**average dwellings per hectare**	**2001 data zone**
ORR	entries/exits	**footfall over time (1998-2015)** (Total entries/exits used for cluster; over time for station information)	**station**
open data		**share of season ticket holders**	**station**
		station facility owner	station
		local authority	station
		ORR station category (1-10)	station
		regional authority	station, council
Scotland Census Data (2011)		**average distance to place of work/study**	**council**
open data		distance to work per mode	council
		modal split of commuters (bicycle, rail and car are used)	**council**
		n of people work in same vs different council	council
		% of population of working age	zone 2001
		% population per urban/rural type	council
Scottish Household Survey (2014)		**bicycle ownership per household (0/1+)**	**council**
open data		**car ownership per household** (% households with 0 cars is used)	**council**
		average congestion delays (% trips)	**council**
	travel diary	**modal split of all journeys** (bicycle, rail, BTM and car are used)	**council**
		estimated median gross total household income per week	**zone 2001**
		share of trips with purpose commuting or education	council
		% population per urban/rural type	council
Met Office		**days of rain (rain days $\geq$1.0mm)**	**district region (contain several councils each)**
open data; requested data			

APPENDIX I: Dashboards of the prototype Scottish Station Scanner

Four dashboards are developed in the prototype building for Scotland. The “introductory dashboard” and “zoomed-in station dashboard” are depicted on this page. The slide that introduces bicycle-rail and refers to existing tools is shown on the next page, and the final page shows the station comparison dashboard as depicted earlier in chapter 6.

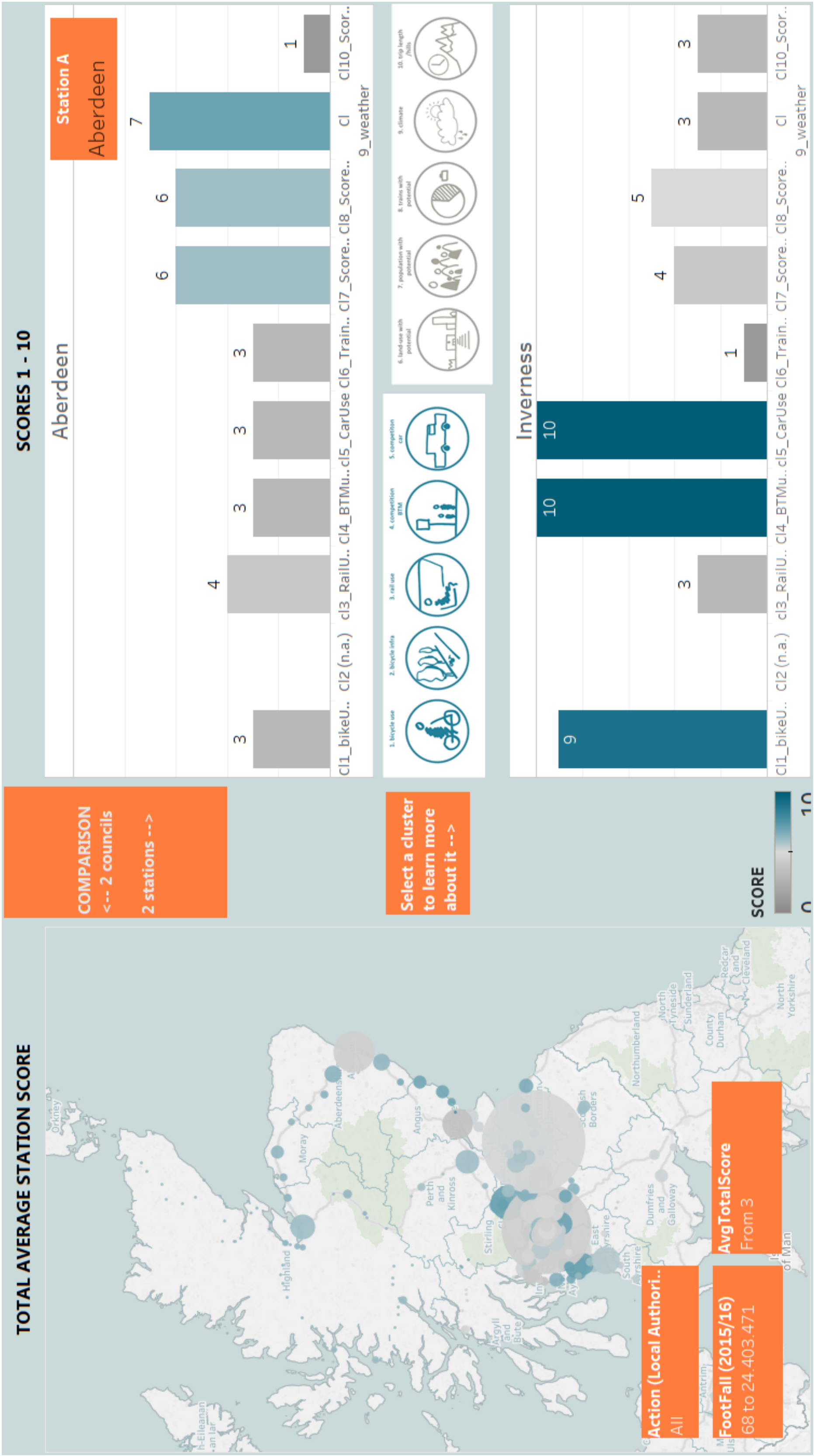


Dashboard 1: introduction to scanner



Dashboard 4: Zoom-in to station (example: Inverness)

Dashboard 2: Introduction to bicycle-rail use



Dashboard 3: Comparison of councils and stations