UNDERSTANDING THE ROLE OF PERCEPTIONS, DEPRIVATION AND PUBLIC TRANSPORT PROVISION IN THE VARIABILITY OF WALK DISTANCES TO ACCESS PUBLIC TRANSPORT ACROSS URBAN AREAS

by

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ABSTRACT

A shift from car travel to active transport can offer benefits to various problems in urban areas, such as public health, traffic safety and congestion. A major disadvantage of active transport (in particular walking) for most people compared to motorised transport is the limited range, which can be complemented by public transport. Therefore, it is important to understand how walking relates to public transport in urban environments. A frequently adopted guideline in public transport planning around the world is that, based on observations, people would be willing to walk up to 400m for buses and 800m for rail transport. Previous research on walk distances to and from public transport however found large variations and mainly considered how these distances are influenced by the type of public transport, the built environment, journey characteristics and personal characteristics such as gender, age, household size and income.

The aim of this research project is to develop the understanding of the role of perceptions, neighbourhood deprivation and public transport provision in the variability of walk distances to and from public transport across urban areas. To do this, the walk distance to and from public transport was conceptualised, based on the literature, as an interaction between the demand for travel using public transport and walking and the provision of public transport services and walk infrastructure in the built environment. Both sides were examined in further detail in this research. With regard to the demand side, the perceived barriers towards public transport and walking were investigated using a postal questionnaire survey in four different areas of Birmingham, mainly distinctive for their level of deprivation and railway access. The perceived barriers were questioned in two different ways: by rating sets of predefined barriers and using an open approach based on free associations. The supply side was studied using a smartphone

tracking study that gathered detailed travel data of participants in the two least deprived study areas.

Whereas walking was associated with many positive aspects, public transport was perceived much more negatively and associated with various barriers, of which travel time, the unreliability of the service, expense and access issues were the most prevalent ones. The perceived barriers to public transport were found to be significantly influenced by the public transport provision in a neighbourhood. Differences in neighbourhood deprivation tended to affect perceptions as well, although this effect was mostly attributable to differences in socio-demographic factors. It was also found that the barriers to public transport and walking were related to each other and that the experience of one mode can influence how other modes are perceived.

Overall, it was concluded that the variability in public transport related walk distances is mainly caused by the provision of public transport services (routes and stops). This both directly affects the distances people need to walk as well as the perceived barriers to using public transport and walking, which shape the demand for walking to or from public transport. The directness of the public transport routes in relation to where people live and want to go is of importance, in which the length of the access and egress walks are related to each other.

SAMENVATTING

Een verschuiving van autogebruik naar actieve vervoersmodi kan voordelen opleveren voor verschillende problemen in stedelijke gebieden, zoals de volksgezondheid, verkeersveiligheid en congestie. Een belangrijk nadeel van actieve vervoerswijzen (voornamelijk lopen) vergeleken met gemotoriseerde modi is voor veel mensen het beperkte bereik, wat kan worden vergroot door openbaar vervoer. Het is daarom van belang om te begrijpen hoe lopen en openbaar vervoer gerelateerd zijn in stedelijke gebieden. Een vaak gehanteerde vuistregel in openbaar vervoersplanning rond de wereld is dat, gebaseerd op observaties, mensen bereid zijn om tot 400m te lopen voor een bus en 800m voor de trein. Voorgaand onderzoek op het gebied van loopafstanden van en naar het openbaar vervoer heeft echter grote variaties gevonden en hoofdzakelijk onderzocht hoe deze afstanden worden beïnvloed door het type openbaar vervoer, de gebouwde omgeving, karakteristieken van de reis en persoonlijke eigenschappen zoals geslacht, leeftijd, grootte van het huishouden en inkomen.

Het doel van dit onderzoeksproject is om de rol van percepties, kansarmoede en het aanbod in openbaar vervoer in de variabiliteit in loopafstanden van en naar het openbaar vervoer in stedelijke gebieden beter te begrijpen. Om dit te bereiken is de loopafstand van en naar het openbaar vervoer geconceptualiseerd, gebaseerd op de literatuur, als een interactie tussen de vraag voor het reizen met openbaar vervoer en lopen en het aanbod in openbaar vervoersdiensten en voetgangersinfrastructuur in de gebouwde omgeving. Beide zijden zijn gedetailleerder bekeken in dit onderzoek. Met betrekking tot de vraagzijde zijn de waargenomen barrières voor openbaar vervoer en lopen onderzocht middels een papieren huis-aan-huis enquête in vier verschillende wijken in Birmingham, GB, vooral verschillend op het gebied van kansarmoede en toegang tot het spoornetwerk. De waargenomen belemmeringen

zijn op twee manieren bevraagd: door het waarderen van groepen voorgedefinieerde belemmeringen en door een open benadering gebaseerd op vrije associaties. De aanbodszijde is onderzocht door middel van een smartphone tracking studie, waarbij gedetailleerde verplaatsingsdata verzameld werd van deelnemers uit de twee minst kansarme wijken.

Terwijl lopen werd geassocieerd met veel positieve aspecten, werd openbaar vervoer veel negatiever gezien en geassocieerd met verschillende belemmeringen, waarbij reistijd, de onbetrouwbaarheid van de diensten, de kosten en bereikbaarheid de meest voorkomende waren. De waargenomen belemmeringen voor openbaar vervoer bleken significant te worden beïnvloed door het aanbod aan openbaar vervoer in de wijk. Verschillen in kansarmoede van de wijk leken de percepties ook te beïnvloeden, al was dit effect vooral te wijden aan verschillen in socio-demografische factoren. Ook bleek het dat de belemmeringen voor openbaar vervoer en lopen aan elkaar waren gerelateerd en de ervaring van één modaliteit kan invloed hebben op hoe de ander wordt gezien.

Over het algemeen werd geconcludeerd dat de variabiliteit in loopafstanden van en naar het openbaar vervoer voornamelijk wordt veroorzaakt door het aanbod in openbaarvervoersdiensten (routes en haltes). Dit beïnvloedt zowel de afstand die mensen moeten lopen als de waargenomen belemmeringen voor het gebruik van openbaar vervoer en lopen, die de vraag voor lopen van en naar het openbaar vervoer mede vormgeven. De directheid van de openbaar vervoerroutes in relatie tot waar mensen wonen en naartoe willen gaan is van belang, waarbij de lengte van de looproutes van en naar het openbaar vervoer gerelateerd zijn aan elkaar.

to my parents

Walking is the first thing an infant wants to do
and the last thing an old person wants to give up

~ John Butcher, founder Walk21, 1999

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LIST OF ABBREVIATIONS

AI	Artificial intelligence
API	Application Programming Interface
BRT	Bus rapid transit
CBD	Central Business District
CI	Confidence interval
CRUD	Create, read, update, delete
EU	European Union
FMS	Future Mobility Sensing
GIS	Geographical Information System
GPS	Global Positioning System
GTFS	General Transit Feed Specification
HH	Household
ITN	Integrated Transport Network
JSON	JavaScript Object Notation (file format)
LRT	Light rail rapid transit
LSOA	Lower Super Output Area
MaaS	Mobility as a Service
Min, mins	Minute, minutes
MIT	Massachusetts Institute of Technology
NHS	National Health Service
OD	Origin – Destination
OS	Ordnance Survey
PT	Public transport
QR-code	Quick Response code
TfWM	Transport for West Midlands
TPB	Theory of Planned Behaviour
TRID	Transport Research International Documentation
UK	United Kingdom
US, USA	United States of America
WMCA	West Midlands Combined Authority
XML	Extensible Markup Language (file format)
y/o	Years old

LIST OF PUBLICATIONS

- Van Soest, D., Tight, M.R., Rogers, C.D.F. (2020). Exploring the distances people walk to access public transport. *Transport Reviews*. 40 (2). 1-23
- Van Soest, D., Tight, M.R. and Rogers, C.D.F. (2019) Exploring transport perceptions across urban areas using free associations. *Transportation Research Part F*. 65. 316-333
- Van Soest, D., Tight, M.R. and Rogers, C.D.F. (2019) Investigating the importance of walk stages as a factor in the choice between car and public transport in urban areas. In Tira, M. et al. (ed.): *The XXIV International Conference Living and Walking in Cities (LWC 2019)*. Brescia, Italy

Under review:

- Van Soest, D., Tight, M.R. and Rogers, C.D.F. (2019) Synergies and Differences between the Barriers to Public Transport and Walking. *Travel Behaviour and Society*.

1. INTRODUCTION

1.1 Background

Transport systems in urban areas are influenced by other systems relating to how people live, work and spend their leisure time. They generally respond to the need for mobility and have the potential to deliver a multiplicity of benefits alongside their main function to provide access. However, at the same time, transport also brings adverse consequences, such as barriers to movement, delays due to congestion, compromised safety, environmental pollution and so on. One of the most important impacts is that of transport on citizens' health and wellbeing.

For example, some transport modes, such as car travel, contribute to a sedentary lifestyle, whilst some other modes require physical activity, such as cycling or walking (MacDonald *et al.*, 2010; Martin *et al.*, 2015). A switch to active modes has been associated with increases in both physical and mental health (Jacob, Munford and Roberts, 2019), for instance through reducing the risks of being overweight or obese (Tajalli and Hajbabaie, 2017). This is of importance, as obesity is in turn linked to conditions like cancer, cardiovascular diseases and type 2 diabetes and can therefore seriously impact length and quality of life (Minster, 2010). Figure 1-1 shows the prevalence of obesity for English adults from 1993 to 2017. Although the total number of overweight people remained fairly steady after 2000, the proportion of adults suffering from obesity has still been growing over the years.

Figure 1-2 shows the number of hospital admissions per 100,000 inhabitants in England, in which obesity was an attributed factor. There clearly are differences with regard to the severity of the obesity problem across the country. The current thesis focuses on the city of Birmingham. Although Birmingham itself is not in the highest tier on the graph, the areas surrounding Birmingham are among the worst areas in England in terms of obesity when considering the number of hospital admissions related to it, with over 2,000 annual obesity-related hospital admissions per 100,000 inhabitants.

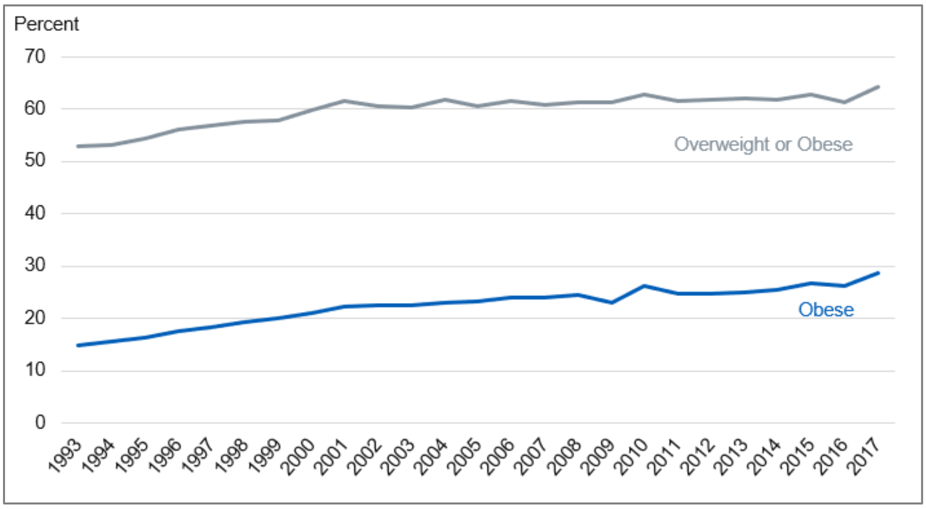


Figure 1-1 Obesity prevalence in England 1993-2017 (NHS, 2019)

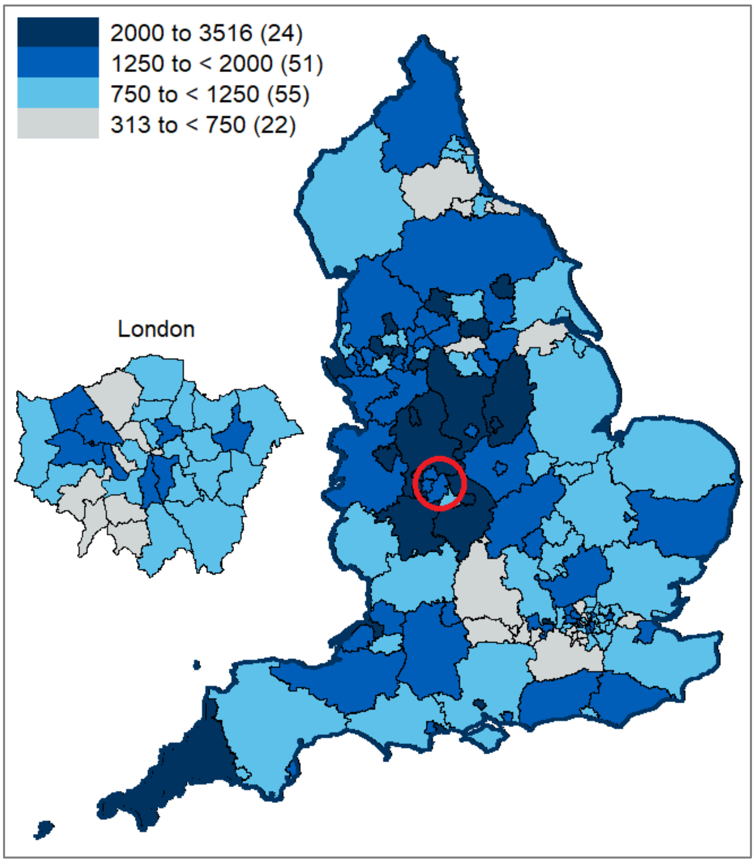


Figure 1-2 Hospital admissions per 100,000 population in which obesity was a factor (the red circle refers to the Birmingham area; NHS, 2019)

The rate of obesity is, among other factors, related to the level of deprivation in an area. And these differences in obesity across deprivation levels have increased over recent years (Figure 1-3).

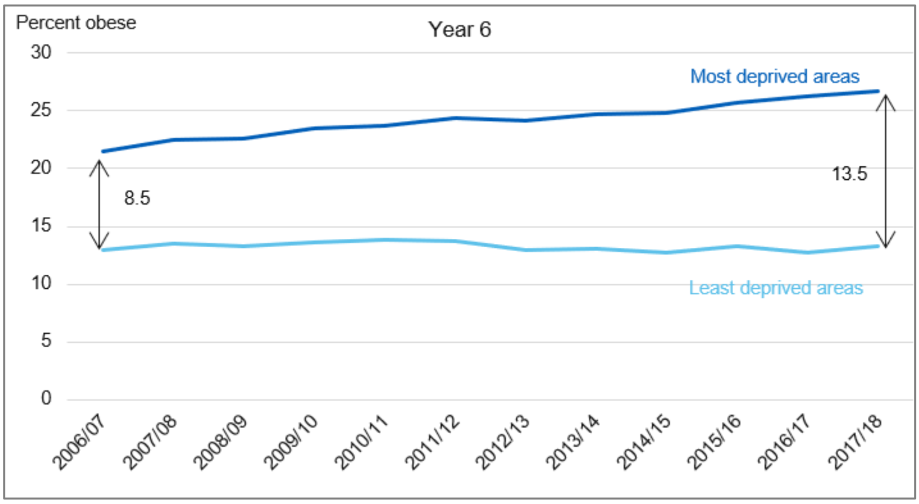


Figure 1-3 Proportion of Year 6 children suffering from obesity in the least and most deprived areas in England (NHS, 2019)

Active transport can be a convenient means to be physically active in modern living, since a lack of time is an important barrier to being physically active (Das and Petruzzello, 2016; Nieuwenhuijsen and Khreis, 2016) and using active transport diminishes the need to spend additional time on physical activity.

The UK government recognises the importance of increasing walking and cycling for public health (Public Health England, 2013). In England, 81% of the trips shorter than 1 mile are undertaken on foot or by bike[1] (Figure 1-4, Department for Transport, 2019). However, a major disadvantage of active transport (in particular walking) for most people compared to motorised

[1] The number of active trips might in fact be higher, due to the underreporting of short trips and exclusion of trips that are not on the public highway (e.g. walking in shops, airports, and nature).

transport is the limited range (Rojas López and Wong, 2017). For trips more than 2 miles, the share of active transport drops significantly, with about 80% of those trips undertaken by car and just 6% by walking and cycling (Department for Transport, 2019).

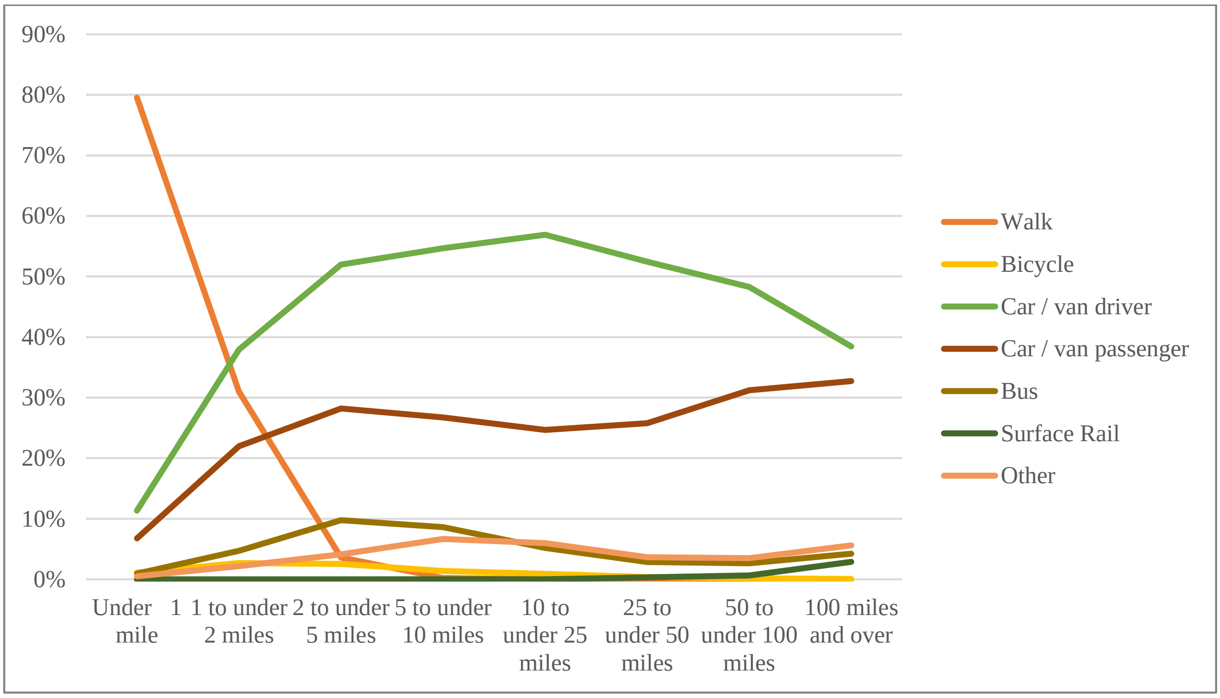


Figure 1-4 Modal split (according to number of trips) per trip distance band (Department for Transport, 2019, adapted)

Public transport (PT) can complement the use of active modes and extend the range considerably (Rietveld, 2000). For this reason, and the fact that cars bring many other well-known concerns, there might be potential for a modal shift towards active and public transport, which would decrease the use of cars and simultaneously contribute to increases in physical activity (Tight, Rajé and Timms, 2016). Since urban planning can influence travel behaviour (Næss *et al.*, 2018), it is relevant to understand how walking relates to PT journeys in urban environments in order to achieve an increase in physical activity. A frequently adopted guideline in PT planning around the world is that, based on observations, people would be willing to walk up to 400m for buses and 800m for rail transport (e.g., Canepa, 2007). It is however often found that there is a lot of variance in the actual distances people walk to or from PT (El-Geneidy *et al.*, 2014).

A significant body of research, especially over the last decade, has been developed which provides more insights into public transport-related walking. The factors that influence the distances people walk to and from public transport could be divided into two broad categories. On the one hand, there are demand factors that determine someone's choice to walk and use public transport (in which choice is not in all cases free, e.g. depending on the transport alternatives available and how much someone can afford to spend on transport). The context people live in, on different levels, can play a role in the demand, such as personal characteristics and attitudes, household characteristics and the wider social environment or culture. On the other hand, there are supply factors, which include the built environment and the provision of public transport systems and walking infrastructure. These supply factors basically define how much someone should walk in case he or she decides to use public transport. It needs to be noted, however, that the demand and supply sides cannot be considered completely independently from each other. For instance, a better supply can result into a more attractive service, which might in turn increase the demand for the service, although in some cases, such as when the services supplied are not in line with the trips people wish to undertake, demand might not increase. Likewise, a high (low) demand for a service might increase (decrease) the level of supply of a service in the longer term if responsible authorities try to match their service supplies with the travel demand.

1.2 Aim and objectives

This research aims to develop the understanding of the role of perceptions, neighbourhood deprivation and public transport provision in the variability of walk distances to and from public transport across urban areas. To meet the research aim, the following objectives are defined:

1. To identify which barriers people perceive towards using public transport and walking.
2. To explore if and how these perceived barriers vary across neighbourhoods.
3. To study to what extent these perceived barriers are related to each other and the actual travel behaviour.
4. To investigate how public transport related walks are influenced by public transport provision.
5. To explore the potential for the use of public transport and walking for current car trips.

1.3 Relevance of the research

Although Chapter 2 will more clearly define the research gaps that this study aimed to fill, this section outlines some of the aspects indicating the relevance of the research. Eventually, the enhanced understanding of walk distances can support transport planning practice by providing a better idea of how the willingness to walk a certain distance to access public transport can differ across areas, which subsequently can result into a more tailored transport planning approach to suit the needs of citizens and increase the amount of public transport use and walking.

Firstly, the research should provide better insight into the effects of public transport planning on walking, which can inform transport policies with a focus on public health. The research can particularly contribute by giving more traveller focused insights. Instead of focusing on a transport mode and examining which people use this, it examines the barriers that different groups of people experience to different transport modes and how they travel. The main advantage of this approach is that it gives a much better view on the alternative choices people could have made, since more is known about the available transport modes and the routes someone took, for which alternatives are sought using external data sources. It also takes a closer look at the influence of public transport provision on the travel perceptions as well as the travel patterns, a factor that is often neglected or not fully accounted for in existing research on walk distances to and from public transport. Moreover, the study uses Birmingham, UK, as a case study area, which is of value, as the majority of existing studies focusing on walking to and from public transport were conducted in America, Australia and South-East Asia, whilst European cities tend to have a different urban structure, alongside cultural differences.

The study of the demand side mostly examines the barriers people perceive towards different transport modes. This is done in two ways, by means of a rather traditional way and a more novel approach using a free association technique (participants give their first associations when thinking about a transport mode), which can give richer insights into how transport modes are perceived across the population and lead to a more robust study. Attention is paid more to social dimensions, such as the level of deprivation, which has been suggested to significantly influence travel behaviour but is not often accounted for in research. The supply side is studied using a smartphone tracking survey, which is a relatively novel approach since it has not yet often been used. This makes it possible to obtain detailed, objective, multi-day insights into the travel behaviour of people with a better awareness of a trip's context in their daily schedule.

Lastly, the research explores the potential for change towards more walking and public transport use, which can benefit society in many ways. Many of the benefits contribute to an enhanced public health, either through an increase in physical activity, a decrease in pollution from private vehicles or a potential increase in traffic safety.

1.4 Structure of the thesis

The rest of this dissertation is structured as follows. Chapter 2 provides an overview of key literature on the use of public transport and walking and critically reviews the relevant literature to establish the existing evidence around walk distances to and from public transport. It provides a theoretical background for the research and defines the research gaps to which this research can contribute. The research methods that are applied to meet the objectives set are outlined in Chapter 3. The rationale behind these methods is provided and it explains which analyses are performed. Two main methods are proposed in this chapter: a postal questionnaire survey and a smartphone location tracking survey. The results of the questionnaire survey are presented in Chapter 4. This chapter provides the analyses of the perceived barriers to walking and public transport, relating to objectives 1-3. Chapter 5 illustrates the findings of the analyses related to the smartphone tracking survey. All findings of the two main studies are critically discussed and interpreted in Chapter 6, followed by a presentation of the key conclusions of the research in Chapter 7. The objectives as set in Section 1.2 are addressed, and potential future research is discussed as well as recommendations for policy and practice.

2. LITERATURE

2.1 Introduction

This chapter reviews some of the key literature on modal choice, to understand what factors play a role in the general preference for cars and what makes people choose public transport. It then continues by looking at how people choose their access or egress modes related to public transport, and which factors support the choice for walking. Against this background, a systematic literature review has been undertaken to establish the evidence on walk distances to and from public transport. The methods used to study this topic are critically reviewed and the factors that influence the walk distances are discussed. The review leads to development of a conceptual framework that forms the basis of the research approach outlined in the Chapter 3.

2.2 Understanding modal choice

2.2.1 Mode choice theory

Traditionally, travel behaviour is modelled according to the economic principles of utility maximisation, assuming that people gain utility from the conduct of activities. Someone is assumed to travel as long as the net utility is positive and preferably maximised, supposing that the journeys to and from an activity induce disutility. This disutility can refer to the time or money people need to invest in their travel, as well as aspects such as stress and other mental or physical efforts involved while travelling. Accordingly, people are assumed to choose the mode with the least disutility, which is usually measured by factors such as financial costs and travel time.

However, it is increasingly recognised that this is a rather simplistic representation of real travel behaviour. It appears that individuals do not necessarily seek to avoid travelling. On the contrary, they often appear to gain utility from a trip as well as from the endpoint (Lyons, Jain and Holley, 2007; Cass and Faulconbridge, 2017). It is for instance remarkable that the new transportation technologies have caused the average travel speed to increase considerably, but instead of spending less time on travelling, it led to people travelling further (Lyons and Urry, 2005; Banister, 2011).

Mokhtarian and Salomon (2001) conducted a survey among 1384 workers concerning their commute times and related attitudes. If the assumption that people seek to minimise travel were true, the ideal commute time would be zero minutes. However, hardly anybody in the sample considered this as ideal. The average ideal commute time was found to be 16 minutes. Therefore, instead of minimising travelling, Mokhtarian and Salomon suggested that people rather seek an optimum desired amount of travel. There can be various reasons why travellers do not minimise their travelling. The travel time can be transition time; the traveller feels a need to experience the physical movement to another place or needs some time to adjust between two activities. Travel time can also function as a time-out, some desired private time for the traveller (Jain and Lyons, 2008). Jain and Lyons (2008) go further and even argue that travel time can be considered as a gift. They suggest that people invest travel time to see others face-to-face. A reciprocal act is then often expected, e.g. in the form of an enhanced social network. An investment in time often expresses greater value than, for instance, just giving money.

Milakis et al. (2015) suggested that people have a trip time budget, meaning that individuals seek for an ideal trip time, but accept a longer time until the total benefits related to the trip decrease. They found commuters to have an ideal commute time of 18 minutes (quite similar to the previously mentioned study of Mokhtarian and Salomon (2001)), and an acceptable commute time of approximately 43 minutes. In addition, they found that there are differences between modes. Public transport and bike commuters in particular tended to have higher acceptable commute times.

Thus, there can be different underlying motivations for people to travel, instead of only the activity at the destination, commonly distinguished into two types: (1) extrinsic reasons; travel as a derived demand, and (2) intrinsic reasons; travel for its own sake (Mokhtarian and Salomon, 2001; Cao, Mokhtarian and Handy, 2008; Mokhtarian, Salomon and Singer, 2015). The extent to which these reasons apply differs for each trip and each individual. For some people, travel pleasure plays a very important role, whilst others attach a high value to time savings (Pronello and Camusso, 2011). When travel is completely because of extrinsic reasons, it can be called utilitarian, instrumental or directed travel; if travel is based entirely on intrinsic reasons and the destination does not play a role, it can be called undirected or autotelic travel (Mokhtarian and Salomon, 2001; Cao, Mokhtarian and Handy, 2008). Between these two extremes, a continuum exists with a mix of intrinsic and extrinsic motivations (Mokhtarian and Salomon, 2001). Extrinsically motivated travel can also fulfil intrinsic motivations (Mokhtarian, Salomon and Singer, 2015).

To understand the choice for a travel mode, one needs to understand firstly which options are in the choice set, i.e. the set of alternative means of transport available to the traveller to undertake a trip. Focussing on public transport and its main ‘competitor’, the private car, travellers are commonly segmented into different categories, depending on the availability of public transport or a car: (1) auto dependent users, who only have a car available as appropriate travel option and no public transport, (2) transit captive users, who only have PT available to travel, and (3) choice users, who have both modes available. A fourth category, people who do not have any acceptable transport mode available can be considered as well (Beimborn, Greenwald and Jin, 2003).

These categories are useful for the understanding of mode choice, as the requirements for each category with regard to a transport mode differ. Travellers in the second category are forced to use public transport, because they can for instance not afford to possess a car. These people will use public transport regardless of the qualities offered by the system, unless the system does not meet the minimum requirements and the individual is restricted from travelling at all. Choice users, on the other hand, have public transport available as a reasonable travel option. For these people, the qualities of the system do matter, as an underperforming system in terms of desired qualities would make alternative travel modes more favourable. For instance, quality improvements for buses, such as improved frequency and reliability, have been shown to increase ridership (Currie and Wallis, 2008). Choice travellers have the biggest potential regarding an increase in public transport trip share, and hence an increase in active transport. The ultimate choice is determined partly by instrumental motives such as travel time and distance, but affective motivations play an important role as well (Stradling, 2011).

A wide range of (psychological) theories have been developed to help understanding how people choose a transport mode (Chng *et al.*, 2018; Rojas López and Wong, 2019). A very frequently adopted approach is using the Theory of Planned Behaviour (TPB; Ajzen, 1991). This theory implies that the choice for a certain mode is a deliberate process, in which behaviour follows from an intention, which in turn can be predicted by attitudes towards the particular behaviour, subjective norms and perceived behavioural control. The TPB has several inadequacies for travel behaviour (Anable, 2005), however, and a number of researchers made efforts to extend the TPB to be more applicable for modal choice decisions (Donald, Cooper and Conchie, 2014; Fu and Juan, 2017). One of the most important issues concerning the application of the traditional TPB in mode choice is that this process in reality is rarely deliberate. Especially for very regular journeys, such as commutes, habitual behaviour occurs. Therefore, several researchers included habits in the model along with intention, meaning that behaviour is not necessarily based solely on intentions (Donald, Cooper and Conchie, 2014; Fu and Juan, 2017; Schoenau and Müller, 2017). Besides, Donald et al. (2014) added some other explanatory factors to the model, including moral norms, descriptive norms and environmental concerns, which enhanced the predictive power of the model. Also other research has found influences of attitudes and subjective, descriptive and personal norms on the intention to drive (Gardner and Abraham, 2010). Instead of adding additional variables, Fu & Juan (2017) included the factor satisfaction along with habit and intention. They argue that the satisfaction with a certain mode choice influences the habits as well as the behavioural outcome. Schoenau and Müller (2017) included external costs and a person's socio-economic status next to habits to study the choice for sustainable mobility modes.

Another approach of considering the mode choice decisions is adopted by De Witte et al. (2013). They conducted a comprehensive literature review, revealing the frequency by which factors had been studied with regard to modal choice and how often these were found to be significant. Based on this literature, they developed a framework to group the factors that affect modal choice. This framework builds on the motility concept of Kaufmann et al. (2004). Motility refers to the capacity to be mobile and is based on three elements: access to forms of mobility, competence to access, and appropriation of a mobility choice. De Witte et al. (2013) group the influencing factors into socio-demographic, spatial, journey characteristic and socio-psychological indicators, where the latter group mediates the other factors and the modal choice, as is illustrated in Figure 2-1. The indicators in the outer circle determine the access and competences, whilst the socio-psychological indicators define the appropriation of a certain modal choice.

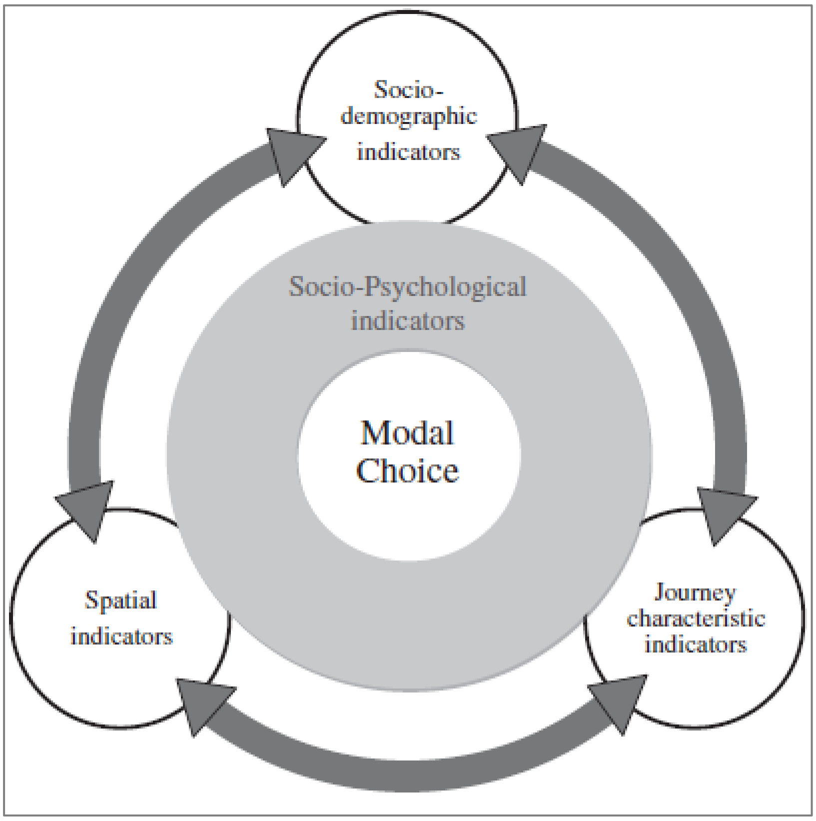


Figure 2-1 Framework for structuring modal choice determinants (De Witte et al., 2013)

Whereas the TPB focuses more on explaining the process of choosing a certain mode or not, the framework of De Witte et al. (2013) pays more attention to the available travel options and the choice between them. It provides a better insight into the decision process by considering a wider range of factors, including a central role for socio-psychological indicators, which can incorporate phenomena such as habitual behaviour.

Socio-psychological indicators can also point at differences in attitudes of people (Prillwitz and Barr, 2011; Şimşekoğlu, Nordfjærn and Rundmo, 2015; Van Acker, 2015). Anable (2005) made a psychological segmentation with regard to travel behaviour. There were clearly distinctive groups of people, showing differences in their attachment to the car and the responsibility they feel for the environmental effects of car use. Other segmentation approaches found differences in, for instance, the value people attach to time saving or the extent to which they travel for pleasure (Pronello and Camusso, 2011), or the perceptions about active and public transport (Hickman and Vecia, 2016).

The aspects in the framework by De Witte et al. (2013) also come forth in the theory of routine mode choice decisions, proposed by Schneider (2013) and displayed in Figure 2-2, albeit in a different format. The theory distinguishes five different steps in the mode choice process. Firstly, one should be aware of the available modes. Then situational trade-offs are made within the choice set, based on basic safety and security, convenience and cost, and enjoyment. Finally, this can lead to the development of habits for routine trips. They suggest that the way in which different individuals deal with the first four steps can be explained by socioeconomic factors.

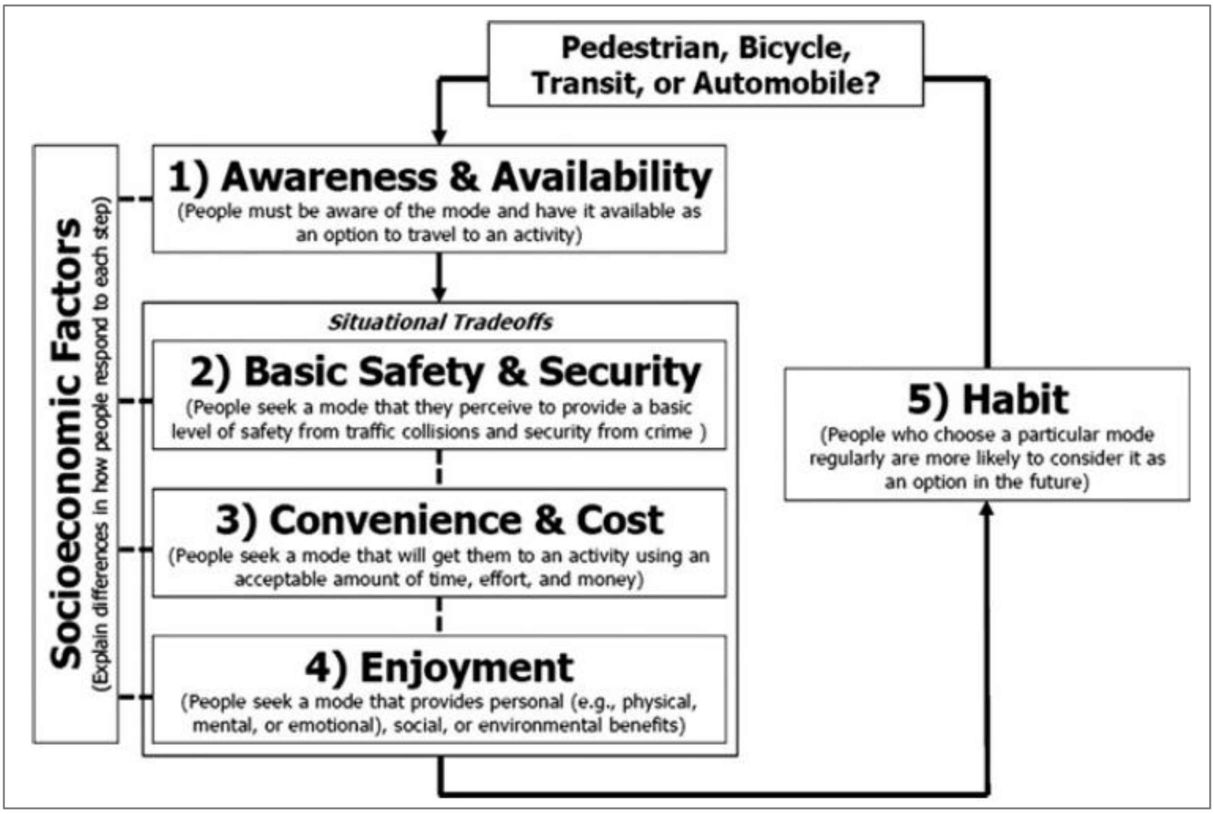


Figure 2-2 Theory of Routine Mode Choice Decisions (Schneider, 2013)

The second, third and fourth step in the framework imply some important aspects that people seek for when choosing a mode. Firstly, a mode is preferred to provide some basic level of safety, both from traffic and security from crime, after which people prefer to minimise the time, effort and monetary costs involved in travelling using a certain mode. Finally, the mode preferably also provides additional mental, physical or emotional benefits to the traveller. When a mode lacks some of these aspects, or another alternative mode performs better, the chances of using that particular mode will decrease. The following section takes a closer look at the choice for public transport as a travel mode.

2.2.2 Choice for public transport

Public transport only accounts for a minor proportion of all trips in England, about 10%, whilst over 60% of the trips are made by car and over 25% on foot. About half of the public transport trips are by bus, and just over 2% by train (See Figure 2-3; Department for Transport, 2019). Figure 2-4 shows a comparison of the modal split between car, bus and railway travel across Europe. The UK has a relatively high share of car travel, although in all countries included car travel appears to be the dominant mode of transport.

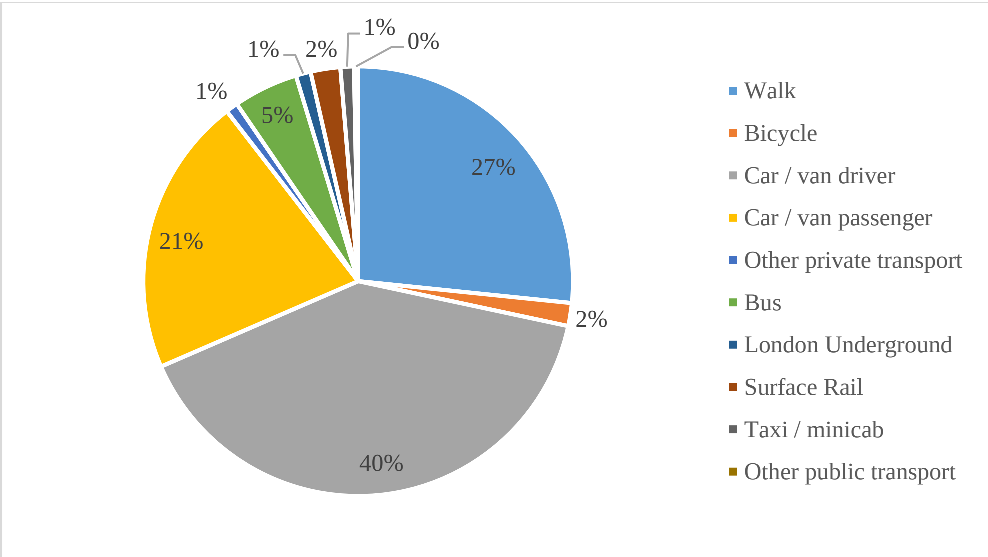


Figure 2-3 Modal split in trips per person in England (Department for Transport, 2019)

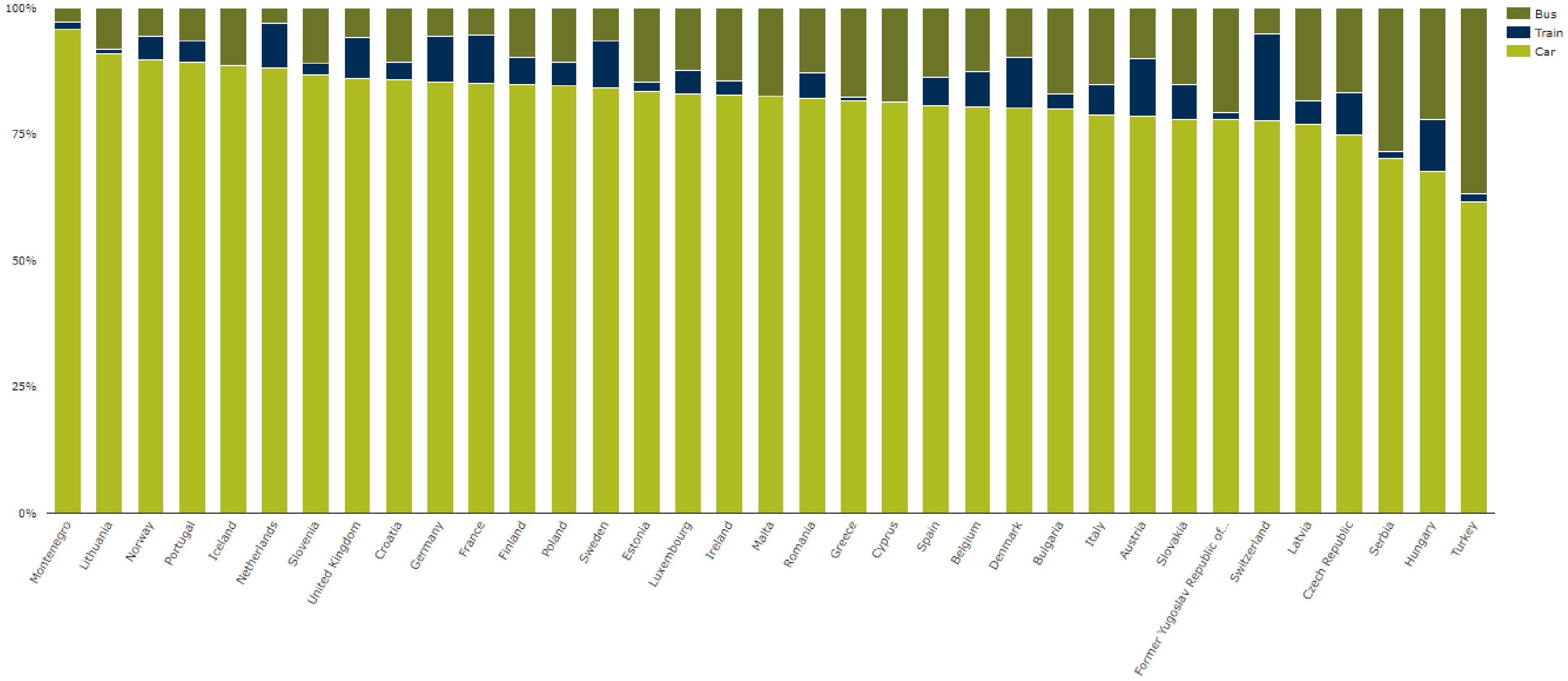


Figure 2-4 Modal split for European countries, only considering bus, train and car travel (European Environment Agency, 2015)

To understand why the proportion of public transport travel is so low, it is of interest to understand which barriers people experience to public transport use. As stated earlier, these barriers to public transport services will be more prevalent for choice riders than PT-captives (Krizek and El-Geneidy, 2007).

Ti (2016) states that the use of public transport actually brings many undesirable experiences. In particular the fact that people need to share the space with strangers (Bissell, 2010), implying social and physical tensions, and the cognitive and psychological burden of planning and managing the trip (Ti, 2016). The efforts people need to make for a journey by public transport are distinguished in three main categories by Stradling (2002). At first, there is physical effort involved, such as walking and carrying luggage. Secondly, it involves cognitive effort, which refers to effort for gathering information, planning, navigating, and changes in case of interruptions. Thirdly, there is affective effort, related to the emotional energy, such as uncertainty about safety, comfort, or reliability.

In contrast to all these efforts related to a public transport trip, the private car can often offer a better experience to people, with less efforts involved, which might explain its popularity compared to public transport and other modes. There can be various reasons why people choose a car rather than public transport. The need to carry heavy goods, a shortage of time and convenience are important reasons, as well as darkness and bad weather in case of an alternative to walking (Mackett, 2003). Concerns about personal space, minimising monetary costs and a desire for control, freedom or flexibility are additional key motivators for using a car instead of other modes like public transport (Gardner and Abraham, 2007; Kent, 2014). These motivators for car use could in turn be considered barriers to public transport use, especially the fact that travelling by public transport generally takes more time and offers less freedom and control, as the user is dependent on the service provided by a transport operator. Particularly more complex trip-chaining patterns can increase the need for aspects such as flexibility and freedom in mode choice (Ye, Pendyala and Gottardi, 2007). An advantage of public transport, compared to car driving, is that the time can sometimes be used in a more productive way, which can also increase someone's acceptable travel time (Milakis *et al.*, 2015).

Besides many practical reasons, symbolic motivations, such as status in the society, and affective motivations, such as a pleasurable driving experience, can make people choose to travel by car instead of public transport (Hiscock *et al.*, 2002; Beirão and Sarsfield Cabral, 2007). Of course, there are also enabling factors that make people choose for public transport instead of the car, such as its costs, less stress, the ability to relax, the ability to rest or read, travel time in heavy traffic, talking to other people or environmental reasons (Beirão and Sarsfield Cabral, 2007).

As suggested in the modal choice theory in Figure 2-2 (Schneider, 2013), a mode should first and foremost provide a basic level of safety and security to the traveller. This is often perceived to be a problem in public transport. Personal safety at public transport terminals has been found to be an important issue (Atkins, 1990), as travellers are observed to be more likely to feel unsafe at the out-of-vehicle stages of a public transport trip (Hiscock *et al.*, 2002). Also the fact that one has to travel with unknown passengers causes concerns, especially in the night (Currie, Delbosc and Mahmoud, 2013). There are some gender differences, though, as women tend to express more fear of crime than men (Carter, 2005), and the level of fear might also be related to the actual crime rates in a certain place.

Another crucial concern in PT trips is the need to transfer between different services. A transfer is a disruption of a journey and people tend to have a resistance to it, for example because of the related uncertainty (Hine and Scott, 2000). Therefore, it is important that the transfer facilities (stations and stops) enhance the integration of the different modes. A lowering of the burdens of walking, waiting and transferring can increase the connectivity of a public transport journey, and likely also its attractiveness (Iseki and Taylor, 2009). Bins Ely et al. (2012) concentrated on the comfort of bus stops and identified two different factors: physical and psychological comfort. Physical comfort refers to bioclimatic and functional comfort, so protection for weather conditions and offering comfortable places to sit or stand. Psychological comfort refers to elements enhancing safety perception, the visibility of the buses, and elements that could reduce fatigue, such as timetable information. Passengers tend to value information and service more than the time an interchange takes (Allard and Moura, 2016).

The time people need to spend at a station or stop obviously depends on how long they arrive before the departure of the public transport service. In general, people try to minimise the waiting time. The shorter the time until departure, the better it is perceived. This only holds up to some threshold, though. When it gets too short before departure, chances increase that the passenger will miss the service, which then increases stress and reduces the psychological comfort (Csikos and Currie, 2008). The arrival behaviour differs for each passenger. There are passengers who always arrive shortly before departure, with a strong regularity, and on the contrary, there are passengers who arrive largely at random. Between these two types there is a grey area of passengers who arrive consistently, but sometimes later or earlier, or passengers who arrive with a weaker regularity in general (Csikos and Currie, 2008).

There is also a strand of research that specifically looks at satisfaction with public transport travel, which service attributes contribute to this, and how this enhances ridership (e.g., Wen, Lan and Cheng, 2005; Minser and Webb, 2010; Lai and Chen, 2011). Van Lierop et al. (2018) systematically reviewed literature around satisfaction and loyalty in public transport, in which a wide range of factors were identified to be of importance. The key attributes that were found to influence satisfaction were on-board cleanliness, comfort, the behaviour and attitude of personnel, safety, punctuality and frequency of the service. For loyalty, these were the perception of value-for-money, on-board safety, cleanliness, interactions with personnel, the image the user holds of public transport and commitment to public transport that the user feels. Value-for-money refers to the passenger's perception of how good the offered service is compared to the costs he/she pays. This is not necessarily directly related to the costs of other modal choices such as car driving, but these can play a role in the perception of value-for-money as they are substitute products.

2.2.3 Choice to walk to public transport

Traditionally mode choice has mainly been studied in the context of one main mode and there is therefore a rich literature base around walking in general. In the last two decades there has become more attention for walking as part of other trips, such as trip stages in public transport. These different trip stages are dependent on each other, which makes it an even more complex choice process. The choice for a public transport service can be dependent on the choice for a station or stop to access the public transport system, which in turn can depend on the mode used to access the stop or station. Dependencies could also work the other way around, subject to which aspects the traveller finds more important or in which he or she has less freedom of choice. This section will firstly review some of the literature about influences on walking in general and then look specifically at literature that focuses on the choice to walk to or from public transport.

2.2.3.1 General walking

Literature on walking has especially gained insights with regard to physical characteristics of the environment. These are often categorised using the 3 Ds: density, diversity and design. Density and diversity are more concerned with the access to facilities, whereas design is more associated with the quality of the routes (Cervero and Kockelman, 1997). Later, two D's were added: distance to public transport and destination accessibility (Cervero *et al.*, 2009). Saelens and Handy (2008) reviewed several reviews on built environment factors that correlate with walking. A high density and proximity (relating to the density dimension), mixed land use (diversity), and aesthetic qualities (design) were frequently found to be associated with higher walking rates in the literature. They mostly looked at how many studies found an effect and whether this was in the expected direction, but did not provide figures on the magnitude of the effects, as this differed per study depending on the local characteristics.

Most studies in this field appear to be conducted in a non-European context, which often differs from the European in both the physical environment and the travel behaviour. For example, less dense suburban environments tend to be less uncongenial for active transport and can still offer adequate facilities (Christiansen *et al.*, 2014). Van Holle et al. (2012) systematically reviewed the available studies on the relationship between the physical environment and several domains of physical activity of adults in Europe. Walkability (residential density, land use mix diversity, and street connectivity), access to common destinations, traffic safety, and environmental quality were found to have a positive effect on physical activity in Europe.

Another limitation of most of the considered studies is that they are cross-sectional. This implies that they generally can only find associations between variables, but that it is hard to establish evidence for causal mechanisms. The association between the built environment and travel behaviour could work in various ways (Feuillet *et al.*, 2016): the built environment can directly cause differences in travel behaviour; there can be an association because similar people (e.g. with similar preferences) live in the same area (which is often referred to as self-selection); or an association is found because people in an area become more similar over time, since someone's behaviour can be influenced by neighbours.

An issue that is commonly studied in this context is residential self-selection (Mokhtarian and Cao, 2008; Hong, Shen and Zhang, 2014). This refers to the phenomenon that people choose the neighbourhood in which they want to live, based on preferences for travel behaviour. This can involve, for instance, people who prefer walking who choose to live in a more walkable neighbourhood. Although in that case a positive relationship can be found between the prevalence of walking and the walkability of the area, this effect may not completely be attributed to the built environment, because the personal preferences of people are confounding.

Some researchers argue, however, that the influence of self-selection should not be overestimated. Transport is only one of the various factors affecting the choice for a home location, and its importance differs among people (Chatman, 2014; Næss, 2014; Ettema and Nieuwenhuis, 2017). Preferences related to demographic or life-cycle attributes, such as the presence of a private garden, can play a significant role as well (Wolday, Cao and Næss, 2018). Moreover, in European contexts, the effect of residential self-selection tends to be smaller than in the US (Wolday, Cao and Næss, 2018). Christiansen et al. (2014) found that self-selection factors did play some role in travel behaviour in a Danish city, but that the relationship between walkability and walking was still significant beyond self-selection. Also in the UK, residents tend to have more opportunities to travel using their preferred modes, leading to a lower impact of the self-selection effect (Aditjandra, Mulley and Nelson, 2009).

Yet, several European studies have found unequal relational strengths between the built environment and travel behaviour throughout the geographical space. Macintyre et al. (2002) emphasised the importance of considering compositional (related to individual characteristics) and collective (related to community characteristics) effects alongside contextual, to explain differences in effects in different places. In the study of Feuillet et al. (2016), significant differences in travel behaviour (walking) were found between neighbourhoods with similar built environments. Social dimensions, such as the level of deprivation of the neighbourhood were suggested to have an important effect here, together with varying perceptions of travel modes and the built environment. Perceptions can mediate the relationship between built environment and travel behaviour (Ma and Cao, 2017) and they can differ for every person (Ewing and Handy, 2009).

The amount of walking can also depend on socio-demographic characteristics, but these relationships differ across regions. Buehler et al. (2011) compared walking statistics between Germany and the U.S. Whereas in Germany younger and older people tended to walk more than middle-aged adults, in the U.S. the oldest category walked least. People with a higher degree generally walked more in both countries, and also in both countries the number of cars owned was inversely related with the amount of walking. Unemployed people in the U.S. tended to walk slightly less than the employed, whilst in Germany the unemployed walked much more.

Some alternative methods instead of cross-sectional studies can shed more light on the relationship between the built environment and travel behaviour. Longitudinal studies, for instance, can follow the behaviour of residents over time and potentially relate changes in walking behaviour to changes in the walkability of the environment. In this way, effects are controlled for the influence of personal differences, as the studied sample stays the same. There is still an assumption that people do not change their personality over the studied period, which might happen to some extent. There are a few longitudinal studies available, which support the idea that higher levels of walkability in a neighbourhood can lead to higher levels of walking (Handy, Cao and Mokhtarian, 2005; Wasfi *et al.*, 2016). It is also possible to conduct matched-attitude studies. In these studies, people with similar attitudes and preferences are compared with each other. In this way, their personal characteristics are controlled, and differences in travel behaviour are more likely to be caused by the built environment (Guo, 2009).

The relationship between the built environment and walking can be studied in a more differentiated way as well. Alfonzo (2005) suggested that the environmental factors affecting walking can be ordered hierarchically relating to the needs of the walker. This so-called 'hierarchy of walking needs' is embedded in a social-ecological framework and consists of five levels, respectively feasibility, accessibility, safety, comfort, and pleasurability. The upper four levels relate to urban form characteristics, while the lowest level refers to the ability to walk at all. The importance of this feasibility level is stressed by Lindelöw et al. (2014). They found that the way people perceive the built environment does not always play a role. Most of the times people walk, they do so because the trip is necessary. An environment that is very attractive for walking is therefore not enough to let people walk, as a walking trip needs to be feasible for them, e.g. suitable in the daily schedule. Some basic support offered by the built environment to allow people to walk might be required, however.

The less there is a choice to walk (meaning there is a need to go to a destination with the availability of other appropriate modal alternatives than walking), the less important are the higher levels of the hierarchy of walking needs. The level that needs to be reached for someone to be satisfied to walk is influenced by individual characteristics and circumstances, the type and length of the walking trip, and the perception of the environmental factors (Alfonzo, 2005). This implies that the built environment does not directly influence walking behaviour, but is rather mediated by the perceptions people have towards it, as is suggested by several researchers (Nasar, 2008; Gebel, Bauman and Owen, 2009; Adams, Bull and Foster, 2016; Liu and Titheridge, 2017). Obviously, those perceptions are influenced by the objective walking environment, but are not necessarily the same for everybody. Gebel et al. (2009) compared objective assessments of the walkability of the built environment with the perceptions of residents and found that these can vary clearly. Residents who do not make many utilitarian walking trips, who have a lower socioeconomic status, who have children in the household, or who are overweight tended to undervalue an objectively assessed high walkable neighbourhood. This implies that they unnecessarily perceive the walkability to be poor, and hence, their probability to undertake trips on foot is likely to be less as well.

2.2.3.2 Walking to and from public transport

Walking is the most used mode to access public transport, especially in the case of bus transport (e.g., Besser and Dannenberg, 2005). In Birmingham, 98% of the bus users walked to the bus stop (Centro, 2014) and of the train riders 46% walked to the station (Centro, 2013).

Considering the research that looks at walking to and from public transport specifically, there are various studies that have attempted to model this access mode choice together with the station choice, in which some assume that station choice comes first and some assume that access mode choice comes first (Chakour and Eluru, 2014). Nested logit models are commonly used, in which similar alternatives (i.e. with correlated error terms) are grouped together into nests. In a nested logit model there are two modelling levels. The upper level models the access mode choice, after which the station choice is modelled at the lower level. It is important to note that this modelling sequence does not imply a behavioural sequence, as is sometimes assumed. In other words, the model structure is a mathematical construct and does not mean that the person is assumed to firstly choose an access mode and then a station (Young and Blainey, 2018). The probability to choose for a certain option, such as the access mode choice, is commonly estimated using utility functions. Each alternative can have its own function, and different variables that are deemed to influence the attractiveness of an option can be taken into account (Debrezion, Pels and Rietveld, 2009).

One of the most often studied variables in station choice as well as access mode choice models is the distance between the origin and the public transport station or stop (e.g., Debrezion, Pels and Rietveld, 2009; Givoni and Rietveld, 2014; Young and Blainey, 2018). A longer distance generally leads to a lower probability of choosing a station and a lower probability of choosing walking as the mode of access or egress (Loutzenheiser, 1997; Olszewski and Wibowo, 2005; Bergman, Gliebe and Strathman, 2011; Park, Choi and Lee, 2015; Tilahun and Li, 2015; Halldórsdóttir, Nielsen and Prato, 2017).

Socio-demographic characteristics have also been found to play a role in the choice for an access or egress mode. Women, for instance, tend to walk less to access public transport (Loutzenheiser, 1997; Park, Choi and Lee, 2015; Tilahun and Li, 2015). For age, there are mixed results. In some studies older people tended to be less likely to walk (Loutzenheiser, 1997; Givoni and Rietveld, 2007; Tran, Zhang and Fujiwara, 2014; Durand, Tang, *et al.*, 2016), whilst in other studies younger people walked less (Kim, Ulfarsson and Hennessy, 2007; Tilahun and Li, 2015). These characteristics can be (partly) mediated by effects of crime, which also influences the willingness to walk (Kim, Ulfarsson and Hennessy, 2007; Appleyard, 2015; Tilahun and Li, 2015). Tilahun and Li (2015) found people to be less sensitive to safety from traffic, compared to crime, possibly because they feel more control over this aspect.

Furthermore, a higher income was observed to have a negative effect on walking probability (Loutzenheiser, 1997; Tilahun and Li, 2015). Car ownership was found to be another important factor, where car owners tend to walk less to public transport (Loutzenheiser, 1997; Kim, Ulfarsson and Hennessy, 2007; Park, Kang and Choi, 2014; Park, Choi and Lee, 2015; Tilahun and Li, 2015). Similarly, the provision of parking spaces at a station is correlated with a lower share of walking (Loutzenheiser, 1997; Kim, Ulfarsson and Hennessy, 2007; Walton and Sunseri, 2010; Maghelal, 2011), and if there are parking spaces available, weather (the chance of rain) was found to be a very important factor in the choice between walking or driving to a station (Walton and Sunseri, 2010). Related to this, placemaking (factors referring to safety and security, liveliness, crowding and aesthetics of the walking environment) were found to have a positive influence on the walk share (Chidambara, 2019).

2.3 Walk distances to and from public transport

This section reviews the literature that specifically considers the distances people walk to and from public transport, rather than the share of walking or other aspects. Because this present research project focuses on walk distances, this literature review was performed using a more systematic approach, in order to thoroughly establish the existing evidence base around these walk distances to and from public transport.

2.3.1 Approach to systematic literature review

Three common databases used in transport studies (Scopus, Web of Science, and TRID) were searched in October 2017 for relevant studies. The scope was limited to peer-reviewed books, articles and conference papers in the English language. Potentially in scope items needed to include both walking and public transport elements. The walking aspect was represented by the key terms[2]: 'walk*', 'physical activ*', 'active commut*', 'active travel*', and 'pedestrian'. For the public transport aspect, the key terms 'transit', 'public transport*', 'bus', 'rail*', 'tram', 'metro', or 'subway' were used. Studies were included if they quantified the amount of walking (being in either distance or time) that is directly related to the use of public transport. Studies that quantified PT-related walking using general measures of daily physical activity or walking, studies that only focused on walking proportions in access transport, or those that used stated preference designs were excluded, since these studies are less able to shed light on the true

[2] (*) can represent any character(s)

walking distances at the trip level. However, in the discussion on influencing factors, occasionally stated preference studies are included to supplement the evidence on a particular effect, as it is believed that, even though they offer limited value to establishing actual walk distances, these studies can offer insights into the role certain variables play.

The selection process is shown in Figure 2-5. The results of Scopus (n=5,322), Web of Science (n=4,495) and TRID (Transport Research International Documentation) (n=3,902) were merged in one EndNote library. Duplicates were removed automatically but, due to slightly different formatting in the three databases, many were not detected by the system. All titles were screened for precise alignment with regard to the inclusion criteria, and 384 records were left in the database for potential selection. For these records, the abstract was checked and, where there was doubt, also parts of the full text. In the end, 35 studies were selected for the review. Eight studies were published after the initial search process and included later. The reference lists of all publications were checked as well.

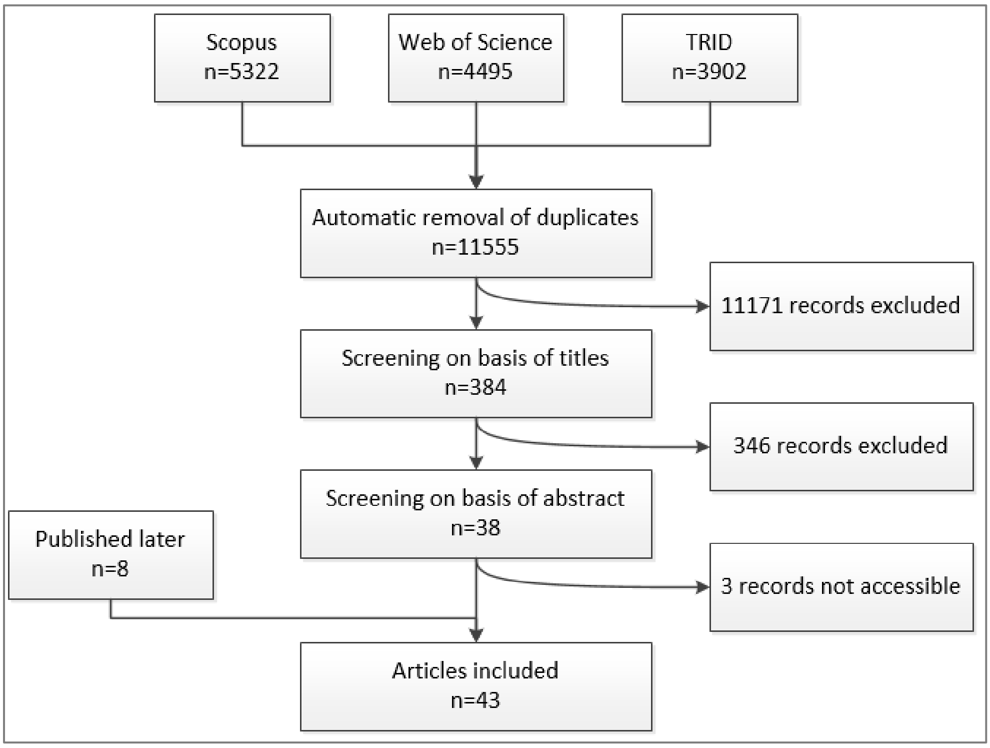


Figure 2-5 Article selection process

The studies identified are listed in Table 2-1. The table provides information on the country of study, the PT modes considered (bus, bus rapid transit (BRT), tram, metro, light rail (LRT) and train) and which aspects of walking were considered. In one round-trip by PT, four types of walking stages can be distinguished; it is either at the home or activity end of a journey, and either an access trip (towards PT) or an egress trip (from PT).

Table 2-1 Overview of studies concerning walking distance or time to public transport

Study	Public transport mode	Major data source	Physical activity
Agrawal et al. (2008) San Francisco, USA Portland, USA	LRT	Survey at 5 stations, with map n=328 travellers (18+)	Traced walking route distance to PT
Alshalalfah & Shalaby (2007) Toronto, Canada	Bus, metro	Transportation Tomorrow Survey Toronto; n=15830 morning peak trips	Straight-line distance to PT
Besser & Dannenberg (2005) USA	Bus, train	National Household Travel Survey; n=3312 trips (travellers 18+)	Self-reported time to/from PT
Chaix et al. (2014) Paris, France	Bus, tram, metro, LRT, train	Survey with accelerometer and GPS; n=234 adults	Physical activity time related to PT use
Chia et al. (2016) Brisbane, Australia	Bus	South-East Queensland Household Travel Survey; n=679 trips (adults, 18+)	Self-reported time to PT
Daniels & Mulley (2013) Sydney, Australia	Bus, train	Sydney Household Travel Survey; n=1906 trips	Shortest network distance to PT
Day et al. (2014) New York, USA	Bus, BRT	Survey at 3 bus stop pairs; n=403 travellers (18+)	Self-reported distance to PT in blocks
Durand et al. (2016) California state, USA	Bus, train	California Household Travel Survey; n=400 trips (children, 5-17 y/o)	Self-reported time to/from PT

Study	Public transport mode	Major data source	Physical activity
El-Geneidy et al. (2014) Montreal, Canada	Bus, metro, train	Montreal OD survey; n=16014 trips	Shortest network distance to nearest PT stop on used route
Evans & Addison (2009) UK	Train	National Travel Survey; n=5749 trips	Self-reported distance to/from PT
Freeland et al. (2013) USA	Bus, train	National Household Travel Survey; n=4195 trips	Self-reported time to/from PT
Garcia-Palomares et al. (2013) Madrid, Spain	Metro	Madrid Household Mobility Survey; n=17000 trips	Shortest network distance to/from PT
He et al. (2018) Nanjing, China	Metro	Survey at 6 stations, origins marked on map; n=611 passengers	Shortest network distance to PT
Hoback et al. (2008) Detroit, USA	Bus	On-board travel survey, with information on origins	Shortest network distance to/from/in PT for several route options
Ivan et al. (2019) Olomouc + Ostrava, Czech Republic	Bus, train	Survey in two cities, residence address and most used PT stop known; n=1,041 respondents	Shortest network distance to/from PT
Jiang et al. (2012) Jinan, China	BRT	Survey at 19 stations, with map; n=1233 travellers	Traced walking route distance to/from PT

Study	Public transport mode	Major data source	Physical activity
Johar et al. (2015) Delhi, India	Bus	Survey at various stations about walking distances; n=1748 commuters	Self-reported distance to/from PT
Ker & Ginn (2003) Perth, Australia	Train	Survey at 5 stations, with map	Distance to/from PT
Kim (2015) San Francisco, USA	LRT	Following people from 2 stations; n=139 travellers (18+)	Measured distance and time from PT
Kim et al. (2010) Busan, South-Korea	Bus, LRT	Survey at 6 stations, with map; n=600 travellers	Traced walking route distance to/from PT
Kim & Nam (2013) Seoul, South-Korea	LRT	Surveys at 7 stations, with information on destinations; n=635 travellers	Shortest network distance to/from PT
Krygsman et al. (2004) The Netherlands	Bus, tram, metro, train	Dutch national travel survey; n=1700 trips (travellers 12+ y/o)	Self-reported time to/from PT
Lam & Morrall (1982) Calgary, Canada	Bus	Survey at stops in 5 areas, with map	Traced walking route distance to/from PT
Li & Deng (2015) Shanghai, China	LRT	Survey at 5 stations, with map; n=317 travellers	Traced walking route distance to/from PT
Morency et al. (2011) Montreal, Canada	Bus, metro, train	Montreal OD survey; n=31950 trips	Shortest network distance to/from PT and calculating amount of steps

Study	Public transport mode	Major data source	Physical activity
O'Sullivan & Morrall (1996) Calgary, Canada	LRT	Survey at 23 stations, with information about origins/destinations; n=2294 travellers (18-65 y/o)	Distance of likely walking route to/from PT
Patterson et al. (2018) UK	Bus, LRT, train	National Travel Survey; n=3638 trips	Self-reported time to/from PT
Petersen (1968) Washington D.C., USA	Bus	Survey of bus riders with information about origins/destinations; n=2448	Distance of likely walking route from home to PT
Ratanawaraha et al. (2015) Bangkok, Thailand	LRT	Survey aboard trains from 34 stations; n=1020 travellers	Self-reported distance to/from PT
Rodriguez-Gonzalez & Aguero-Valverde (2017) San José, Costa Rica	Bus	Survey at 10 stops, with map	Traced walking route distance to/from PT
Sarker et al. (2019) Munich, Germany	Bus, LRT, metro, train	Survey at 10 stations, with address; n=500 travellers	Shortest network distance to/from PT
Seneviratne (1985) Calgary, Canada	Bus, LRT	Surveys in CBD; n=886 travellers	Traced walking route distance to PT
Sun et al. (2016) Beijing, China	Metro	Walking together with travellers; n=495 adults (18-65 y/o)	Measured time from PT
Townsend & Zacharias (2010) Bangkok, Thailand	LRT	Following people from 6 stations; n=1489 travellers	Measured distance from PT

Study	Public transport mode	Major data source	Physical activity
Vandebona & Tsukaguchi (2013) Japan	Bus, train	Postal survey in 15 cities; n=3560 individuals	Time to/from PT
Voss et al. (2015) Vancouver, Canada	General	Survey with accelerometer and GPS; n=42 high-school students (12-14 y/o)	Measured time to/from PT
Wang & Cao (2017) Minneapolis-St Paul, USA	Bus, LRT	On-board survey with information on destinations and used stations; n=7077 travellers	Shortest network distance from PT
Wasfi et al. (2013) Montreal, Canada	Bus, metro, train	Montreal OD Survey; n=6913 trips (18+, to school/work)	Shortest network distance to/from nearest PT stop on used route
Xi et al. (2016) Toronto, Canada	Metro	Transportation Tomorrow Survey Toronto; n=21470 trips	Straight-line distance to PT
Yu & Lin (2016) USA	General	National Household Travel Survey; n=18180 trips	Self-reported time to/from PT
Zacharias & Zhao (2018) Beijing/Tianjin/Shenzhen, China	Metro	Following random passengers in 43 walking environments with GPS; n=2409 passengers	Traced walking route distance from PT
Zhao & Deng (2013) Nanjing, China	Metro	Survey at 16 stations, with map; n=1544 peak-hour travellers	Traced walking route distance to/from PT

Study	Public transport mode	Major data source	Physical activity
Zuo et al. (2018) Cincinnati, USA	General PT	GPS-based household travel survey; n=1330 trips	Tracked walking route to/from PT

2.3.2 Measuring Public Transport-Related Walking

The methods used are important in comparing the different studies, as they largely determine the quality of the results. Some methods allow more factors influencing PT-related walking to be taken into account, while others might give a limited, but perhaps more accurate, picture of the walking characteristics. The different studies are discussed according to the main method that was used to assess the amount of walking in PT journeys. Firstly, studies that use subjective data as a major data source are discussed, meaning that the data regarding PT-related walk distances were self-reported by participants. The second section deals with studies using more objective methods to measure PT-related walk distances.

2.3.2.1 Studies using subjective data

Examining data from national/regional surveys

A group of studies use data coming from national travel surveys or other regional/local surveys by governmental bodies or PT operators. In such surveys, the focus is typically on travel time rather than distance, because this is easier to estimate for respondents. People usually need to register all their trips in a travel diary for a certain period of time, often including the origins and destinations, the (main) mode used, the start and end time, and possibly other characteristics. Table 2-2 presents the results of such studies, in which there appears to be some variance across countries and according to the type of PT.

Table 2-2 Overview of main results of studies considering walking distances to/from public transport, using national travel surveys[3]

Study	**Sample**	**Result**	
		Mean	**Median**
Besser & Dannenberg (2005) USA, n=3312 Bus, train	Adults walking to/from PT	24.3 min/day	19.0 min/day, 4.0 min/trip
Chia et al. (2016) Australia, n=679 Bus	Bus users, 18+	6.62 min	
Durand et al. (2016) USA, n=400 Bus, train (State-wide survey)	Children 5-17 y/o using PT		21 min/day
Evans & Addison (2009) UK, n=5749 Train	Surface rail journeys	1077m (access+egress, within London), 872m (trip to/from London), 795m (not in London)	
Freeland et al. (2013) USA, n=4195 Bus, train	Adults walking to/from PT		21 min/day
Krygsman et al. (2004) Netherlands, n=1700 Bus, tram, metro, train	PT users 12+ y/o	5.9 min (bus), 9 min (train)	
Patterson et al. (2018) UK, n=3638 Bus, LRT, train	Passengers walking to/from PT	28.1 min/day (train), 16.0 min/day (bus)	
Yu & Lin (2016) USA, n=18180 General PT	Adults walking to/from PT	7.6 min (home) 7.87 min (activity)	

[3] Under the assumption that people walk at 5.0 km/h, 1 minute of walking equals 83.3m

The reliability of these walking times reported is however doubtful. In the USA's National Household Travel Survey, participants record their trips for 24 hours in a relatively limited travel diary, but additional questions are asked in a follow-up telephone interview, including questions about the access and egress modes for PT trips and the respective travel times (U.S. Department of Transportation, 2004). In the English survey, participants are requested to record their trips for a period of seven days. They have to report all trip stages, which are the trip parts completed by different modes or leading to intermediate destinations (e.g. access and egress walks). However, walks under 1 mile (1.6 km) are only registered on the first day (seventh day in earlier editions), to reduce respondent burden (NatCen Social Research, 2017), which implies that many short walks to/from PT are not reported. There can also be confusion about, for instance, how walks with intermediate destinations should be reported.

The usage of self-reported data can also lead to underreporting, as people can forget to include certain trips, particularly short walk trips. Sometimes only half of actual transport and activity gets reported (Ong, 2009). Self-reported duration might also be subject to experiential influences and people have a tendency to round times at 5 minute intervals (e.g., Chia, Lee and Kamruzzaman, 2016), even though every minute of difference has a relatively large impact with regard to short walking stages.

Besides large-scale national surveys, several studies used secondary data from other mobility surveys. As these studies are carried out in a smaller spatial area, they can include more detailed data about the trips, sometimes enabling a finer analysis. These studies typically contain origin and destination data and construct potential walking routes by calculating the shortest path to the used stop or station (Alshalalfah and Shalaby, 2007; Morency, Trépanier and Demers, 2011; Daniels and Mulley, 2013; García-Palomares, Gutiérrez and Cardozo, 2013; Wang and Cao, 2017). In two studies (Wasfi, Ross and El-Geneidy, 2013; El-Geneidy *et al.*, 2014), only the public transport route used was known, so the walking route to the nearest station or stop on that service was assumed to be used. Table 2-3 presents an overview of some results from these studies, in which distances clearly differ per mode and often exceed the conventionally assumed limits of 400/800m. This might, in part, depend on policy guidelines used by transport authorities with regard to acceptable walk distances to public transport stops. In Canada, for instance, these guidelines were found to range between 300 to 900m for light rail transport. Some authorities used different guidelines per mode, whereas others had a general guideline for all surface transport (O'Sullivan and Morrall, 1996).

Table 2-3 Overview of main results of studies considering walking distances to/from public transport, using secondary data sources other than national travel surveys

Study	**Result**					
	Mode	**Average**	**Percentiles**			
			25%	**50%**	**75%**	**85%**
Alshalalfah & Shalaby (2007) Toronto, Canada n=15830	Bus Metro			+100m		
Daniels & Mulley (2013) Sydney, Australian n=1906 trips	Bus Train	461m 805m	162m 539m	364m 749m	655m 1018m	
El-Geneidy et al. (2014) Montreal, Canada n=16014	Bus (city centre) Metro Train	276m 565m 818m		214m 527m 785m	371m 731m 1103m	484m 873m 1259m
Garcia-Palomares et al. (2013) Madrid, Spain n=17000 trips	Metro	420m		375m		
Ivan et al. (2019) Olomouc and Ostrava, Czech Republic, n=1041	Bus, train - Ostrava - Olomouc	 568m 438m	 290m 237m	 488m 356m	 738m 543m	
Wang & Cao (2017) Minneapolis-St. Paul, USA, n=7077 trips	Bus LRT	464m 657m				815m 1092m
Wasfi et al. (2013) Montreal, Canada, n=6913	Bus Metro Train	12-40 min both ways 20-35 min 35-50 min				
Xi et al. (2016) Toronto, Canadan=21470 trips	Metro (Pedestrian catchment)	707m				

Custom surveys at stations

Another group of studies conducted custom surveys at stations, which frequently included maps on which the participants indicated their (approximate) origin and/or destination (Petersen, 1968; O'Sullivan and Morrall, 1996; Ker and Ginn, 2003; Kim and Nam, 2013; He *et al.*, 2018).

In addition to origins and destinations, several researchers asked travellers to trace their walking route (Lam and Morrall, 1982; Seneviratne, 1985; Agrawal, Schlossberg and Irvin, 2008; Kim, Lee and Chun, 2010; Jiang, Zegras and Mehndiratta, 2012; Zhao and Deng, 2013; Li and Deng, 2015). These studies could therefore provide a better idea of the real walking routes, since they did not reconstruct walking routes based on certain assumptions. For example, although PT-related walk distance tends to be minimised (Agrawal, Schlossberg and Irvin, 2008), the often-assumed shortest path in these reconstructions can underestimate the real walked distance (Hess, 2012), as various factors can lengthen walking routes, such as the (un)attractiveness of certain paths (Kim, 2015), accompaniment, or the need to visit other destinations en-route. To get insights into the chosen routes, Agrawal et al. (2008) asked respondents to indicate avoided places besides tracing the routes walked. Yet, these tracing studies assume that participants are all able (and willing) to trace their real routes correctly on a map. This is not an easy task for everyone, as implied by O'Sullivan and Morrall (1996) in which route tracing was left out due to difficulties experienced by the participants.

Johar et al. (2015), Ratanawaraha et al. (2015) and Vandebona & Tsukaguchi (2013) only used self-reported distances, which can be rather unreliable. Day et al. (2014) measured distance in street blocks, which is more reliable as a self-reported measure, but only useful in grid-structured areas and inaccurate where block sizes vary. Table 2-4 lists the findings of the most accurate studies using map tracing. Similar to the previously discussed methodology, a highly variable distribution of distances emerges.

Table 2-4 Overview of main results of studies considering walking distance to and from public transport using map tracing

Study	**Result**					
	Mode	**Average**	**Percentiles**			
			25%	**50%**	**75%**	**85%**
Agrawal et al. (2008) San Francisco and Portland, USA n=328	LRT	837m	435m	756m	1094m	
Chaix et al. (2014) Paris, France n=234	Bus, tram, metro, LRT, train	1.6-2.9 minutes of physical activity more per 10 minutes of trip time than car users.				
Jiang et al. (2012) Jinan, China n=1233	BRT	549m (typical) 586m (transfer) 1392m (terminal)		435m 458m 1311m		
Kim et al. (2010) Busan, South-Korea n=600	Subway Bus	564m (CBD) 499m (sub-CBD) 447m (regional) 430m (CBD) 372m (sub-CBD) 339m (regional)				
Lam & Morrall (1982) Calgary, Canada	Bus	327m 170-373m, depending on service and area		292m	450m	
Li & Deng (2015) Shanghai, China n=317	LRT		+/- 500m	+/- 675m		980m
Rodriguez-Gonzalez & Aguero-Valverde (2017) San José, Costa Rica, n=305	Bus	310m	150m	250m	400m	
Seneviratne (1985) Calgary, Canada n=886	Bus LRT	250m 287m		215m 265m		

Voss et al. (2015) Vancouver, Canada n=42	General	9 minutes of physical activity per school trip				
Zhao & Deng (2013) Nanjing, China n=1544	Metro	882m (typical) 682m (transfer) 1291m (terminal)		821m 624m 1094m		

2.3.2.2 Studies using objective data

Surveys including objective tracking

Some studies included objective measurement tools such as GPS-trackers combined with accelerometers (Chaix *et al.*, 2014; Voss *et al.*, 2015; Zuo, Wei and Rohne, 2018). This type of method can accurately track travel behaviour in a detailed way, assuming that the participation does not affect behaviour. Except for Zuo et al. (2018), these studies were conducted in the field of public health and were therefore more focussed on the health benefits of PT usage, rather than PT-related walk distances and influencing factors related to the transport system and built environment.

Observational studies

In three studies, researchers followed travellers on their trip from PT towards their destination (Townsend and Zacharias, 2010; Kim, 2015; Zacharias and Zhao, 2018). The travellers were unaware of their participation in the study, which perhaps gives the best representation of real walking behaviour, assuming that the participants did not notice the researchers who were following them. However, for both practical and ethical reasons, these studies could not reveal much detailed information about other factors, such as the participants, and only egress trips could be taken into account as researchers could only follow people from a station and not from homes.

Finally, in one study (Sun *et al.*, 2016), researchers walked together with participants from a metro station towards their destination while they recorded the route. Compared to the methodology of following people, travellers in this case were aware of their participation in a study, which potentially influenced their walking activity. However, the opportunities to ask questions and, for instance, gather perceptions about the built environment are beneficial.

2.3.3 Factors of influence

Various studies considered factors that possibly influence PT-related walk distances, which can be categorised as personal factors (relating to the traveller and his/her household), factors referring to characteristics of the PT service, environmental factors, and factors related to the journey. Although studies often identified the effects of several factors, not all studies used statistical tools to assess their significance. This section reviews the available evidence in the literature concerning the factors that influence the PT-related walk distance (or time), considered in at least two publications. Table 2-5 presents an overview of the relative effects reported in the publications reviewed. The signs in the table indicate whether the study found an insignificant effect (/), a positive effect (+), a negative effect (-), an n-shaped effect (n; meaning a concave curve, i.e. first increasing and then decreasing) or a u-shaped effect (u; meaning a convex curve, i.e. first decreasing and then increasing). Relatively strong effects in each study are indicated by a double sign.

Table 2-5 Overview of effects on PT-related walk distances per study ([+] positive, [-] negative, [n] n-shaped effect, [u] u-shaped effect, [/] insignificant; double signs indicate a relatively strong effect)

Study	Gender: Female	Age	Available vehicles	Driving licence	PT card	Household size	Income	Education	Employment	Ethnicity: white	PT frequency	PT type (rail > bus)	Density	Location: CBD	Purpose: work	Time: morning	Trip length	Transfers	Frequency of use
Distance based																			
Alshalalfa & Shalaby (2007)	-	/	+	+	-						++	++	-	--	/	/		-	
Daniels & Mulley (2013)	/	nn	/	/	--		+		++			++			++	-	+		
El-Geneidy et al. (2014)	-	-	+			+	+				+	++	-	-	+	-	+	-	
Garcia-Palomares et al. (2013)	-	n	+							+									
He et al. (2018)	/	nn					--								+				u
Ivan et al. (2019)	-	--	/			/		/	++					--					
Jiang et al. (2012)	/	/	/				--		/					-	/				/
Johar et al. (2015)	-	/					-								+				
Kim (2015)	/																		
Kim et al. (2010)	+	-	-				-		/					+					/
Kim & Nam (2013)	-	/	/				/		/					/	+				
Lam & Morrall (1982)											+			-					
Morency et al. (2011)	-	-										++		-	++				
O'Sullivan & Morrall (1996)	-													--					
Petersen (1968)							-												

Study	Gender: Female	Age	Available vehicles	Driving licence	PT card	Household size	Income	Education	Employment	Ethnicity: white	PT frequency	PT type (rail > bus)	Density	Location: CBD	Purpose: work	Time: morning	Trip length	Transfers	Frequency of use
Sarker et al. (2019)														--					
Townsend & Zacharias (2010)	/	/											/		--				
Wang & Cao (2017)				-								++	++	--	-		-		
Wasfi et al. (2013)	-	-					++				+	++	/			/			
Zacharias & Zhao (2017)													/						
Zhao & Deng (2013)	/	nn					/		/					-	/	+			
Zuo et al. (2018)			-				-							--					
Time based																			
Besser & Dannenberg (2005)	+	/	++				--	--		--		/	+						
Chaix et al. (2014)												++							
Chia et al. (2016)		-																	
Durand et al. (2016)	/	/	/	--		/	--		/	--		+							+
Freeland et al. (2013)	/	/	-				--	-	/	-									
Krygsman et al. (2004)	+	-	/			-			+			++	+	-			+	-	
Patterson et al. (2018)	-	n	+				-			+		++							
Sun et al. (2016)	/	/											+						
Yu & Lin (2016)	/		/				-	u		-			--		+				

2.3.3.1 Personal

Gender

The studies that found a gender effect mostly reported that women tend to walk shorter distances to and from PT than men. Feelings of a lack of safety, which are more prevalent among women, might play a role. There are, however, some studies in which women were found to walk for longer (Krygsman, Dijst and Arentze, 2004; Besser and Dannenberg, 2005), making the role of gender in walking to and from public transport less clear. Gender could be strongly related to cultural aspects. The share of women in the workforce (The World Economic Forum, 2016) and, related to this, responsibilities in the household, can vary significantly between countries, leading to different gender effects in travel behaviour. Other cultural norms regarding clothing and activities can affect travel patterns as well (Almahmood *et al.*, 2017). This suggests that the gender effect on PT-related walk distances can be explained to a large extent by factors such as differences in travel purpose and car availability, which vary through cultural norms.

Age

Studies that found a significant age effect typically discovered that people in the youngest (i.e. children, youth) and oldest age-categories tend to walk less and shorter distances than younger adults. This is a very logical pattern, which is likely related to factors such as the physical abilities of the person and differences in activity-travel schedules. Moreover, especially younger children are dependent on permission from their parents or guardians to walk and use PT. Although some studies found a negative relationship between age and walking distances (Morency, Trépanier and Demers, 2011; Wasfi, Ross and El-Geneidy, 2013; El-Geneidy *et al.*, 2014), this might be due to the analysis tools used, as most common statistical methods can detect linear effects only.

Available vehicles and the possession of a driving licence or public transport pass

People who have more private vehicles available generally walk less, but the walk distances are often found to be longer. This can be explained by the fact that in most studied areas, the people with more vehicles tend to live further from the PT services than the people who are more dependent on this form of transport, perhaps partly due to self-selection of home locations. Often, areas with higher car ownership levels have lower densities, implying that PT services are less financially viable, which leads to longer walking distances.

A similar effect can be expected for the possession of a driving licence, although it is perhaps a weaker indicator for the dependence on PT than the availability of private vehicles. Alshalalfah and Shalaby (2007) found that PT riders walk further if they have a driving licence, whilst Daniels and Mulley (2013) showed it was insignificant. Arguably, the possession of PT passes has a stronger and inverse influence. As pass-holders usually need to pay a monthly or annual fee, they are likely regular PT users, who can be expected to live closer to PT-systems (Alshalalfah and Shalaby, 2007; Daniels and Mulley, 2013), although free passes can increase PT use as well (e.g., Coronini-Cronberg *et al.*, 2012). The possession of a driving licence, in contrast, is for a long term and does not necessarily imply that one has regular access to a vehicle.

However, the particular study area and related housing situation influences this effect, as contrasting results were found by Jiang et al. (2012). They distinguished captives and choice riders, and found that captives walk longer distances to BRT systems. This is almost certainly due to the freedom of choice riders, who can choose another transport mode if they find the distance to PT too long, although Chia et al. (2016) did not find significant differences between captives and choice riders.

Household size and housing type

Two studies found a significant influence of household size. El-Geneidy et al. (2014) found PT-related walk distances to be on average about 7 metres per trip longer per additional person in the household. On the other hand, Krygsman et al. (2004) saw a decrease in walk time if there were young children in the household.

Similarly, five studies looked at the influence of the type of housing. Alshalalfah and Shalaby (2007) discovered that people living in apartments walk shorter distances to or from public transport than people living in houses. Two South-Korean studies (Kim, Lee and Chun, 2010; Kim and Nam, 2013), however, found the opposite effect. Additionally, Patterson et al. (2018) discovered that people living in rented houses walk less than house owners and Durand et al. (2016) saw an increase for people living in mobile homes compared to single-family attached homes. Generally, smaller households and smaller dwellings like apartments tend to be located in areas with higher densities and higher availability of PT services, leading to shorter walk distances, but the effect relies on the characteristics of the built environment of the study area.

Income

North-American and Australian studies found a positive relationship between income and PT-related walk distance (Daniels and Mulley, 2013; Wasfi, Ross and El-Geneidy, 2013; El-Geneidy *et al.*, 2014), whilst Asian and European studies found a negative one (Kim, Lee and Chun, 2010; Jiang, Zegras and Mehndiratta, 2012; Johar *et al.*, 2015; He *et al.*, 2018; Patterson *et al.*, 2018). The North-American studies that focus on walk time instead of distance also found a negative effect (Besser and Dannenberg, 2005; Freeland *et al.*, 2013; Durand, Gabriel, *et al.*, 2016; Yu and Lin, 2016).

The variability in results indicates that the effect of income depends on the study context. Income can be associated with the housing situation, as well as vehicle availability and the type of job or lifestyle and related travel-patterns. Moreover, cultural aspects are likely to play an important role. In some cultures, PT (particularly bus) has a very low status, implying that people with a higher income do not use it much. In other cultures, PT is also used by travellers from higher income-classes (e.g., Buehler and Pucher, 2012).

Employment and education

People who work fulltime (Daniels and Mulley, 2013), or households with dual income (Krygsman, Dijst and Arentze, 2004) were found to walk more. Patterson et al. (2018) discovered that people with managerial occupations walked more than those with intermediate or routine occupations. Finally, Wasfi et al. (2013) found that students walk further than others. An associated indicator is the level of education, which was studied in three North-American publications, all finding a negative effect on PT-related walk time (Besser and Dannenberg, 2005; Freeland *et al.*, 2013; Yu and Lin, 2016). The effect of employment or education on PT-related walking appears to be weak and is expected to be related to income and household type.

Ethnicity

In North-American studies, white people were found to walk shorter distances to or from PT than other ethnicities (Besser and Dannenberg, 2005; Freeland *et al.*, 2013; Durand, Gabriel, *et al.*, 2016; Yu and Lin, 2016), whilst European studies found white people to walk further (García-Palomares, Gutiérrez and Cardozo, 2013; Patterson *et al.*, 2018). This effect is likely partially related to income, and, similarly, dependent on culture and status of PT services.

2.3.3.2 Public transport characteristics

Type

The type of PT appears to be an important factor for the access and egress walking distances. Also in the traditional guidelines walking distance to rail transport is assumed to be double the walking distance to buses (800m and 400m). People tend to walk longer distances to trains, then metro or LRT, and the shortest to buses. It could be stated that the longer the range of the mode, the longer the walking distances to and from that mode, although this can be biased by the total trip length (Krygsman, Dijst and Arentze, 2004). The effect can partly be attributed to the perceived status of the mode, as there tends to be a preference for rail-borne transport (Anderson, Nielsen and Ingvardsson, 2016). Moreover, the density of access points tends to be lower when the range of the mode increases.

Frequency

Four Canadian studies revealed a positive influence of bus frequency on the walk distances to or from PT (Lam and Morrall, 1982; Alshalalfah and Shalaby, 2007; Wasfi, Ross and El-Geneidy, 2013; El-Geneidy *et al.*, 2014). Because a higher service frequency is associated with a higher level of travel comfort (e.g. less waiting time or planning effort), these results confirm the expectations that PT riders are willing to walk more if the offered service is better. They are consistent with the findings of stated preference surveys by Rose et al. (2013) and Mulley et al. (2018). The evidence should be strengthened by research in other contexts.

Station function and route spacing

Three studies in China and Canada (O'Sullivan and Morrall, 1996; Jiang, Zegras and Mehndiratta, 2012; Zhao and Deng, 2013) found that people walk longer distances to terminal stations of a public transport line than other stations, which is reasonable due to the lack of further boarding possibilities.

Only Alshalalfah and Shalaby (2007) directly studied route spacing as a factor influencing the PT-related walk distance. They compared three sets of parallel routes, spaced differently from each other. Their results pointed in the logical direction that the walk distance decreases if the density of PT routes increases. The association was not distinct, though, which could relate to differences in service quality of the studied routes. Wang and Cao (2017) found a negative effect of the number of PT stops on the walk distances.

2.3.3.3 Environment

Density

Density can impact PT-related walk distances through various mechanisms. If the density is higher around the PT stop, on average the origins or destinations are closer, and the density of PT services will often be higher as well, which results in shorter distances people need to walk (Tao, Wang and Cao, 2020). However, density can also relate to better walkability characteristics, which can attract more walkers, either through increasing the share of walking to access/egress transport, or by expanding the catchment area around the stop. This can lengthen the distances people choose to walk. A lower density of the built environment can also lead to lower expectations of PT services, and higher acceptability of longer walking distances (Vandebona and Tsukaguchi, 2013).

Station location

In most studies, people walk shorter distances to and from PT stops located closer to the central business district (CBD). This is likely related heavily to a higher density of stops and stations, which reasonably leads to shorter distances that people need to walk. Kim et al. (2010) however found the opposite effect, which might relate to the finding that land use variety can significantly lengthen the distance people choose to walk (Zacharias and Zhao, 2018).

Walkability

As described earlier, Jiang et al. (2012) found that people walk further to stations on a more walkable corridor. El-Geneidy et al. (2014) studied the effect of street connectivity, and found a positive relationship, whilst for Wasfi et al. (2013) this was insignificant. A positive relationship would be in line with other walkability research, in which street connectivity often plays a role. Higher street connectivity is associated with better walkability, because it reduces the average detour compared to straight-line distance. Fewer detours also arguably lead to shorter walk distances, as shown by Kim et al. (2010), Wang and Cao (2017) and Zacharias and Zhao (2018). Also a visually higher connectivity can lead to shorter walks (Sun *et al.*, 2016). Park et al. (2015) studied specifically the effect of walkability on the PT-related walk distances. Improving walkability at the micro-level for pedestrian corridors leading to a station was found to increase the distances people are willing to walk. This suggests that an increased walkability can shorten the distances people need to walk, but in some cases can also lengthen the distances people choose to walk.

Safety

The effect of (the perceptions of) safety can be related to traffic or crime. The influence of crime characteristics on the walk distances to and from PT is not well researched. There is evidence that crime levels have a negative impact on the probability of walking to PT or using PT at all (Kim, Ulfarsson and Hennessy, 2007; Tilahun and Li, 2015). Additionally, the researchers who considered the effect of different station types (Jiang, Zegras and Mehndiratta, 2012; Zhao and Deng, 2013) associate this partly to differences in crime perceptions. Agrawal et al. (2008) found that the route choice to PT is influenced by safety issues, but rather related to traffic than crime. More research is required to be more conclusive about safety effects, especially with regard to traffic safety.

Weather

O'Sullivan and Morrall (1996) reported that weather influenced the choice of some respondents to use PT or walk directly to the destination. It is however rarely explicitly addressed in the research around PT-related walking, although in Canada, Lam and Morrall (1982) found longer walk distances in winter time than in summer. This was rather surprising, but, according to the authors, might be related to a lower availability of shortcuts due to snow and ice.

2.3.3.4 Journey

Purpose

Generally, people undertake longer walk trips to or from PT for journeys to work than for other purposes. Some studies however found that some other trip purposes led to longer distances (Krygsman, Dijst and Arentze, 2004; Townsend and Zacharias, 2010; Morency, Trépanier and Demers, 2011; Sun *et al.*, 2016; Wang and Cao, 2017).

Time of day

Four studies considered the time of day as an explanatory variable. Daniels and Mulley (2013) and El-Geneidy et al. (2014) found that walk distances to or from PT are longer in the evening, whereas Zhao and Deng (2013) found longer distances in the morning. The evidence for an effect of the time of day on walk distances is not yet strong. The effect is presumably strongly related to daylight and travel purpose with, for instance, a high share of work-related trips in the typical peak hours.

Trip length

Trip length effects were studied in six publications. Although Wang and Cao (2017) found a negative elasticity of -0.06[4], it was generally discovered that longer PT journeys lead to longer

[4] Meaning that a 1% increase in trip length was related to a 0.06% decrease in walk distance

walking distances as well (Daniels and Mulley, 2013; El-Geneidy *et al.*, 2014). The ratio between access/egress distance and total distance, however, reduces slightly (Krygsman, Dijst and Arentze, 2004).

Transfers

The number of transfers in a PT trip was negatively related with walk distances or times (Krygsman, Dijst and Arentze, 2004; Alshalalfah and Shalaby, 2007; El-Geneidy *et al.*, 2014), except for metro-journeys (Alshalalfah and Shalaby, 2007). This is arguably related to the undesirability and perceived inconvenience of transfers (Hine and Scott, 2000), which could imply that people are also less willing to make an effort to walk to and from the PT-system. Because metro systems typically offer high quality service with high frequencies, the transfers are much less onerous, which makes their influence on walk distances to or from PT insignificant.

Frequency of use

Of the three studies examining the influence of usage frequency, only He et al. (2018) found that people who rarely or very often travel walk further than people who travel regularly. Durand et al. (2016) also found that children or adolescents have longer daily PT-related walk times when adults in the household use PT as well.

Type of walking stage

Many studies do not distinguish between the home and activity side, or access and egress trips. If they do so, almost all studies focus on the home side and/or the access trip. Exceptions are Kim (2015), Townsend and Zacharias (2010) and Wang and Cao (2017), who focus on egress journeys only. Whether a trip stage is an access trip or an egress trip is not expected to have any influence on the walking distance, although trips between two points can be asymmetrical

(Bailenson, Shum and Uttal, 2000). More important is the difference between trip stages at the home side or the activity side of a trip. Differences between these walk stages can occur, mainly because the availability of modes is usually different at the activity-side (Krygsman, Dijst and Arentze, 2004).

There is little knowledge available about how home and activity side differ, and how particular activity characteristics might affect this. Both Krygsman et al. (2004) and Yu and Lin (2016) considered a journey from home to work, and found activity side walking trips to be slightly longer than at the home side.

2.4 Summary

The first part of the literature review focused on processes involved in mode choice generally, and which factors play a role in the choice for public transport and walking. The second part considered the literature on walk distances to and from public transport specifically and critically established the evidence.

Mode choice has been shown to be a complex process, which is only partly based on instrumental values such as the travel time or distance. Attitudes and perceptions can play an important role, as well as a multitude of additional aspects, such as safety, weather and characteristics related to the trip itself. Moreover, the choice for a mode is in many cases not a deliberate process, but rather habitual behaviour, especially for routine travel.

The literature on walk distances to and from public transport was reviewed in more detail, using a systematic approach. The conventionally assumed 400m or 800m thresholds for walking for bus and rail transport respectively tend to be inaccurate in many cases. How far people walk to and from public transport is dependent very much on the particular location and circumstances, ranging from an average distance of 170m to buses in Calgary, Canada (Lam and Morrall, 1982) to an average of 1392m to terminal BRT stations in Jinan, China (Jiang, Zegras and Mehndiratta, 2012).

The relevant studies identified have adopted a range of methods to study PT-related walking. These include (1) the examination of data from national or regional travel surveys, (2) conducting questionnaire surveys at stations, sometimes including map-tracing, (3) following or walking with passengers, and (4) tracking passengers using GPS-devices and accelerometers.

The first method in particular can be questioned regarding its accuracy. Short walk stages that function as access or egress trips related to another main mode are often underreported in national surveys. Also studies using the second method frequently assume that travellers take the shortest path. Studies that attempt to accurately report walking distances are those using methodologies in which routes are traced on a map, in which travellers are followed, GPS/accelerometer tools are used, or in which researchers walk together with the travellers. Hence, there is only a very limited amount of research on real PT-related walk distances.

As results differ greatly across study locations (e.g., Agrawal, Schlossberg and Irvin, 2008; Daniels and Mulley, 2013; Wang and Cao, 2017), factors that potentially influence the walking to and from PT were considered. In the existing literature, a range of factors have been found to play a role, although the strength of the evidence for each factor differs. The results were sometimes contrasting, showing the need for more research in different urban settings to explore the influence of certain factors in a more detailed way. One of the restrictions is that many factors are related to each other, making it more difficult to study effects separately. Moreover, the current research has a very limited ability to distinguish demand and supply effects on walking distances; the research has been able to find how much people currently walk to and from PT, but not which other options were available to them. The effects of changes in PT services could not be established either, as well as the characteristics of those that did not use the current PT services.

A limitation of the review is that a large amount of relevant research on this topic is possibly available within public transport operators or consultants, but this body of research is hard to access. The review was also limited to publications in the English language, which can restrict the inclusion of research from some areas of the world where other languages are used.

An attempt has been made to design a preliminary conceptual framework of influences on PT-related walk distances, based on the underlying key factors revealed in the discussion of the established evidence, as shown in Figure 2-6. The factors are separated into supply (defining the need to walk) and demand (defining the willingness to walk), and factors that are directly modifiable by urban or transport planning authorities are distinguished from non-modifiable (or less easily modifiable) factors.

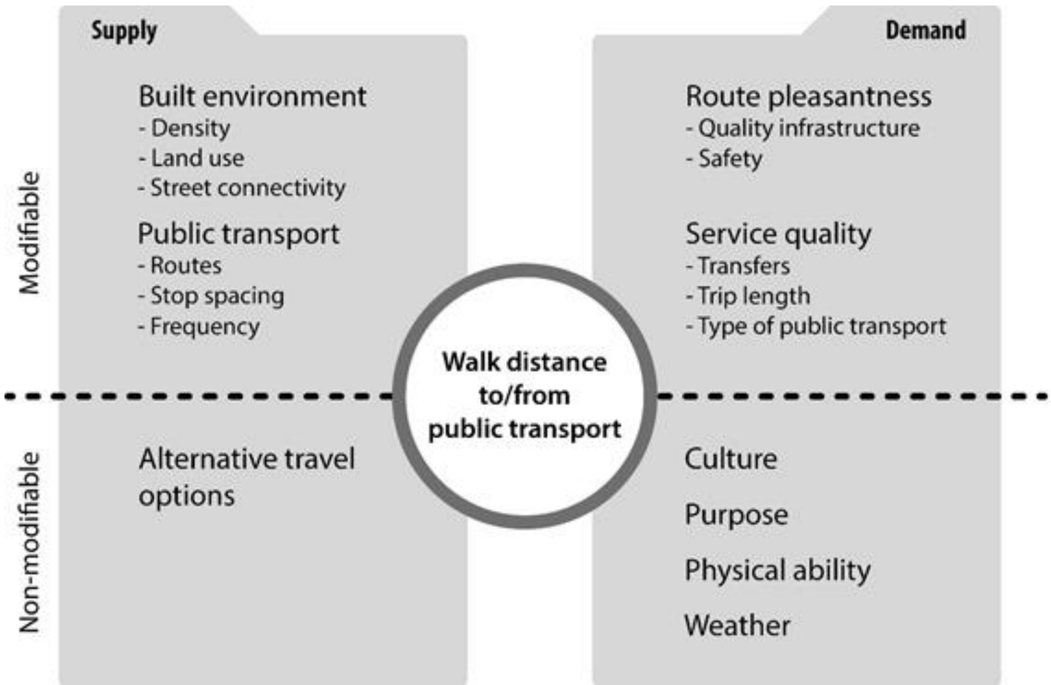


Figure 2-6 Conceptual framework to explain PT-related walk distances

Whereas the non-modifiable factors define the context in which walking to and from PT takes place, the modifiable influences can be used by urban or transport planning authorities to influence the distances people walk to and from PT. The alternative travel options available determine whether someone is PT-captive or not, which is considered as a personal situation in this framework and therefore non-modifiable. This can in practice be influenced to some extent, for example through car restrictive policies.

The factors that are found to influence PT-related walking do not fundamentally differ from factors that have been found to affect urban walking in general, particularly regarding built environment characteristics (e.g., Saelens and Handy, 2008; Van Holle *et al.*, 2012). Specific to walking to and from PT are the attracting characteristics of PT that affect how far someone is willing to walk, along with the PT services offered and the transport options available to people that define the need for walking a certain distance to/from PT.

3. METHODS

3.1 Introduction

This chapter outlines the research strategy used to achieve the aim and objectives depicted in the first chapter. It explains which methods were used, how they are applied and how they link together. Every part of the methodological approach is designed to target the aim and objectives of the research. Section 3.2 illustrates the overall research design, followed by Section 3.3 which gives more detailed descriptions of the main research tools used in the project. Section 0 describes the study areas and how they were selected, after which the study sample is described in Section 3.5. Section 3.6 outlines how measures for walkability and public transport provision were created using external data sources. The detailed analytical approach for the data obtained through the methods described in Section 3.3 are provided in Section 3.7. Finally, the chapter is summarised in Section 3.8.

3.2 Research design

In order to meet the objectives stated in Section 1.2, a mixed methods approach was used, with two main components. To study the demand side of walk distances (objectives 1-3), subjective data were gathered by doing a questionnaire survey to obtain data on the barriers different groups of people might perceive to walking and public transport. As is explained in further detail in the next section, the questionnaire addresses barriers in two ways. Participants were asked to rate a set of potential predefined barriers and to write down three free associations with several modes. These free associations formed an open approach, so that barriers as well as enablers could be identified. Objectives 4 and 5 require more detailed data on the actual travel behaviour of people and the paths they have followed through the built environment and the public transport systems. Therefore, a smartphone location tracking survey was undertaken, since the use of these contemporary technologies was expected to give detailed insights in a way that has a relatively low burden on participants.

Although travel behaviour is more related to the conditions of an individual's full activity space than just the residential environment (van Heeswijck *et al.*, 2015; Howell *et al.*, 2017), someone's home is a central location in his or her activity-travel pattern (Schönfelder and Axhausen, 2003; Ellegård and Vilhelmson, 2004). Therefore, participants for this study were sought in the residences of a variety of urban study areas, with differences in built environment and public transport provision. It is impossible to address the full activity space of a random sample, as there is no prior data available about the individuals' exact activities. Hence, a questionnaire survey was physically distributed in these areas, as in this way participants living in a specific area can be addressed, which is harder when using, for instance, online survey distribution.

Besides obtaining relevant research data, the questionnaire was used to gather participants for the smartphone tracking study. By asking the questionnaire respondents whether they are interested in the follow-up study, the list of interested potential participants for the tracking study can also be linked to their questionnaire responses, which creates a richer dataset overall.

A visualisation of the overall structure of the research project is presented in Figure 3-1.

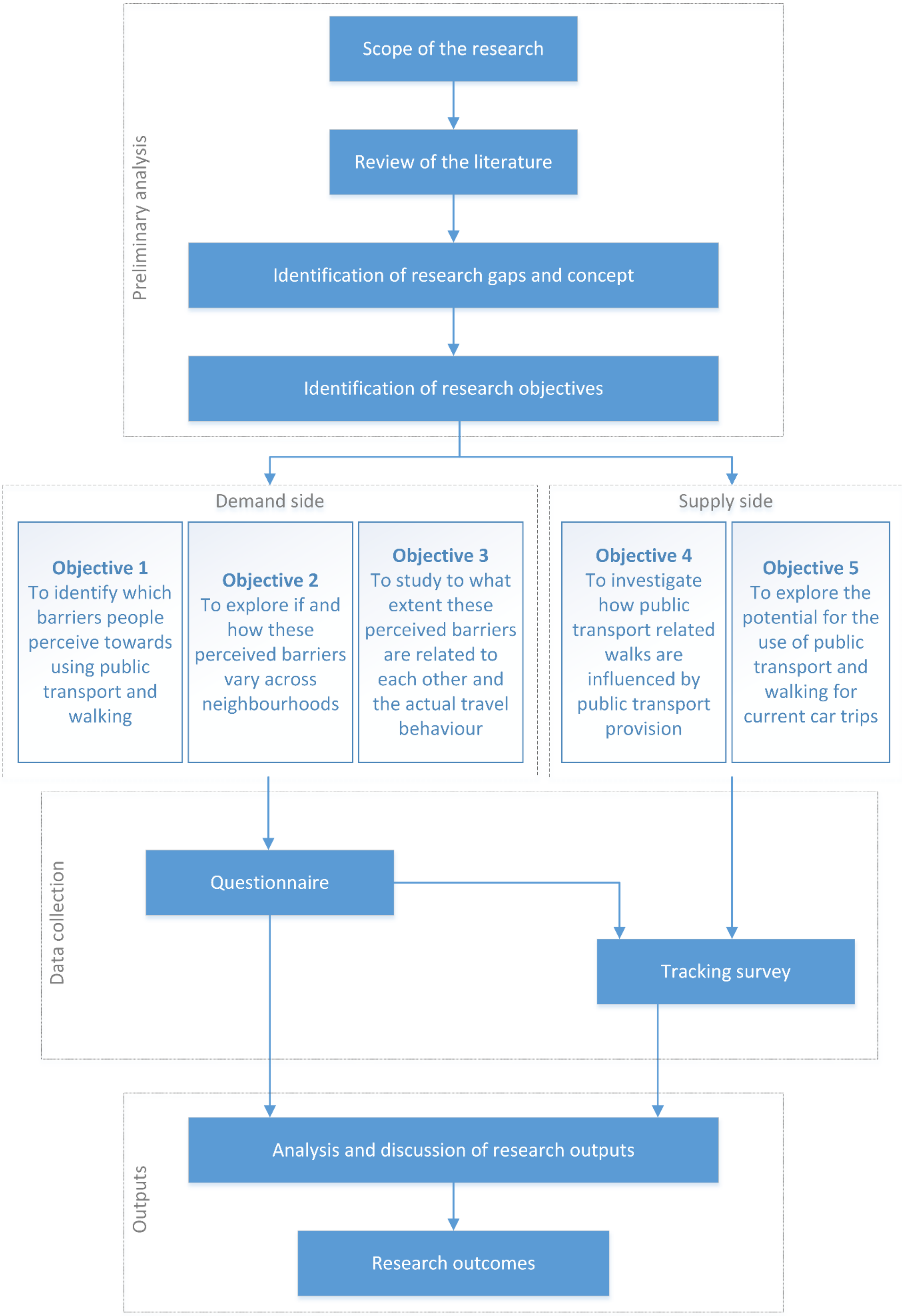


Figure 3-1 Visualisation of project structure

3.3 Research methods

3.3.1 Questionnaire

3.3.1.1 Contents and design

The goals of the questionnaire are primarily related to Objectives 1, 2 and 3. It needed to explore the perceived barriers to walking and public transport and how these relate to each other and to actual behaviour. An additional goal of the questionnaire was to recruit participants for the tracking study. One of the most prevalent issues in questionnaire design is the trade-off between level of detail or amount of data to obtain and the respondent burden. To enhance the participation rate, the questionnaire should be kept as short as possible, and easy to complete (Edwards *et al.*, 2009). To facilitate completion and analysis, open questions were kept to a minimum. The questionnaire is designed to be clear, with a limited amount of questions per page and a reasonable font size. The final questionnaire pack is presented in Appendix A.

General information

The questionnaire starts with several socio-demographic questions. These involve some basic characteristics of the respondent, and make it possible to get a general indication of the sample's background and how representative the sample is. Gender and age are the most commonly asked characteristics. Furthermore, the composition of the household and the characteristics of the job/occupation were asked, as these are major factors that can affect a person's activity-travel pattern. To make the questions more concrete for the respondent, the questions refer to the working conditions in the preceding month. Finally, also income category and ethnic designation are asked. Income can significantly affect travel behaviour, for instance through the affordability of different travel options. Ethnic designation is of interest as Birmingham has a population with a large variety of nationalities and cultures, which might affect travel attitudes as well.

Perceived barriers to public transport and walking

Socio-demographics can help describe differences in travel patterns among people, but they do not reveal the underlying reasons for travel behaviour. The existing research on motivators and barriers to walking or public transport have used in-depth interviews (e.g., Beirão and Sarsfield Cabral, 2007), focus groups (e.g., dell'Olio, Ibeas and Cecin, 2011), or questionnaires, in which typically a range of attributes had to be rated on Likert-type scales (Gatersleben and Uzzell, 2007; Bordagaray *et al.*, 2014; de Oña *et al.*, 2015; Abenoza, Ettema and Susilo, 2018; Deb and Ali Ahmed, 2018; Eboli, Forciniti and Mazzulla, 2018). Understanding the true motivations or barriers for a specific behaviour is a difficult task, as respondents are not necessarily aware of their actual motivations or barriers and, in case they are aware, are not always willing to disclose these to the researcher (Tadajewski, 2006). Therefore, two approaches to studying the barriers were used in this research: (1) a standardised approach using Likert type scales, and (2) an open approach using free associations.

This latter method, the free associations task, explores associations with a topic, which is a way of more indirectly investigating how people think about a certain topic (Oppenheim, 1992). The idea of exploring associations to reveal more unconscious mental content was first introduced by Galton (1879). This approach was later picked up and developed further by market researchers to understand customers' motivations (Tadajewski, 2006) and by psychoanalysts to understand psychological problems of patients (Joffe and Elsey, 2014). Free association-based approaches acknowledge that thoughts and behaviours arise via non-conscious processes and try to address the underlying aspects. Several methods have been developed that use free associations, such as affective group analysis, affective image analysis, core-periphery approach and the grid elaboration method (Joffe and Elsey, 2014). In affective group analysis, people of different groups give associations to a stimulus for a minute, after which the groups can be compared. Affective image analysis collects large samples of associations with a topic through a survey. The core-periphery approach explores the core of a representation of an unfamiliar topic by asking participants for associations and elaborating on them. With the grid elaboration method, respondents are asked to write or draw any image, word, or feeling with a topic in a grid of four boxes, after which they elaborate on them in an interview. Of these methods, affective image analysis is appropriate for large survey mailings (Joffe and Elsey, 2014) and therefore used in this study.

Affective image analysis has been applied earlier in risk perception research (Benthin *et al.*, 1995; Leiserowitz, 2005; Connor and Siegrist, 2011; Dohle, Keller and Siegrist, 2012). In these studies, participants need to give usually about three or four associations to a topic, such as 'climate change', 'drinking beer', or 'biotechnology'. Hence, they evaluate how positive or negative each association is to them, which is their affective rating. Thus, the technique produces two valuable sets of outcomes: the contents of the association, which can be analysed to explore what themes people find important regarding the topic; and the affective rating, which gives an indication of the people's affect evoked by the topic. In contrast to the pre-defined statements for potential barriers, this technique identifies what themes people find important themselves, which could be of importance regarding their decisions and behaviour.

To apply this technique in the context of transport mode choice, the questionnaire asked people about their first three associations with *walking*, *cycling*, *car driving*, *using buses*, and *using trains*, including the respective affective ratings. The content of the associations can then indicate which positive or negative aspects of a mode are important to the respondent, giving insights into how the different modes are perceived by the respondent. Participants rated the positivity on a 7-point scale from very negative to very positive, in line with Connor and Siegrist (2011). Some studies have used scales of different lengths, but a 7-point scale was deemed to offer sufficient nuance without increasing the respondent burden too much. A shorter scale, for instance with 5 points, can make it more difficult for respondents to differ between the items and choose the right response (Finstad, 2010).

The other method to explore barriers follows a standardised approach using predefined potential barriers, for which it can be rated on a 7-point scale to what extent they apply to the participant. Unlike the open approach, this standardised approach allows for easier comparisons between, for instance, the four urban areas and assessment of correlations between different barriers. The sets of barriers represent a variety of potential barriers to walking, bus use and train use that appeared in the literature and were deemed to be relevant. These barriers were presented later in the questionnaire than the free association section, to reduce the chances that these pre-defined barriers affect the free associations of people.

Other travel-related information

It is uncertain to what extent the free associations catch the respondents' complete perceptions of the different travel modes, because the free associations are more closely related to the affective component and likely to be influenced by recent experiences with a certain mode, possibly differing from the general perceptions. Hence, two related questions were asked. Firstly, respondents were asked to rate what they think about using several transport modes in or around Birmingham, which gives an indication of their satisfaction. Furthermore, it was asked to what extent several modes are available to use for the respondent and how much the respondent likes using those modes. This latter question can give a more general insight into the attitudes, which might differ from the rating of the transport systems in Birmingham. Someone might, for instance, generally love driving cars, but find that using a car in Birmingham is not a favourable option due to bad traffic conditions in the city.

To get a view on the actual travel behaviour, particularly the use of travel modes, questions are asked about how often per week several common modes were used in the last month. These questions are important to determine whether the respondent uses public transportation regularly or not. If he or she does so, the questions about the availability of modes can give an indication regarding how dependent the person is on public transport, i.e. whether the person is a choice rider or a public transport captive. This is important regarding the potential for public transport use and the walking distance to/from public transport (Chia, Lee and Kamruzzaman, 2016). However, if the person does not use public transport and also states that public transport is not feasible for most of his/her trips, it is less clear whether the person is a car captive. It might be the case that he/she has never really considered public transport as an appropriate option. A person might also be captive to walking or cycling, or other modes he or she has access to, such as a scooter or motorbike. If a person uses a public transport mode, it is asked which modes he or she uses for the access and egress transport to and from this mode. Finally, a map of the neighbourhood is provided on which people were asked to indicate their approximate home location and mark any roads or paths they found unpleasant to walk. The home location is useful for more detailed personal measures related to public transport provision etc. The unpleasant roads indicated might be of use to explain certain route choices in the tracking study.

Participant recruitment and consent

Finally, people can indicate whether they are willing to participate in the second part of this research project and if they would like to get informed about the results of the project. They need to provide their contact information, so that they can be contacted with details about the follow-up. Consent information is included at the end of the survey, which gives mainly information about participation and data protection. If the respondent returns the completed questionnaire, it means that he or she agrees with the stated terms and conditions of the study.

3.3.1.2 Questionnaire distribution

All residences in selected study areas (see Section 3.4) received a paper questionnaire in their letterbox. The questionnaires were delivered in a plain envelope, with the phrase 'To the residents' handwritten in the middle. The handwriting was expected to give the pack a more 'personal' touch, rather than just printed contents, in an attempt to enhance interest to participate. The envelopes contained a cover letter, a freepost return envelope, and the questionnaire booklet. The cover letter invited one member of the household between 18 and 65 years old to participate in the study and provided a brief introduction and explanation to the study. Also the cover letter was hand-signed. Further participant information could be found on the backside of the cover letter. The questionnaire was presented as a general travel survey, since referring directly to the project (i.e. the links between public transport and walking) might discourage non-public transport users to participate.

As an alternative to completing the paper questionnaire, the cover letter and questionnaire booklet contained a link to an online version of the same questionnaire survey. This might make completion of the questionnaire more attractive for certain participants. To further enhance access, the questionnaire booklet also presented the link as a QR-code, which could be scanned to open the online questionnaire. The online questionnaire was made using Qualtrics, in which the questions were presented as much as possible in the same way as the paper version. The presentation of the questions differed slightly in terms of design, of which the impact is expected to be limited, and Question 24 was more restricted as people could only indicate 10 spots on the map instead of freely drawing like on the paper copy.

All questionnaires were distributed by hand in the study areas. In most cases this was done with multiple people. For safety purposes everyone stayed together as much as possible and had identification cards on them. Nobody stayed for longer on someone's premises than necessary to put the questionnaire pack in the letter box.

3.3.2 Smartphone tracking

3.3.2.1 Overview of tracking technology

For Objectives 4 and 5, a method was required which can gather detailed information on the trips people make and, if applicable, the routes people walk to and from public transport and related trip characteristics. One way to get an accurate view on the real routes people walk is using tracking technologies. In the past, several studies in this field have applied GPS tracking devices. In these studies, participants were typically asked to carry a dedicated tracking device together with an accelerometer for a certain period of time. However, these studies mostly focussed on the general walking activity, without using the full potential of the rich available data (e.g. time, distance, origin and destination, the exact routes through the built environment) to study the walking behaviour more closely and factors that influence this.

The relatively quick evolution of technology enables new research methods as well. Nowadays, a large proportion of society possesses a smartphone[5], which is often carried all day long. Smartphones are typically equipped with several sensors that can detect movement and locate the device, e.g. accelerometers and GPS sensors. Moreover, in contrast to the traditional GPS-trackers, which rely solely on signals from GPS satellites, smartphones have access to multiple technologies that can help locating the device, such as Wi-Fi signals and cellular networks.

[5] In 2019, 88% of the UK population aged 18-75 years had a smartphone. For 18-44 years old, this was about 93%, whilst in the age group 55-75 80% had a smartphone. 95% of the population uses their smartphone daily (Deloitte, 2019).

Therefore, smartphones can provide more precise location information, especially in challenging environments such as high-density urban areas in which GPS signals, for instance, can be reflected against buildings (Greaves *et al.*, 2015; Donaire-Gonzalez *et al.*, 2016). Also compared to traditional activity-travel diaries, the collected data by smartphones can offer much more detail (Allstrom, Kristoffersson and Susilo, 2016). However, the data collected by smartphones is not without mistakes; there are still several issues that can lead to considerable amounts of missing data (Lopez *et al.*, 2017), such as the time between leaving a building and getting the first location signal, a dead battery, or battery-saving procedures that reduce the frequency of location data collection.

Besides some better tracking possibilities of smartphones, they have several other practical advantages. Firstly, participants do not need to carry additional devices, as most already carry a smartphone with them in daily life. This reduces the potential influence on the participants' behaviour and makes participating less onerous (Abdulazim *et al.*, 2014; Almahmood *et al.*, 2017). Furthermore, smartphones offer additional possibilities alongside passive tracking. They could be used in a more active way and ask participants questions about a certain trip. One of the weaknesses of the smartphone approach is, where the participants' own devices are used, the range of used devices may have differences in accuracy, which could affect the quality of the dataset generated. Additionally, battery drain is an important issue for tracking apps, especially because participants often value using their limited battery power for their personal apps higher than running an app for a research project.

If walking behaviour can be tracked in a more accurate way, it offers various opportunities for research that have not been addressed before with regard to public transport-related walking, such as:

- The walking behaviour is assessed in an objective way instead of self-reported.
- Walking routes can be studied in more detail, with information about the rest of the activity-travel schedule.
- Rather than a single trip, tracking can take place over a longer period, so that the variability in behaviour can be addressed.
- The data collected also includes more information about the public transport trip that is related to the walking stage of interest.

Several apps have already been developed that can track the location of smartphones and collect other travel data, whether or not developed for research purposes. Table 3-1 lists a few examples of smartphone apps for tracking.

Table 3-1 Examples of smartphone apps used for tracking travel behaviour

Moves	Almahmood et al. (2017) tracked the walking behaviour of participants using their mobile phones with the app Moves installed. Through the Application Programming Interface (API), they could access the tracking data. The app recorded locations with intervals between 5 seconds to 1 minute. *https://www.moves-app.com/*
Flocktracker	Flocktracker is a project of Massachusetts Institute of Technology (MIT) to support field data collection through mobile phones. It is an app developed for Android and able to track, survey and count, and is connected to a web-dashboard to visualise and download data. *www.flocktracker.org*
Future Mobility Sensing	Future Mobility Sensing (FMS) is another project of MIT. It aims to collect activity-travel diaries. FMS is an app available for Android and iOS for data collection and combines this with an additional recall survey on the web. The app is tested by Cottrill et al. (2013). *http://its.mit.edu/future-mobility-sensing*

MEILI	MEILI is a travel diary collection, annotation and automation system developed by KTH university in Stockholm. The platform is similar to Future Mobility Sensing, and combines a smartphone application to track movements with a website where movements can be annotated by participants. *http://testmeili-stackth.rhcloud.com*
Catch!	Catch! is an app developed by the company TravelAI in collaboration with five local authorities, two universities and three other companies in the UK. It aims to collect travel data for UK cities. It is a journey planner that can collect the travel data of people. *http://www.travelai.info/*
Sense.DAT	Sense.DAT is developed by DAT.mobility in the Netherlands. The app can detect where and when people travel, by what mode and which route. Trips can be viewed and corrected by the users. The app also includes self-learning algorithms to detect habitual travel patterns and increase the accuracy. *http://www.dat.nl/nl/producten/sensedat/*

There are several trade-offs to be made regarding the choice of an app for the study. One of the most important choices is the level of battery drain, which is related to the level of accuracy. A higher level of accuracy (i.e. more frequent location detection) is obviously desirable in terms of data quality, but the higher battery drain might in turn curtail data collection.

Another important decision is the level of activity for the user. For passive tracking, the user will only need to setup the app and then the app will track all movements without any further input by the user. Apps can also function in a more active way, meaning that there is more interaction with the user. A possibility is to offer the user insights in the tracked behaviour and give him or her an opportunity to correct any mistakes, either via a website or in the app itself. A further step of interaction would be to ask additional information about each trip, such as the purpose or questions about aspects like the satisfaction with or experience of a trip. Again, the higher the level of involvement of the user, the richer the dataset can become, although it also leads to a higher respondent burden that might lead him or her decide to quit participation in the study. A higher activity could potentially also be more influential on the actual behaviour. Closely related to this issue is the amount of time participants should use the app for and provide tracking data. This could range from a day to several months. The level of activity required by the participant is the most important factor in this decision. Although the variability in behaviour will differ, tracking for a week is arguably an optimal length to get a view of a person's travel behaviour including both week and weekend days, assuming that for most people behaviour does not differ substantially over weeks.

3.3.2.2 The MEILI system

It was decided to use the MEILI travel data collection app (Prelipcean, Gidófalvi and Susilo, 2018), which is a passive tracking app that was developed with a focus on battery-efficiency. Besides some of the considerations pointed out above, two major reasons for choosing MEILI were that (1) the app is open-source and freely available (which would be required due to the limited research budget and is desirable for academic purposes) and (2) the database system can be installed on a private server, meaning that the collected data does not need to be used by third parties for (commercial) purposes other than this research, which is important with regard to research ethics and possibly participant recruitment. In this project, an Ubuntu server of Amazon Web Services was used, which could be used for free for 12 months.

The architecture of the MEILI system is visualised in Figure 3-2, and consists of two main parts: a client and a server side. The client side consists of the data collection app that the user installs on his or her smartphone and a website on which users can view and edit their collected trips. The server side consists of the database in which all collected data is stored, which is connected to the client via an API (application programming interface). Additionally, there is an artificial intelligence (AI) component that tries to segment the location points into trips and trip legs and detect the mode, purpose and destination for each of these trips. In order to use these AI features reliably, the system needs to be trained with annotated data on which it can base its estimations. Since the experiences with the automatic trip detection were not great during tests, it was decided to not use these features in the research. Therefore, the app was solely used for raw data collection, and participants were not required to annotate the trips detected. Another reason for this was the need to minimise participant burden in order to maximise the amount of collected data, because there were only little incentives available for the participants in this study. Trip annotation was instead done manually by the researcher, as is described in further detail below. The server-side software was installed on a server of Amazon Web Services, due to problems with arranging a server based at the university. It was however ensured that data could only be accessed by the researcher.

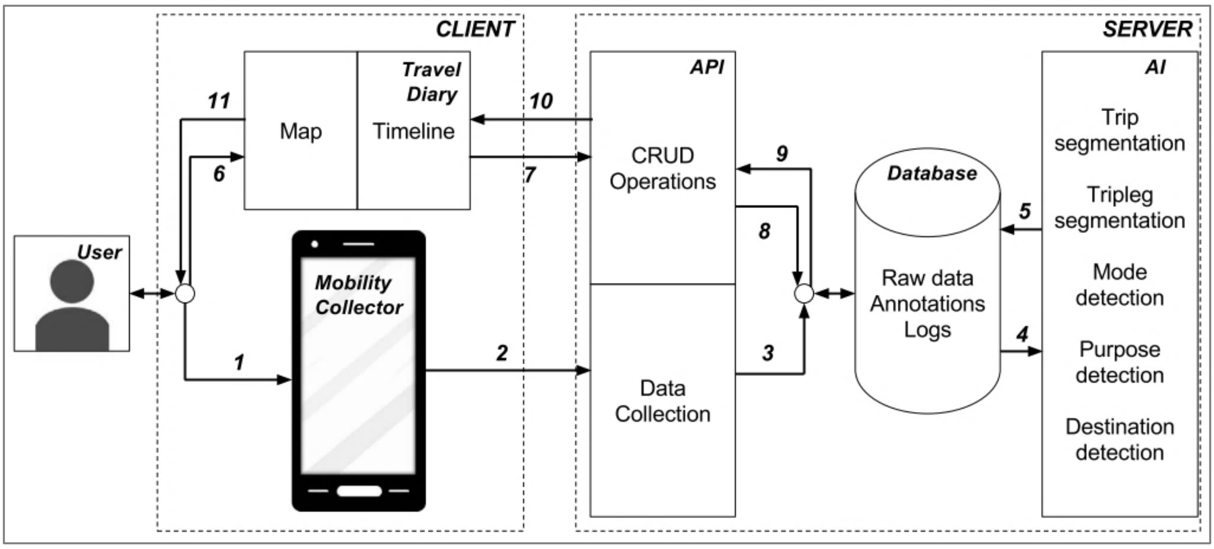


Figure 3-2 MEILI system's architecture (Prelipcean, Gidófalvi and Susilo, 2018).

The app code is available for both Android and iOS, the two largest smartphone operating systems. The major downside of using MEILI is that the back-end system needs to be installed by the user (i.e. the researcher) and the apps still need to be built, using the open-source available code, and published in the app stores to be downloaded by participants. These are highly technical tasks, which is difficult for research teams without technical support or technical background. One of the difficulties was that the MEILI code available still contained a few problems, of which some were caused by updates to the policies of the two operating systems, since the code was last developed in 2016. The apps were eventually published in the Google Play Store for Android phones and the Apple App Store for iPhones, so they could be easily downloaded by the participants.

The trip annotation was performed manually by the researcher, as this was expected to be more accurate than the automatic detection. Although there is no full certainty about the inferred trip characteristics, several tests of annotating the author's own data and data of colleagues were successful. It was found to be relatively straight-forward and reliable to detect the transport mode used based on factors such as the speed throughout the trip and the infrastructure followed. For instance, walking is typically done at speeds around 5 km/h and cycling at 15-25 km/h. These modes do occasionally also follow paths, which would not be accessible by car or bus. Car trips, however, do cover a larger range of speeds, and this range is often shown throughout the trip. Although traffic might move slowly in some places, there are mostly some free flow sections as well in which cars drive faster, a pattern that would not appear on walking or cycling trips that show a relatively constant speed. It was sometimes challenging to distinguish between cars and buses, especially if data was not fully complete. Bus journeys could be detected based on the presence of an access or egress trip to or from a bus stop and sometimes also the driven routes. Buses do not always follow the most direct or logical route, hence, if such routes were observed, bus route maps were checked to get an indication if it might be a bus. Train journeys were easy to detect, as they, obviously, solely took place on railways. Although this manual data processing increased the workload, it allowed the researcher also to familiarise himself with all the data collected.

3.3.2.3 Data processing

The raw data collected consists of a sequence of location points, in which the most important aspects are the longitude/latitude coordinate and the timestamp. To deduce some information from this, the first step is to calculate the distance and time between two subsequent points and thereafter the speed and acceleration and the angle with the previous and next point. A location point was requested for every 50m in case of movement, meaning that a large time gap between two points indicated a stay location (or missing data).

Based on these calculated variables, a first cleaning of the data is performed by omitting data points with unlikely values. These calculation and data cleaning steps are all automated using an R script. For the cleaning, an approach similar to the one used by Marra et al. (2018) is applied. Points with speeds higher than 175 km/h or an acceleration of more than 5 m/s^2 are likely false, as well as points that have an angle of less than 15 degrees between the previous and next points. After omitting all 'false' points, the speed etc. between subsequent points are recalculated. Then, new false points are detected and this process is repeated until all false points are omitted.

The next step to reduce noise in the data is by applying a smoothening technique. A regularly applied technique in tracking studies is the Kalman filter (Nitsche *et al.*, 2014; Marra *et al.*, 2018). With a Kalman filter, a tracking location is estimated using a joint probability based on information from previous locations and additional information like the speed. This process led to the slight adjustment of the coordinates of some points to form a smoother trajectory. After these adjustments, the distance, speed, etc. between location points were recalculated again. This cleaned data was then used to infer the trip diaries.

To do this, all data points were plotted on an interactive map using R (R Core Team, 2018) with the Leaflet package (Cheng, Karambelkar and Xie, 2018), together with a path connecting them. The colour of the points was dependent on the speed and points were bigger in size if the time difference with the previous point was larger than 3 minutes, likely indicating a stay location. This way of visualising helped with the inference of trips. An example of this plotting is displayed in Figure 3-3. Extra information of each data point can easily be obtained by hovering over a point or clicking on it. The example clearly shows the home location (with many stay points), two bicycle trips to and from the university and two bus trips to and from the city centre, with the walks between the bus stop and home. Trips were registered manually using a form in a Microsoft Access database (see Figure 3-4), in which the ID of the start and end points of a trip leg were noted, the most likely transport mode was selected and an origin and destination name. These origin and destination names were registered in separate tables, so the same origin or destination could easily be used multiple times. The destination type was inferred from the map, sometimes with additional web searches. There were also tick boxes to indicate if a trip was not completely tracked (i.e. either the origin or destination of the trip is unknown due to missing data). A third tick box could indicate whether the trip connects to the previous (in case there were multiple trip stages in a larger trip). If there were still some ‘false’ points in the data, these could be deleted, or the position could be adjusted on the map.

Figure 3-3 Example of recorded data plotted on a map

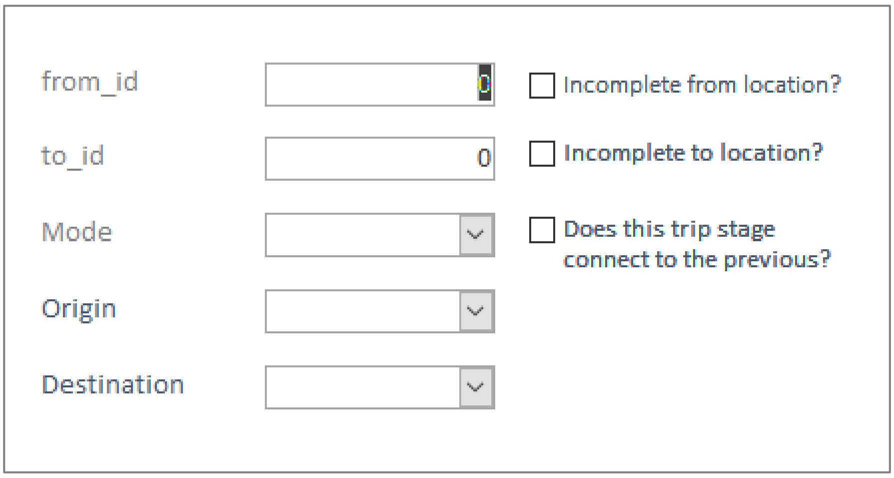


Figure 3-4 The trip registration form in Microsoft Access

3.4 Research areas

3.4.1 Selection of study areas

The project focusses on developing the understanding of the link between public transport and walking. With regard to this link, three major groups of factors can be identified: the people, the built environment, and the public transport services provided. To explore the effects of clear differences in these factors, or rather control for them, several urban areas have to be selected to conduct this study. The areas are selected within the city of Birmingham, which covers an extensive area, with a variety of public transport services and urban environments. Moreover, Birmingham is convenient with regard to the researcher's location and local knowledge.

Birmingham is the second largest city of the UK, after London, with a population of about 1.2 million and 3.8 million in the wider metropolitan area. The population is younger than the average in the UK (13% of the population is 65 years or older, versus 18.3% in the UK (Office for National Statistics, 2019)), and is ethnically diverse. Many functions are clustered in the city centre, but there are approximately 70 local centres which serve communities. Large parts of the city experience high levels of deprivation (Birmingham City Council, 2013). Approximately half of all trips by Birmingham residents are undertaken by car, about 20% by public transport, 2% by bike and about 25% on foot (Birmingham City Council, 2013).

Some other studies that compared walking or travel behaviour in different urban environments selected three to five areas to study (Kitamura, Mokhtarian and Laidet, 1997; Lachapelle, 2010; Choi, 2012; Lindelöw, 2016). In this study, four different areas in Birmingham are chosen. The study areas were selected based on various criteria, using the characteristics of the lower-layer super output areas (LSOA) within Birmingham (Census 2011). LSOAs are statistical units in England with an average population of around 1,500 people.

Because the public transport provision is expected to influence both the demand and supply sides that determine the walk distances to and from public transport, this was used as one of the main dimensions for the area selection. As major indicator, the access to the railway network was used. Bus services are provided throughout the entire urban area of Birmingham, but not all neighbourhoods have direct access to trains, which can be a distinctive feature for the residents' travel behaviour. Access to such stations can after all encourage the use of train and walking (Ewing and Cervero, 2010). The proximity of each LSOA to a railway station is determined by calculating the Euclidian distance from each LSOA centroid in Birmingham to the nearest railway station. LSOAs with a distance of less than 1500m to a railway station are considered as areas proximate to a station, since these areas are roughly within a walkable distance from stations. LSOAs with distances of more than 1500 m are considered for selection as an area without railway access.

The second main dimension used for selection is the level of deprivation. Differences in deprivation can lead to differences in travel behaviour, which might be related to differences in perceptions of transport or the built environment (Feuillet *et al.*, 2016). This is especially a factor of interest when studying the demand side (research objectives 1-3). For this dimension, the index of multiple deprivation was used, which is the official measure for neighbourhood deprivation in England, based on seven domains (income, employment, education, health, crime, barriers to housing and services, and living environment; Department of Communities and Local Government, 2015). All LSOAs in Birmingham were ranked on their level of deprivation. Two of the areas were selected with a high level of deprivation (from the top quartile in the city), whereas the two other areas exhibited relatively low levels of deprivation (selected from the lowest quartile in the city). For each of those pairs of areas there was one with access to the train network nearby, and the other without a train station.

Only residential areas were considered for selection, offering basic pedestrian infrastructure (pavements along all streets), so that walking was at least a reasonable transport option. Areas were also chosen with – for Birmingham – average levels of car ownership. In each of the four areas, several streets were selected with in total 1,000 households per area to which to deliver the questionnaire. The streets were located close to each other, as a wider spread of households might lead to larger variance within the sample and for convenience (since the researcher had to deliver the questionnaires by hand, without the availability of a car or such). This also implied that the study areas did not follow the exact borders of the LSOA statistical units.

3.4.2 Description of study areas

The location of the four study areas is shown in Figure 3-5. Bournville is an area with low deprivation and good access to trains, Moseley is also less deprived but without a train station. Castle Vale and Small Heath both have higher levels of deprivation. Small Heath has a railway station, whereas Castle Vale does not have direct access to the railway system. On the following pages, more detailed maps are shown of the individual areas, including a transport map. For each area a photo from Google Streetview is shown as well. Some general characteristics of the four areas are presented in Table 3-2, based on the Census data and observations of maps and satellite imagery.

Figure 3-5 The four study areas; A: Bournville, B: Moseley, C: Small Heath, D: Castle Vale (base: openstreetmap.org)

Figure 3-6 Google Streetview imagery of Moseley

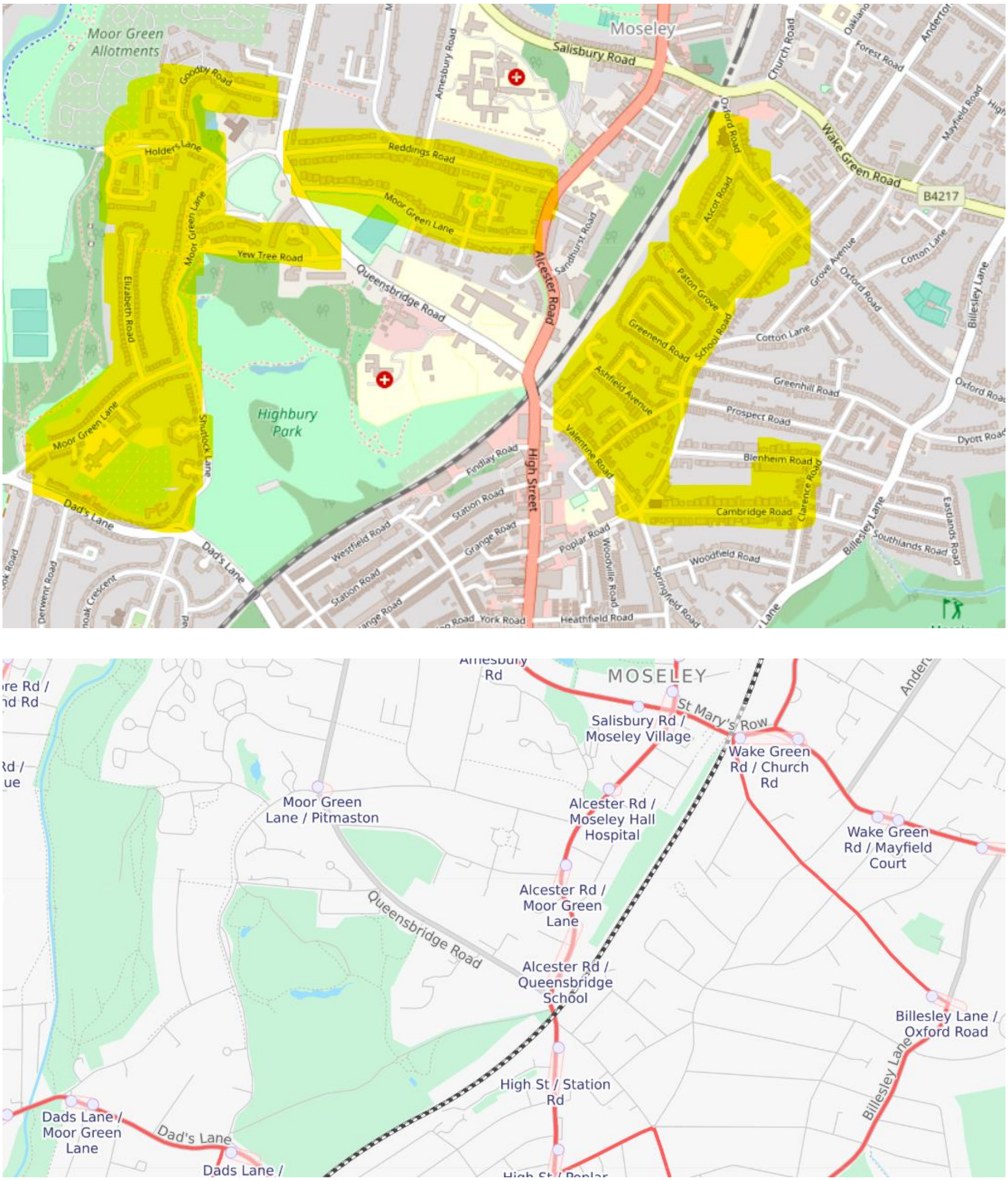


Figure 3-7 Maps of the Moseley study area. Questionnaire distribution areas are marked yellow. The bottom map highlights the bus routes and bus stops.

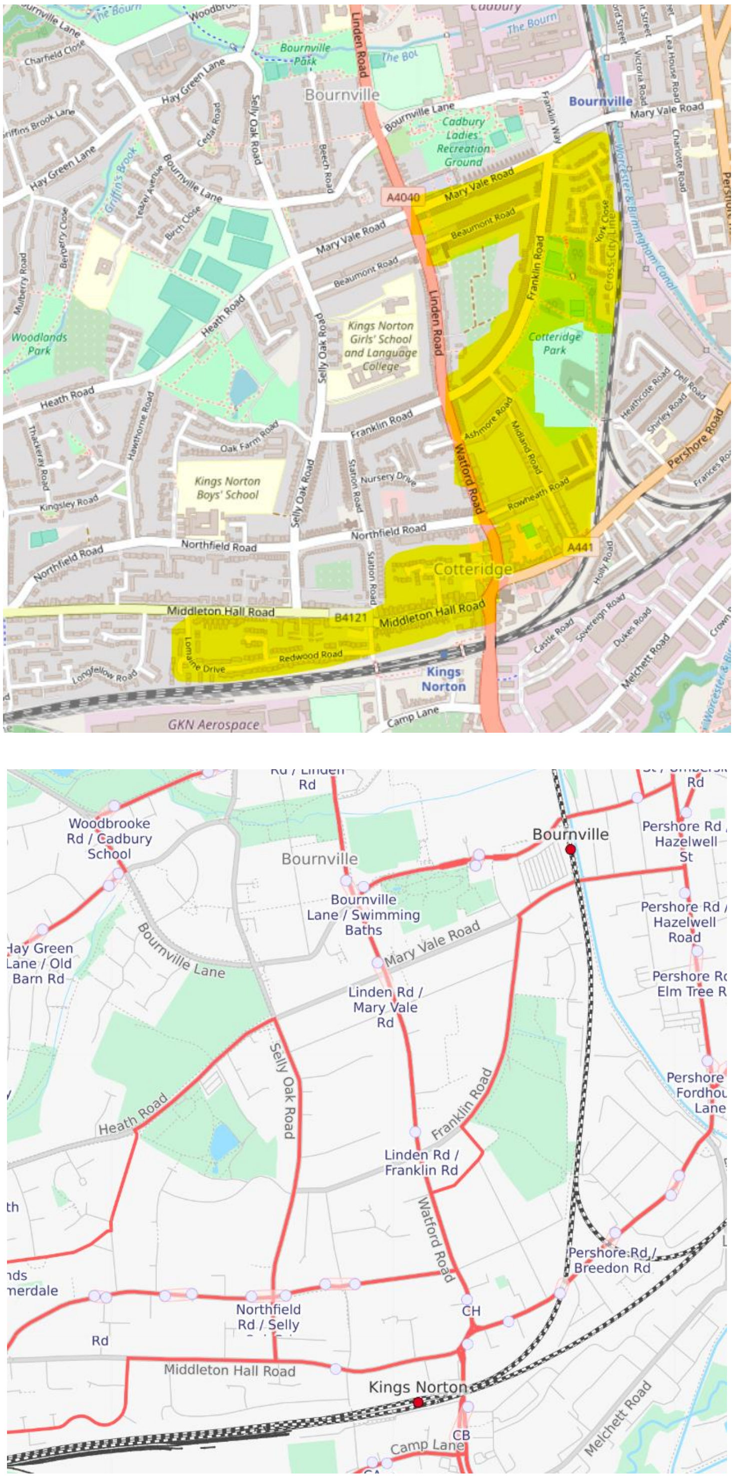


Figure 3-8 Maps of the Bournville study area. Questionnaire distribution areas are marked yellow. The bottom map highlights the bus routes and bus stops and railway stations.

Figure 3-9 Google Streetview imagery of Bournville

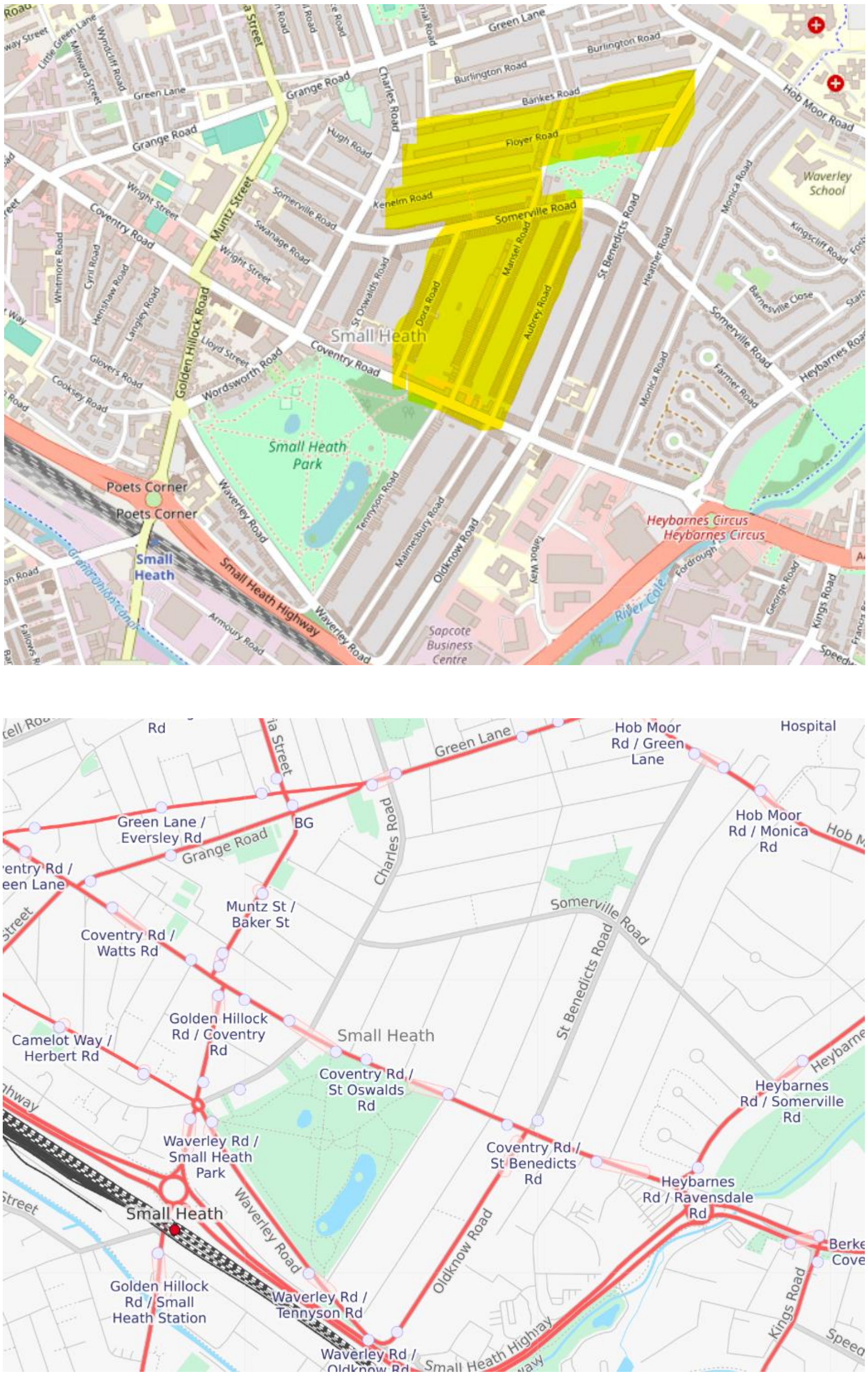


Figure 3-10 Maps of the Small Heath study area. Questionnaire distribution areas are marked yellow. The bottom map highlights the bus routes and bus stops and railway station.

Figure 3-11 Google Streetview imagery of Small Heath

Figure 3-12 Google Streetview imagery of Castle Vale

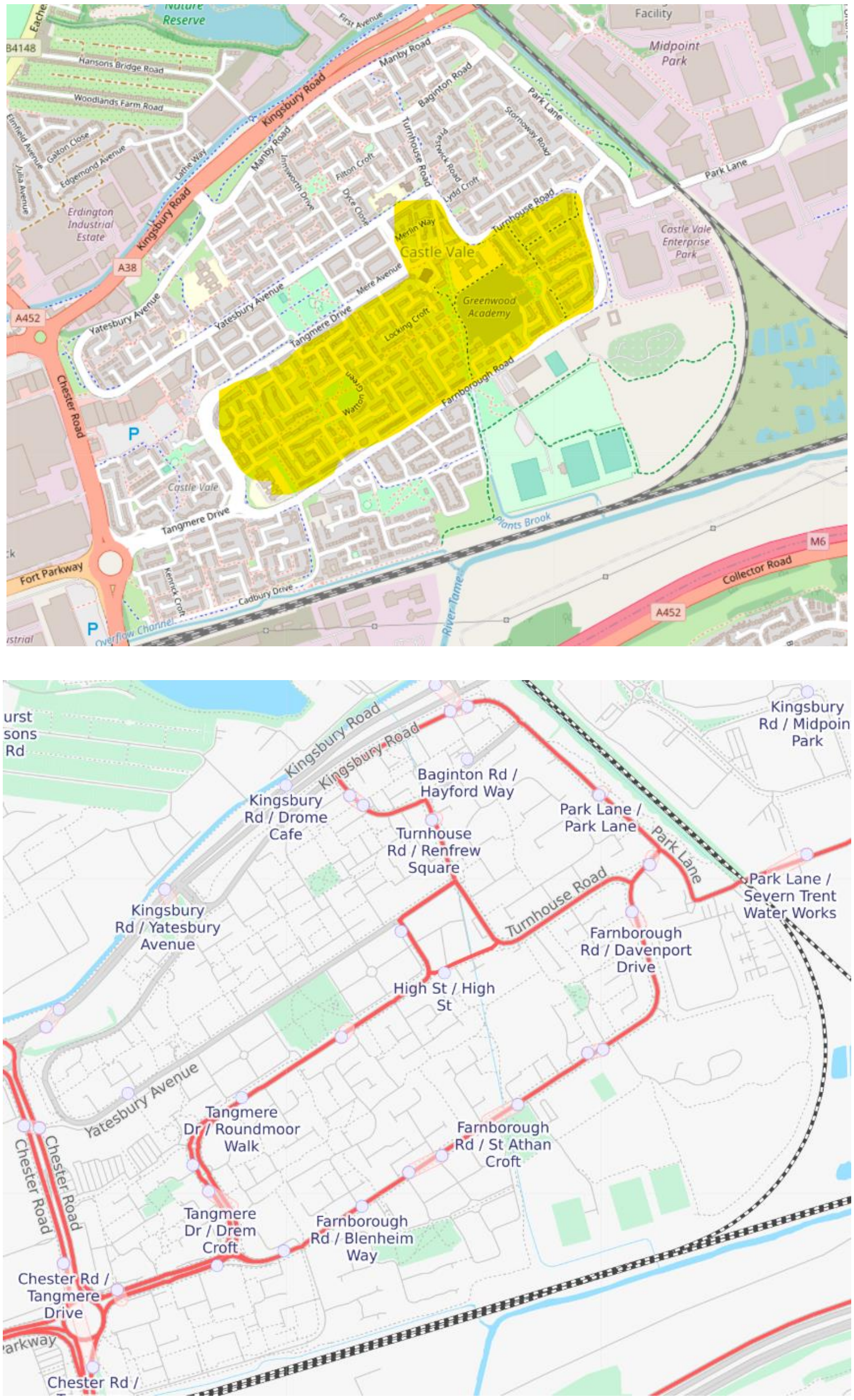


Figure 3-13 Maps of the Castle Vale study area. Questionnaire distribution areas are marked yellow. The bottom map highlights the bus routes and bus stops.

Table 3-2 Characteristics of study areas (Q: Quartile in the city)

Area	**Moseley**	**Castle Vale**	**Bournville**	**Small Heath**
Distance to centre (Straight line to New Street station)	5 km	9 km	6.5 km	3 km
Average HH size	2-2.5 *(Q1/2)*	2.1-2.5 *(Q1-3)*	2-2.5 *(Q1-3)*	3.4; 2.7 *(Q4)*
% no car ownership	25-40% *(Q2/3)*	30-50% *(Q2-4)*	25-40% *(Q2/3)*	47.4%; 36.9% *(Q2/3)*
% HH not deprived	40-55% *(Q4)*	20-25% *(Q1/2)*	40-55% *(Q4)*	10-15% *(Q1)*
Index of multiple deprivation decile	5	1	4-5	1
Education (% no qualification)	15-20% *(Q1)*	40-50% *(Q4)*	15-25% *(Q1/2)*	40% *(Q4)*
Avg. house price	136-230k *(Q2/4)*	119k *(Q2)*	151-168k *(Q3)*	90-100k *(Q1)*
Population density	Average	Average	Average	High
Ethnic groups	50-70% white British; 5-35% Indian/Pakistani;	80-85% white British; 5-10% white Caribbean mixed	80% white British	55-70% Pakistani; 5-15% Bangladeshi; 10% Black, African, Caribbean
Economically active population	60-75%	55-60%	70-80%	50%
Street network	Irregular grid with cul-de-sacs	Fine grid with many cul-de-sacs for motorised traffic	Irregular grid with cul-de-sacs	Grid with very long streets
Walking infrastructure and green space	Basic; parks in east and west	Many traffic free paths	Basic; several parks	Basic; a park
Public transport	Bus, some with high frequency	Bus; some with high frequency	Bus and train; some with high frequency	Bus and train

The types of dwellings also differ among the various areas. Four dwelling types are distinguished, based on the categories in the Census data: (1) detached whole houses or bungalows; (2) semi-detached whole houses or bungalows; (3) terraced whole houses or bungalows (including end-terrace); and (4) flats, maisonette or apartments. In the original data, the latter category was divided into three different sub-categories based on the type of building the dwelling is situated in. For a clear comparison of the neighbourhoods, this subdivision would make it unnecessarily complicated. In Figure 3-14, the distributions of the dwellings in each area and Birmingham in total are shown and several differences emerge. Moseley clearly has much more detached housing than average, which might relate to its less deprived character. The housing distributions of Bournville and Castle Vale are closest to the average, but with slightly more terraced housing. Castle Vale has a higher proportion of flats and Small Heath has a very high share of terraced housing, which reflects the more deprived character of these areas.

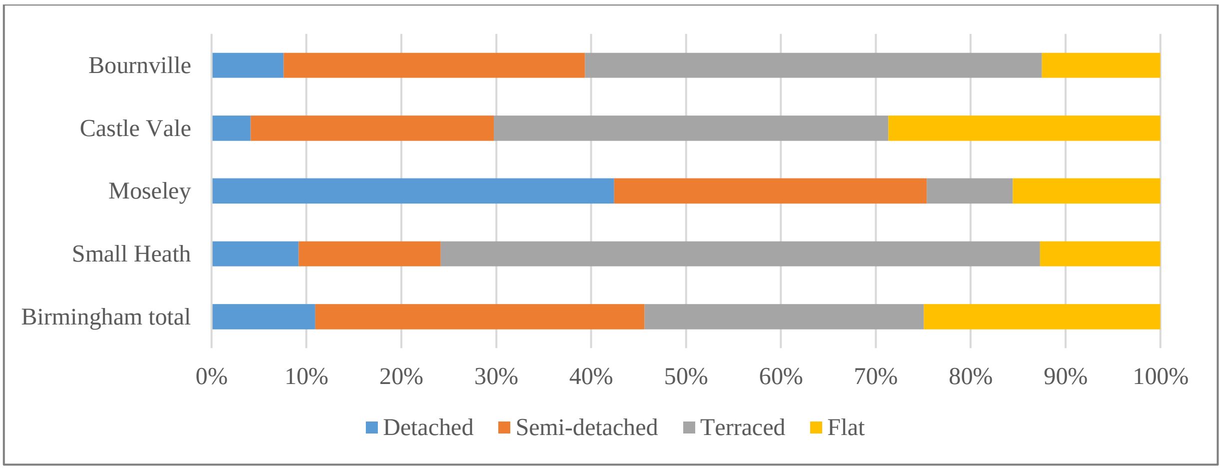


Figure 3-14 Types of dwellings in the selected areas and Birmingham in total

3.5 Sample

3.5.1 Questionnaire survey

Although a postal questionnaire is a common and relatively convenient method to gather data about participants in certain areas, one of the issues is that the researcher is dependent on the willingness of people to participate. Even though several measures can be taken to increase the chance someone is actually willing to complete the questionnaire and return it, these decisions are out of control.

The questionnaire invited one member of the household between 18 and 65 years old to participate in the study. The age range was chosen to reduce the likelihood of limitations in mobility freedom (such as the need for assistance or for minors to be accompanied), which might bias the perceptions of people. In total, questionnaires were received from 587 respondents (a 15% response rate), of whom several had not completed it at all, or with insufficient adequacy or were not compliant with the defined age-range. It was decided to also exclude people who indicated that they were not able to walk distances under 1 mile, as physical difficulties can affect the way someone experiences and uses transport. After application of these exclusion criteria, the sample size for analysis was n=500 responses.

While the overall response rate is typical for such questionnaires in the UK (e.g., Hayden, 2018), it is still just a small proportion of the study population, with potential biases in the types of people who respond. There were also some practical issues in the delivery of the questionnaire, as letterboxes of flats were often not accessible, for instance. Table 3-3 gives an overview of some socio-demographic characteristics of the samples from each area. There are large differences in the response rates between the more deprived and less deprived areas.

Overall, more respondents identified themselves as females than males (especially in Castle Vale), no respondents self-identified as non-binary. The Small Heath neighbourhood is distinctive in several other characteristics. The sample in this neighbourhood is on average younger, lives in bigger households with more children under 12 years old and a large proportion have an Asian ethnicity. Additionally, the proportion of employed respondents is lower and students higher. As expected, the annual household income of respondents in the two less deprived areas, Moseley and Bournville, is higher than in the deprived areas, especially when taking the larger household sizes of Small Heath into account. In work characteristics the differences are not very big, except for the fact that people in Castle Vale tend to have less freedom to choose the time to start or finish working.

Table 3-3 Descriptive characteristics of the questionnaire sample

		Moseley	Bournville	Castle Vale	Small Heath
	N	215	203	42	40
Gender	*Not say*	0.5%	0.0%	0.0%	2.9%
	Male	42.3%	37.8%	17.5%	40%
	Female	57.3%	62.2%	82.5%	57.1%
	Other	0.0%	0.0%	0.0%	0.0%
Age	Mean	45.57	44.16	42.27	36.10
	(*Std. dev*)	(*11.824*)	(*11.267*)	(*12.425*)	(*14.055*)
Household Size	Mean	2.82	2.65	2.51	4.58
	(*Std. dev*)	(*1.333*)	(*1.170*)	(*1.279*)	(*1.536*)
Children in Household	None	72.2%	69.8%	72.5%	45.7%
Annual Household Income	*Not say*	10.6%	11.0%	17.5%	30.3%
	< £15,000	1.0%	2.5%	15.0%	15.2%
	… - £25,000	5.8%	10.0%	32.5%	21.2%
	… - £50,000	25.5%	38.5%	30.0%	27.3%
	> £50,000	57.2%	38.0%	5.0%	6.1%
Ethnicity	*Not say*	1.9%	0.5%	0.0%	5.7%
	Asian	8.1%	2.0%	0.0%	82.9%
	Black	0.0%	1.0%	12.5%	5.7%
	Mixed	1.4%	2.0%	0.0%	0.0%
	White	86.7%	93.5%	87.5%	5.7%
	Other	1.9%	1.0%	0.0%	0.0%
Work Status	*Not say*	1.9%	1.5%	2.5%	8.8%
	Full time	60.2%	62.4%	65.0%	47.1%
	Part time	21.8%	20.3%	20.0%	14.7%
	Student	3.7%	3.0%	2.5%	14.7%
	Retired	9.7%	10.9%	5.0%	2.9%
	Unemployed	2.8%	2.0%	5.0%	11.8%
Work days per week	Mean	4.61	4.72	4.62	4.79
	(Std. dev)	*(1.33)*	*(1.05)*	*(1.42)*	*(1.69)*
Work place variability	Fixed location	59.5%	69.8%	64.9%	60.7%
Work time freedom	Free to choose start time	36.4%	31.9%	13.5%	32.2%
Work time variability	Every day similar hours	45.1%	48.3%	50.0%	51.9%

Some of the travel behaviour characteristics are displayed below: Figure 3-15 shows the mode use frequency per week per neighbourhood (Questionnaire: Q18), Table 3-4 shows the proportions of access/egress modes selected per neighbourhood. It needs to be noted that the percentages in this table are not necessarily the mode shares, because the respondents just had to tick which modes were used in the last month to travel to or from bus or train (Questionnaire: Q19). Multiple walks to or from the bus therefore have the same weight as going by car once. It however still gives some indication of the use of modes. For bus use, walking is by great distance the most used mode to or from public transport, in accordance with expectations. For train this share seems to be lower in most neighbourhoods, with particularly bigger roles for the car (either as a passenger or a driver) and bus.

Table 3-4 Proportions of access/egress modes selected per neighbourhood

Neighbourhood	**Bus**		**Train**	
	Walk	**Other modes**	**Walk**	**Other**
Bournville	99%	Taxi (1%)	92%	Cycle (2%), car (4%), bus (2%)
Castle Vale	90%	Car (10%)	29%	Car (50%), bus (18%)
Moseley	97%	Walk (1%), Car (2%)	23%	Cycle (6%), car (32%), taxi (17%), bus (22%)
Small Heath	92%	Car (3%), Taxi (3%)	26%	Car (21%), taxi (11%), bus (42%)

As can be seen in Figure 3-15, there are some differences in mode use between the areas. In Castle Vale there are more people who never drive a car; in Moseley and Bournville they cycle relatively often; in Bournville they drive relatively less frequently whilst in Small Heath people travel more often as a car passenger. Bournville residents use the train much more than others, whilst those in Small Heath travel least by train. This latter finding is surprising, since Small Heath does have a railway station, in contrast to Moseley and Castle Vale. Bus usage frequency is relatively low in Bournville.

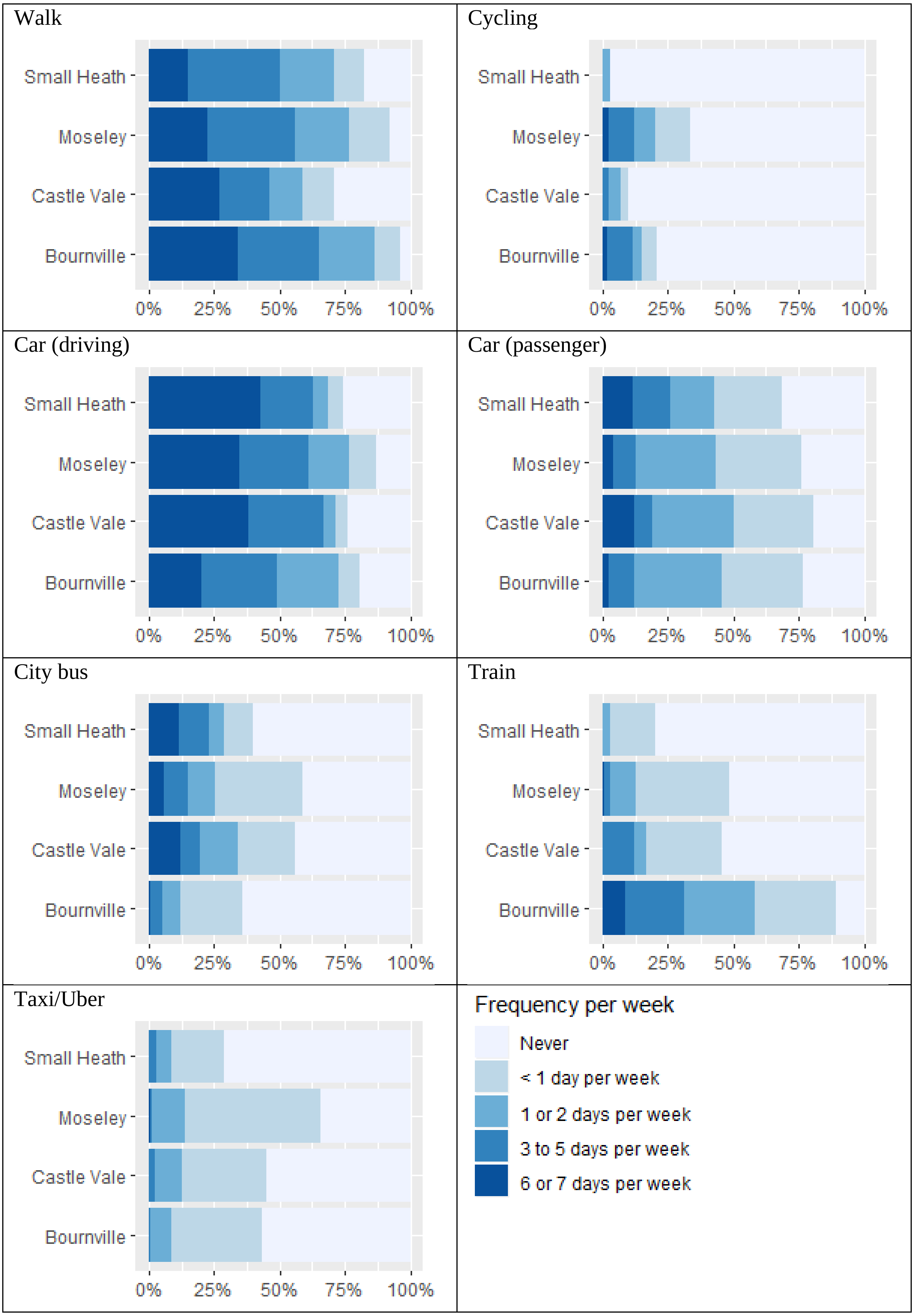


Figure 3-15 Weekly mode use frequency per neighbourhood

3.5.2 Tracking survey

Participants for the tracking survey were gathered via the questionnaire. In the questionnaire, respondents could state their interest in a follow-up study using smartphones, with Amazon-vouchers available to win. In case they did, they were asked to give their email address. At the end of April 2019, all participants who had given their email and indicated their interest in the study (n = 277) were contacted with a request to participate in the follow-up tracking study. As there was a long time period between the questionnaire and the follow-up study (about 15 months – due to difficulties in setting up the tracking system), the email firstly reminded that the addressee participated in a questionnaire in which they had stated their interest in the study. A copy of some results of the questionnaire was attached to refresh their minds and to potentially establish more interest in the new study. Subsequently, the purpose of the tracking study was explained, including what it would involve for the participant. A participant information sheet with consent information was attached to the email as well. These materials are provided in Appendix B. The participant was asked to read this and confirm by means of a return email whether they would agree to participate, and if so, whether they use an Android phone or an iPhone.

Of the 277 emails sent, 27 could not be delivered. For some of these, the original paper questionnaire was approached again to check for mistakes in the email. In some cases the handwriting was unclear, and a different spelling was tried if this was deemed plausible (e.g. ‘s’ instead of ‘5’). A new attempt worked for 2 addresses. In the end, 252 emails were successfully delivered and 35 responses were received. One week later a reminder was sent out to those who had not responded yet, and another 53 responses were received. Again one week later a second and last reminder was sent out, with 29 responses as a result.

Of these 117 responses, 43 people did not want to or could not participate any longer and 74 people were interested. Of these interested people, 53 actually downloaded the app (whether or not after a reminder), of which 45 participants successfully gathered tracking data. Thirteen of these participants used the Android app, 32 used an iPhone. Regarding the eight people that did not successfully collect data, for most the phone did not provide the app with location data, or very sparsely. This might be due to some wrongly configured user settings that block the use of location sensors, but in most cases is likely due to deeper problems (e.g. with firmware) which cannot be addressed by the user – as was experienced in some initial tests with tracking apps for this research project. The break-down of participants is visualised in Figure 3-16.

The sample size of 45 participants is not large, even though there are earlier tracking studies that had similar small sample sizes (Cottrill *et al.*, 2013, n=34; Voss *et al.*, 2015, n=42; Almahmood *et al.*, 2017, n=45). The small sample size requires extra caution when drawing conclusions, but should still be sufficient to give insights into the differences in travel behaviour between, for instance, the two neighbourhoods.

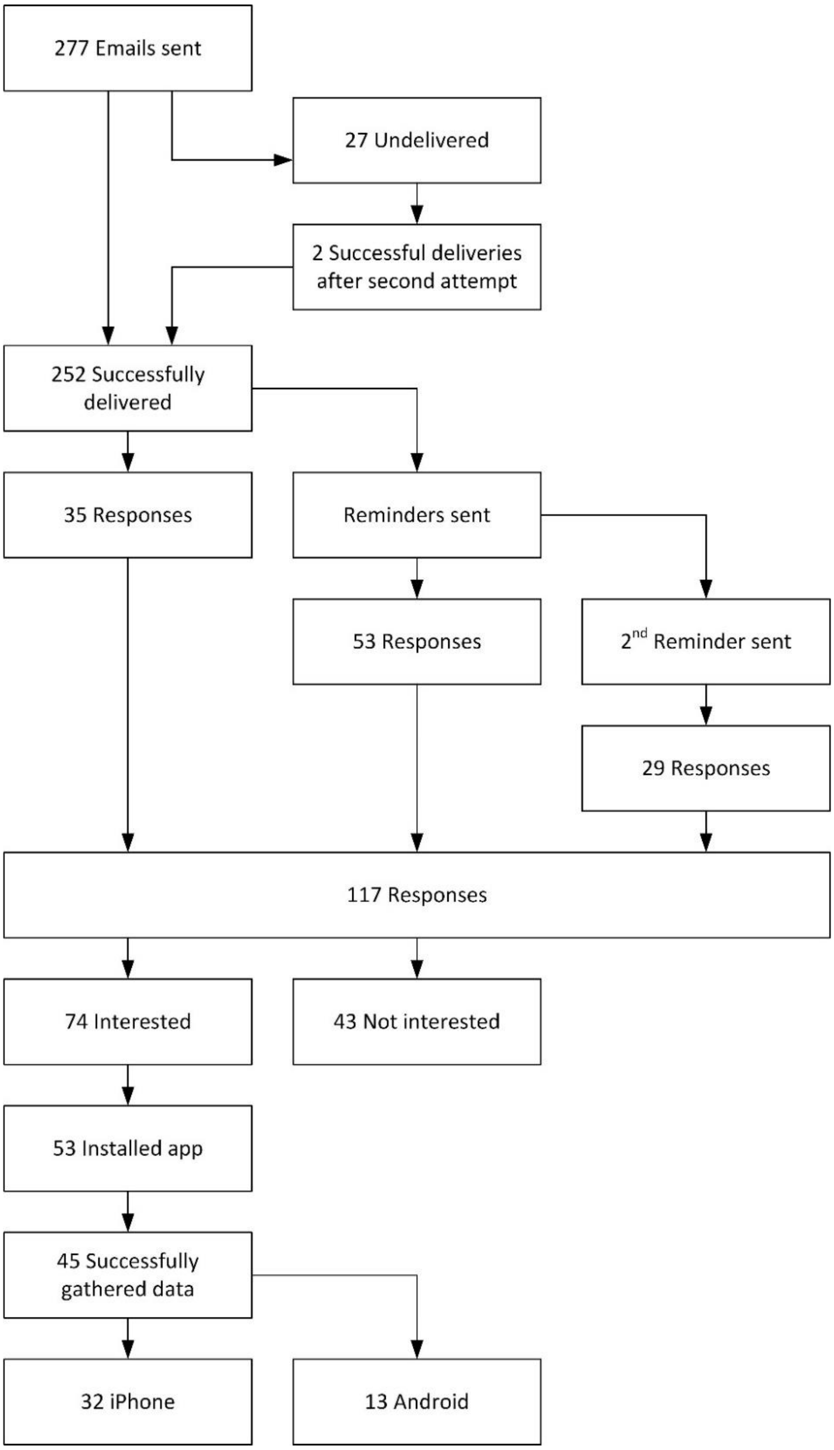


Figure 3-16 Break-down of participants in the tracking study

Some of the socio-demographic characteristics of the tracking sample are displayed in Table 3-5. This sample is relatively older, living in smaller households, with higher income and more of white ethnicity compared to the full questionnaire sample. This difference is partly due to the fact that nobody from the two deprived areas participated in the tracking study: of the participants, 29 live in Moseley (64%) and 16 in Bournville. Another noticeable fact is that over two third of the participants used an iPhone, whilst the market share for iOS is about 49% in the UK (March 2019[6]), which probably reflects the relatively high average household income of the sample. The sample is clearly by no means representative for the population, which needs to be taken into account when drawing conclusions from the findings.

Table 3-5 Descriptive characteristics of tracking sample

		Tracking sample
	n	45
Gender	*Not say*	0%
	Male	38%
	Female	62%
	Other	0%
Age	Mean	50
	(*Std. dev*)	*12*
Household Size	Mean	2.4
	(*Std. dev*)	1.2
Children in Household	None	82%
Annual Household Income	*Not say*	9%
	< £15,000	0%
	… - £25,000	13%
	… - £50,000	33%
	> £50,000	44%
Ethnicity	*Not say*	4%
	Asian	2%
	Black	0%
	Mixed	0%
	White	91%
	Other	2%
Work Status	*Not say*	0%
	Full time	60%
	Part time	29%
	Student	0%
	Retired	9%
	Unemployed	2%

[6] https://www.statista.com/topics/4227/mobile-operating-system-market-in-the-united-kingdom-uk/

3.6 Other data sources

In the questionnaire people could indicate their approximate home location on a map, which allows for some more detailed analysis related to their home's environment. In the analyses outlined in section 3.7, measures are described for both walkability and public transport provision, for which the home location and the surrounding pedestrian network is used. Some of these measures require a pedestrian network file, which is first described in section 3.6.1. Section 3.6.2 describes the development of a measure for public transport provision, which uses, among other sources, the pedestrian network file.

3.6.1 Pedestrian network

As a base map the Ordnance Survey (OS) Integrated Transport Network (ITN) Roads layer was used, obtained from EDINA Digimap. This network data was converted to a file usable in ESRI ArcGIS, after which it was loaded in this GIS-software. The roads layer was clipped to a wide buffer around the study areas to limit computational resources. Streets that were classified as *Motorway*, *Alley* or *Private Road – Restricted Access* were deleted, since these roads would not be relevant for walking to destinations. Alleys are mostly dead-ended streets without any relevant function.

Because pedestrians can also use paths, for instance through parks, the OS ITN Urban Paths layer was added, because the roads layer does generally not include any footpaths. The Urban Paths layer was clipped to the study areas, and manually cleared by keeping only relevant connecting paths. The majority of the paths in the layer were dead-ended, for instance to access backyards, and therefore not relevant for general urban walking. These two network layers were merged together, creating the pedestrian network to obtain the public transport access measures in the next section.

3.6.2 Public transport provision

When considering the level of public transport services, a large range of aspects can be taken into account. It would therefore be challenging, if not impossible, to create a comprehensive measure of the public transport service level. A good initial indication can however be established by considering a few key factors, such as distance to a public transport stop, the public transport service frequency and the different routes available. Against this background, a convenience measure was developed, combining service frequency and the distance between home and a public transport stop.

For each home location, the shortest pedestrian network distance to all stops within 1000m of walking distance were obtained using the Closest Facility function in the Network Analyst package for ESRI ArcGIS. For each of these bus stops, the service frequency and number of different bus routes had to be calculated. The complete set of schedules for all public transport in the West Midlands were downloaded from the Transport for West Midlands API website (api-portal.tfwm.org.uk/docs). These schedules were provided in GTFS (General Transit Feed Specification) format.

Using this data, a convenience score could be assigned to every bus stop for each participant, based on an approach used by Kamada et al. (2009) and developed further by Djurhuus et al. (2014). These studies used a categorisation system for both access distance and service frequency, to which convenience scores were appointed. See Table 3-6 below for the categorisation and scores used in the present study. The categories and scores are adapted slightly compared to the previous studies based on the distribution of data in Birmingham. Djurhuus et al. (2014) also used four categories per dimension, although their two highest categories on each dimension were essentially the same in scoring. Therefore, a bit more differentiation was added to the scores across the different categories. As can be revealed from the scoring scheme, a close distance was valued slightly more than a high frequency with regard to the convenience score (e.g. level 2 frequency [< 192 buses/day] and level 1 distance [< 200m] gives a convenience score of 5, whilst level 2 distance [< 500m] and level 1 frequency [> 192 buses/day] gives a score of only 4). The frequency splits are based on the distribution of the data and average frequencies per hour (e.g. 192 buses/day equals 8 buses per hour on average; 96 buses per day equals 4 buses per hour on average).

Table 3-6 Convenience scores for different levels of bus service frequency and walk distance

Distance Frequency	< 200m	< 500m	< 800m	> 800m
> 192 buses / day	5	4	3	2
97-192 buses / day	5	3	3	2
37-96 buses / day	4	3	2	1
6-36 buses / day	3	2	1	1

After assigning scores to all stops for each participant, the 'best' bus stop for each one was selected. The best stop was defined as the bus stop with the highest convenience score (of all bus stops within 1000m walk distance). If there were multiple stops with this convenience score, the one with the most different bus routes was selected. In case there were still multiple stops left, the one closest to the home was regarded as the 'best' bus stop.

In two of the neighbourhoods, people live relatively close to a railway station too. As railways tend to attract people from further distances, the convenience scoring is slightly different. Only three stations are considered: Bournville and Kings Norton both have a local train every 10 minutes in each direction, which was assigned convenience score 4 for the closest residents (as it is a high frequency for trains, but not as convenient as a larger station with higher frequencies and multiple directions). Small Heath has a local train every 30 minutes (which was assigned convenience score 3 for the closest residents). The convenience scores assigned are higher for a lower frequency when compared to buses, since it was observed that people generally value trains more, which implies that the perceived convenience will be higher for equal service frequencies. The convenience scores determined according to distance are shown in Table 3-7. For each participant, the highest convenience score (for either bus or train) is considered as the convenience score for public transport.

Table 3-7 Convenience scores for railway access, based on service level of the station and walk distance

Distance / Station	< 400m	< 800m	< 1500m	> 1500m
Bournville / Kings Norton	4	3	2	1
Small Heath	3	2	2	1

3.7 Analytical approach

3.7.1 Questionnaire survey

The two main parts of the questionnaire that are considered in Chapter 4 are the section using free associations (Q12-Q16) and the section asking to rate potential barriers to walking, bus and train (Q21-Q23). For both of these sections, three major aspects are studied: (1) their relationship with the neighbourhood environment, (2) their relationship with behaviour, and (3) the relationships between modes. All statistical analyses in this project were performed using the R 3.5 software package (R Core Team, 2018) and $\alpha = 0.05$ is used as level of significance.

3.7.1.1 Data preparation for free associations

In order to do analyses using the free associations, a standardised approach is necessary in which associations with similar meanings are grouped together as one theme. Therefore, the content of each association was coded using a scheme based on issues found in the literature regarding barriers and motivating factors for different modes and was developed further in an iterative process based on the associations given. One of the limitations of the free association approach is the limited context that is provided. The association typically consists of one or a few words, and the further context provided is only the transport mode, affective rating and the other associations given. Some of the associations could be interpreted in different ways, for which the most likely interpretation had to be inferred based on the limited context. Finally, the associations were almost all categorised under 83 codes, whilst 148 associations remained uncoded as they did not clearly fit into a category, were ambiguous or the handwriting was unreadable and were therefore omitted for further analysis. A second independent coder coded 700 associations (about 10% of the data) and agreed with the assignment of associations in 92% of the cases, which is in line with existing research (e.g., Benthin et al., 1995). Differences were mostly due to the limited context and ambiguity of some of the associations. The code book can be found in Appendix C, with for each code a brief explanation and examples of associations.

3.7.1.2 Relationship with the neighbourhood environment

Content of free associations

To discover whether the content of the free associations relates to the neighbourhoods in which respondents live, a series of χ^2-tests have been conducted to test whether the frequency distribution of association codes significantly differs between the neighbourhoods. Associations with each of the five transport modes were considered separately and, to get more meaningful comparison results, association codes with 20 or fewer observations were ignored. To perform an accurate χ^2-test, the expected count in each of the cells of the contingency table should not be lower than five. Since this was often violated, a second *p*-value was obtained based on a Monte Carlo simulation with 10,000 replicates. In this case 10,000 random samples are generated from the data to obtain a reference distribution (Hope, 1968) instead of assuming a Chi-square distribution.

If there is a significant difference between neighbourhoods, it needs to be examined how the content of the associations exactly differed. To this end, correspondence analyses were performed for the modes that show significant relationships. Correspondence analysis is a tool that can be used to examine the relationship between two or more categorical variables and is related to tools such as factor analysis and principal component analysis.

Affective rating of free associations and ratings of predefined barriers

For each association, it was rated on a 7-point scale how positive or negative this association felt to the respondent. Because this is ordinal data, in contrast to the open association responses, it was possible to study the influence of the neighbourhood environment using more detailed characteristics. Also the predefined barriers were rated on a 7-point scale. Analysis of the individual Likert-type responses was undertaken using non-parametric techniques, since this type of rating data can be best treated as ordinal instead of interval data, because the distances between the scale points are not always perceived to be consistent (Kaptein, Nass and Markopoulos, 2010).

Firstly, the differences in ratings across the four neighbourhoods were explored more generally. For each rating (for each mode with regard to the affective ratings and for each predefined barrier), a Kruskal-Wallis test was performed to test whether the ratings differed significantly over the four neighbourhoods. The Kruskal-Wallis test is a nonparametric test to compare three or more groups on a variable (Kruskal and Wallis, 1952). If a significant difference was found, a post-hoc Dunn test was done (Dunn, 1964), that tests which neighbourhoods actually significantly differ from which other neighbourhoods.

Subsequently, the effects of more potentially influencing factors were accounted for by estimating binomial logistic regression models. In these models, being positive about a mode or agreeing with a predefined barrier was considered a binary response variable. The use of a binary rather than the 7-level ordinal variable was preferred to ensure there would be sufficient data to model the various combinations of explanatory categorical variables. Regarding the affective ratings, data were used only from people who gave at least two associations and someone was considered as being positive when at least two of the three associations with a transport mode were positive. For the predefined barriers, someone was considered as agreeing if the person gave a rating of 5, 6 or 7 to the potential barrier. As the different cultures and circumstances present in the various neighbourhoods can lead to different variances in the responses (Delacre *et al.*, 2018), the standard error terms of the parameter estimates in the regression model were clustered by neighbourhood.

Several explanatory variables were included in the models. The major distinctive characteristics of the neighbourhoods were the level of neighbourhood deprivation and the availability of public transport. Neighbourhood deprivation is represented by a binary variable (high versus low), whilst the availability of public transport is represented by three variables. One binary variable denotes the self-reported availability of public transport (yes/no). The two other variables are a convenience score for bus and train, based on the distance to stops and stations and the service frequency, as was described in detail in section 3.6.2. The convenience scores are on a scale of 1 (inconvenient) to 5 (very convenient), but are reduced to three levels based on the distribution of the data. For bus convenience this means levels 1/2, 3, and 4/5. For train convenience this means levels 0 (no provision in the neighbourhood at all), 1/2, and 3/4 (there were no people with convenience level 5 in the dataset).

Because the samples in each neighbourhood differed according to various socio-demographic characteristics, differences in association content and affect might be (partly) attributable to influences of socio-demographic factors. To control for this variation, some further control factors are included in the models: gender, ethnicity (white/non-white), income (up to £15,000/£15-25,000/£25-50,000/£50,000 or more; dummy coded using three dummy variables), availability of a car (yes/no) and availability of a bicycle (yes/no). A full overview of the variables included in the regression models is provided in Table 3-8 below.

Table 3-8 Overview of explanatory variables in the logit models to predict the positivity with a mode or the experience of a barrier to using a mode

Variable	**Levels**	**Meaning**
Deprivation	Deprived – Non-deprived	Neighbourhoods Castle Vale and Small Heath are coded as deprived
Convenience bus 1	1/0	Bus convenience level 3 or higher
Convenience bus 2	1/0	Bus convenience level 4/5
Convenience train 1	1/0	Train convenience level 1 or higher
Convenience train 2	1/0	Train convenience level 3/4
Availability PT	Not available - available	Self-reported availability of public transport (Q20c)
Gender	Female - Male	
Income 1	1/0	£15,000 or more
Income 2	1/0	£25,000 or more
Income 3	1/0	£50,000 or more
Ethnicity	White – non-white	
Availability car	Not available - available	Self-reported availability of a car (Q20b)
Availability bicycle	Not available – available	Self-reported availability of a bicycle (Q20a)

3.7.1.3 Relationship with behaviour

In the questionnaire, respondents were asked how often they used various travel modes in the last month, with five options from “never” to “6 or 7 days per week” (Questionnaire: Q18). Depending on the distribution of answers per mode, some of the five frequency categories are combined to get large enough groups to compare. Differences in content of associations between the usage frequency categories were again tested using a χ^2-test, followed by correspondence analysis in case of a significant relationship. The relationships between the frequency of use and average affective rating per person as well as the barrier ratings were assessed by calculating Kendall's tau for correlation, for which the original categorisations were used.

3.7.1.4 Relationships between modes

To study how the ratings of the series of pre-defined barriers are related to each other, Kendall's Tau correlations were obtained to establish the strength of the associations between the ratings. Kendall's Tau is a non-parametric correlation measurement, using ranks, which is suitable for ordinal data (such as the ratings) and data with tied ranks (Field, Miles and Field, 2012).

Regarding the content of the associations, it was tested whether this differs significantly for people who agree, disagree or are neutral about the influence of a certain barrier. Again a series of χ^2-tests was performed, like for the relationship with the neighbourhood and behaviour. For significant relationships this was also again followed by a correspondence analysis to assess how the association content differed.

3.7.2 Tracking survey

The raw tracking data were cleaned and annotated, as illustrated in Section 3.3.2.3, resulting in a trip dataset. These trips are analysed further. Two major types of trips are of interest for the research objectives: (1) the public transport trips with the associated walks, and (2) the car trips to study the potential of public transport.

3.7.2.1 Public transport trips

Concerning Objective 4 and the overall aim of the project, the distances of the public transport-related walks are of primary interest. These distances are initially described using some general descriptive statistics, after which they are compared further between the modes (bus and train) and between the neighbourhoods (Bournville and Moseley). This comparison is done visually by means of cumulative distribution plots as well as statistically using t-tests.

The influence of public transportation provision on walk distances was firstly explored by the difference in public transport provision between the neighbourhoods. As a basic measure for public transport provision the walk distance to the closest bus stop (with at least 6 services per day) is used. Subsequently, this measure is expanded upon by including service frequencies. For each respondent, a public transport convenience score was assigned (on a scale of 1 – least convenient to 5 – very convenient), based on the respondent's home location, as illustrated in section 3.6.2.

All PT-walks recorded are examined visually on the map to see whether the route walked to or from the bus stop or railway station was the shortest route, or whether alternative routes were taken. To study to what extent walking was minimised in combination with the choice of the complete public transport route, the route taken is compared with feasible alternatives. These alternative routes were obtained using the route planner in Google Maps, planning the trip to and from the same destination and origin at approximately the same time. The comparison reveals some of the aspects that need to be balanced off in the choice for a route. The focus was on total travel time, walking time, the number of transfers and the transport mode types included.

Finally, the relationship between the walk distances and the walking route quality was examined by calculating a 'pleasantness index' for each walking route. The 'pleasantness' of walking along a particular street section was measured using the Link-Place framework (Jones, Marshall and Boujenko, 2008), in which streets are categorised according to their function. The link function refers to the movement of people and goods, whilst the place function relates to the street as a space for activities or to access activities. It is assumed that the lower the link function and the higher the place function of a street, the more pleasant it is to walk on this section. In addition to streets, pedestrians can use urban paths, which are supposed to be the most pleasant walking infrastructure, since these are free of motorised traffic.

As part of the development of the Birmingham Mobility Action Plan, all road sections in Birmingham have been classified according to their link and place status (Birmingham City Council, 2014). The link function is categorised on a scale from 1 (high link function) to 5 (low link function) and the place function is categorised on a scale from a (high place function) to e (low place function), which combine into a link-place category, such as '3-b'. Street sections of the Urban Paths layer (see Section 3.6.1) are traffic-free paths and not categorised in the framework. For each walk related to public transport, it was examined through which link-place categories the walk took place, based on which a pleasantness-index was created. The walked routes were defined by a series of tracked location points, which were then connected via straight lines. Because these lines do not always align with the street network, a buffer of 25m was created around the tracked walking route. Subsequently, the length and link-place categories of all sections of streets that fell within this buffer were gathered. For each category, the total distance was multiplied with a pleasantness weight (Table 3-9). Then the weighted distance of all categories were summed and divided by the unweighted distance.

Table 3-9 Weights for link-place categories
The link function: 1 (high link function) to 5 (low link function); The place function: a (high place function) to e (low place function); Urban paths are free of traffic

Place Link	**a**	**b**	**c**	**d**	**e**	**Urban path**
1	1	0.8	0.6	0.4	0.2	2
2	1.2	1	0.8	0.6	0.4	
3	1.4	1.2	1	0.8	0.6	
4	1.6	1.4	1.2	1	0.8	
5	1.8	1.6	1.4	1.2	1	

3.7.2.2 Car trips

Obtaining the public transport alternative

For all the car trips made, the potential public transport alternative is examined to get a better insight into the mode choice and the potential of using public transport and walking instead of the car (Objective 5). Therefore, the accessibility of the car is compared to the accessibility of public transport. This accessibility analysis can be conducted using various approaches. Traditionally, this is often done using location-based measures, for instance comparing the areas that are accessible within half an hour of driving or using public transport from a certain location (Geurs and van Wee, 2004). However, the spatial scale in such studies can sometimes be problematic, as well as the often rather rough estimates of travel times, for which simplifying assumptions tend to be made (Salonen and Toivonen, 2013), such as the exclusion of access and egress stages. Because the walks to and from public transport are crucial in the measurement of public transport accessibility, the zonal or neighbourhood level is not detailed enough for a good accessibility analysis (Benenson *et al.*, 2011). Advanced models that include the arrival and departure time and take a door-to-door approach are much more realistic (Salonen and Toivonen, 2013).

In the present study, the data about the car trips is available on a detailed door-to-door level. To compare it with public transport, a public transport trip is planned from the same origin to the same destination as the car trip. Nowadays, public transport data is often made available publicly on the internet, which makes it possible to plan a trip realistically using detailed (real time) travel data. The data is mostly made available through an Application Programming Interface (API), via which specific requests can be sent to a webserver after which the desired data (such as a list of potential travel options with route details) is sent back (in most cases in an XML or JSON format). Various studies have estimated travel characteristics by planning trips with the use of such online data services, like Google Maps (Liu *et al.*, 2016; Chaloux *et al.*, 2018; Xia *et al.*, 2018), Openstreetmaps (Salonen *et al.*, 2014), PT operator APIs (Salonen *et al.*, 2014), or Baidu Maps (Xia *et al.*, 2018).

In the research reported here, route requests are sent to the API of www.transportapi.com, which uses the Traveline Southeast journey planner as the public transport route planning engine, covering the whole UK. A route request requires an origin and destination coordinate, and optionally also a date and time can be set and the public transport modes (bus, train, tube and boat) can be restricted.

The origin and destination are defined by the first and last longitude/latitude coordinates of the car trip. Because the API can only give travel advice for a limited period in history, the date was set as the date of the next weekday which is the same as the weekday on which the trip was made. As time the start time of the car trip is used and the public transport modes were left unrestricted.

When the route planning request is sent, the API returns a list of travel possibilities. Of this list, two options are chosen (which might be the same): (1) the first fastest option and (2) the most direct option. The most direct option is defined as the option with the least amount of transfers (and in case there were multiple trips with this least amount of transfers, the first fastest option is chosen). Each travel opportunity consists of a list of trip stages, including access and egress walks. For each stage, also a list of longitude/latitude coordinates is provided that represents the travel route, which is used to calculate the distance of each trip stage.

Instead of just studying the potential public transport trips and related walk stages on their own, it is of importance to compare them with the length of the original car trips. However, many of the car trips missed some data at either the beginning or the end, which has resulted in less accurate calculations of the travel time (for instance, the final location point was recorded about 10 minutes after the approximate actual arrival). It was therefore opted to simulate the car trips as well by planning the routes from origin to destination using an online engine, similar to the planning of the public transport routes. This time the Microsoft Bing Maps API was used, as this API is able to compute car routes which can be adjusted based on the traffic levels at a certain date and time and is also available under a free licence. This approach was believed to give reliable estimates of the actual travel times, which can be used for comparisons between public transport and car.

Analysis of the public transport alternative

The analytical steps taken for the analysis of the potential public transport trips are similar to those for the real public transport trips. Firstly, the duration of the car trips and the public transport/car travel time ratios are compared between the two areas, using boxplots and t-tests. Then, the potential walk distances involved in the hypothetical public transport trips if all car trips were shifted towards public transport. Walk distances were compared between areas, according to public transport convenience scores and the public transport frequency (based on the questionnaire response), using graphs and t-tests.

Instead of clustering based on their public transport use or provision, people could also be clustered based on their transport attitudes, which might partly explain the use of public transport. This clustering can be done using various approaches. Firstly, an attempt was made to use a theory-driven approach by looking at existing research that clustered people with similar transport-related attitudes. One such a study is the EU-funded research project SEGMENT (Ladbury, 2013), which defined eight attitudinal segments related to transport that were present throughout several European cities: devoted drivers, image improvers, malcontented motorists, active aspirers, practical travellers, car contemplators, public transport dependents, and car-free choosers. Based on the descriptions of each segment and the available data of the questionnaire regarding attitudes and transport mode use, each respondent was classified into one (or more) of the eight segments. Some segments were hard to distinguish with the data that was available from the questionnaire and were therefore merged together. In the end, four clusters of respondents were left. These were compared based on their perceptions and experience of transport barriers, but no clear patterns were found for differences between the clusters.

Another approach was therefore used, which was data-driven, meaning that the respondents were clustered based on the closeness of their data points. There are various clustering techniques available, of which hierarchical clustering and *k*-means clustering seem the most commonly used in travel behaviour research. In this case, hierarchical clustering is used, as it does not require a pre-defined number of clusters and can therefore be applied most easily.

Clusters were formed based on the respondent's attitudes towards walking, cycling, car driving, and using buses and trains. Hierarchical clustering starts with considering every data point in its own cluster and subsequently merges pairs of clusters that are closest to each other until there is one big cluster left. Numerous methods have been developed to define this agglomeration process; a few different agglomeration methods have been tried out, of which Ward's clustering method (Murtagh and Legendre, 2011) seemed to give the best result. Ward's clustering method minimises the increase in total within-cluster variance if two clusters are merged, measured as the weighted squared Euclidean distance between cluster centres.

The agglomeration process can be visualised using a dendrogram (see Figure 3-17). The height of each node refers to the dissimilarity between the two daughter nodes. The higher the merging took place, the more distant the clusters were to each other. The clustering tree can be cut at an arbitrary level at which the clusters can be split, based on a trade-off between information and cluster size. In the dendrogram obtained, cutting the tree at four clusters seems a sensible choice. The four clusters are of a reasonable size, without becoming too meaningless.

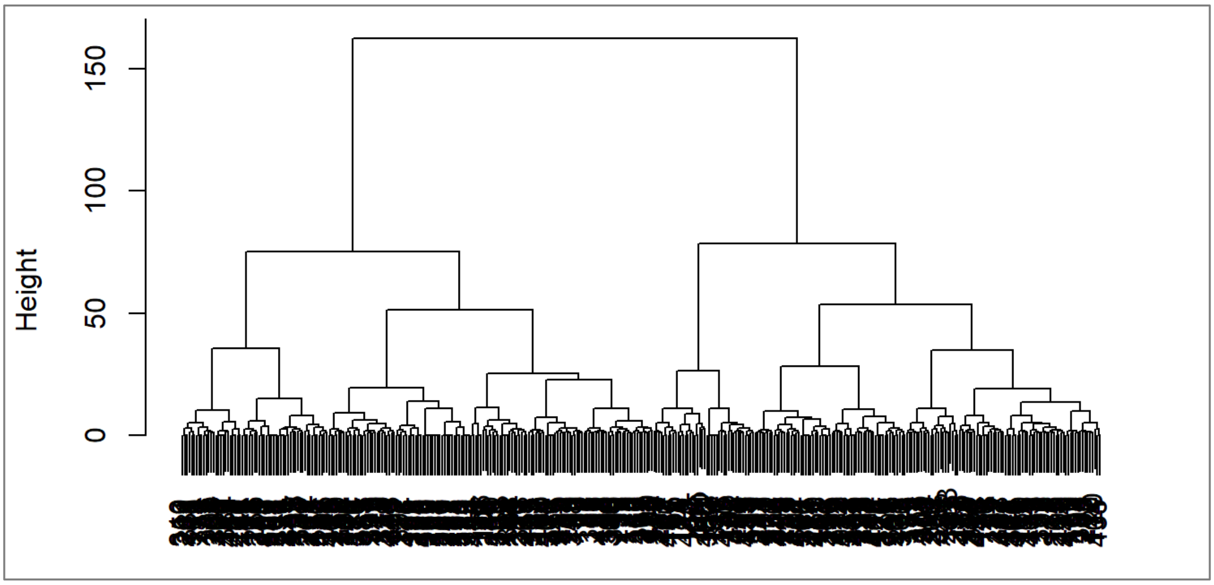


Figure 3-17 Cluster dendrogram

Figure 3-18 shows a comparison of attitude scores for each cluster. The clusters can be defined as follows:

- Cluster 1 (135 people): Positive attitude to all modes, except for bus
- Cluster 2 (61 people): Relatively positive to buses, less positive about car driving, positive about walking, cycling and trains.
- Cluster 3 (144 people): Relatively negative to cycling and bus use, whilst positive about walking, car and train use.
- Cluster 4 (42 people): A bit less positive about walking, negative attitude towards buses and trains, moderately negative about cycling and most positive about car driving.

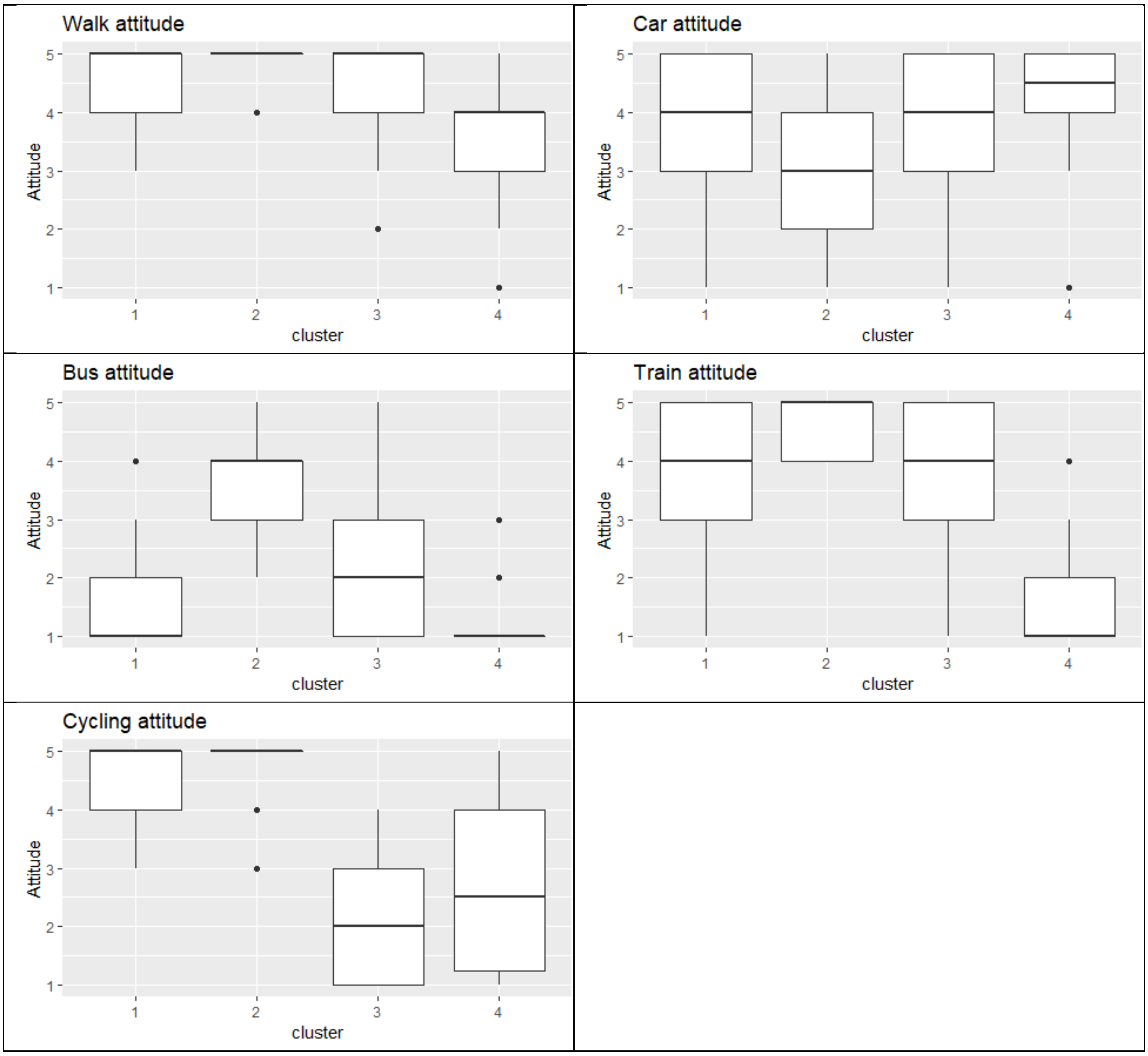


Figure 3-18 Attitude scores per cluster (1: dislike using the mode – 5: like using the mode)

3.8 Summary

This chapter has outlined the research methods that are used in this study in order to achieve the research objectives. The research design consists of two main studies, which can both address different aspects of the study framework. A questionnaire survey was designed to obtain data mostly related to the first three objectives, which focus on the barriers people perceive to and from public transport. A smartphone tracking study was outlined to gather detailed objective travel data. These two methods were connected to each other, as the participants for the second study were gathered using the responses of the survey, and hence a richer dataset could be created.

The questionnaire survey was undertaken by post, in four distinct urban areas in Birmingham, with the level of neighbourhood deprivation and railway provision as major distinctive characteristics. The smartphone tracking study focussed on people from the two less deprived areas. Some external data sources were used to add measures of public transport provision into the study. The exact steps taken for the analysis of the data collected were described in detail in the last section of this chapter.

The next chapter, Chapter 4, will present the results of the questionnaire survey, using the analytical steps outlined in this chapter. Subsequently, Chapter 5 presents the results for the smartphone tracking data analyses.

4. RESULTS AND ANALYSIS: QUESTIONNAIRE SURVEY

4.1 Introduction

This chapter presents the analyses and results of the data gathered using the postal questionnaire. The focus in this chapter is around the first three research objectives, all related to the perceived barriers to public transport and walking. It firstly explores which aspects act as barriers to using public transport and walking in section 4.2. Secondly, in section 4.2.1 it investigates to what extent these perceived barriers differ across neighbourhoods and which aspects play a role in these differences. Thirdly, in section 4.2.2 the relationship between the barriers people perceive and their actual travel behaviour is studied. And finally, in section 4.2.3, it is explored how the perceived barriers to different modes are related to each other. The chapter concludes with a summary in section 4.3. The results presented in this chapter should give insights into the demand side of public transport related walks, which can eventually inform the variability in walk distances to and from public transport.

4.2 Results

Bar charts with the ten most frequent association codes per mode are displayed in Figure 4-1, coloured according to the average affective rating for those associations. The percentage for each code refers to which proportion it represents of all associations with the particular mode. The associations were asked in Questions 12a, 13a, 14a, 15a and 16a of the questionnaire and the affective rating in Q12b, 13b, 14b, 15b, and 16b. For walking, the most frequent words seem to refer to rather positive qualities of this mode, except for weather, traffic, or time. The image changes significantly when looking at how the other active mode, cycling, is perceived. For cycling, traffic safety is by far the most frequently mentioned, after which a mix of positive and negative aspects appear. Also the two public transport modes, bus and train, are perceived differently. Although they have many overlapping themes, buses appear to be associated with more negative aspects. For cars, the most frequent associations seem to be rather negative as well, apart from convenience and fastness.

Figure 4-2 presents boxplots for the ratings of the predefined barriers to walking (Q21), bus use (Q22) and train use (Q23; scale 1 (disagree) to 7 (agree)). For most of the barriers there is a relatively wide range in ratings, but some potential barriers are clearly more relevant than others. For walking, luggage, safety at night and time are rated as the most important barriers. Time, crowding and expense are rated most as a barrier to bus and train use, although in different orders. Time is more important for bus use, whilst for trains the ticket prices are a clear number 1 barrier, with only about 25% of the respondents disagreeing to some extent (rating under 4) that expense acted as a barrier. Generally, the set of barriers to bus use is rated higher than the train barriers.

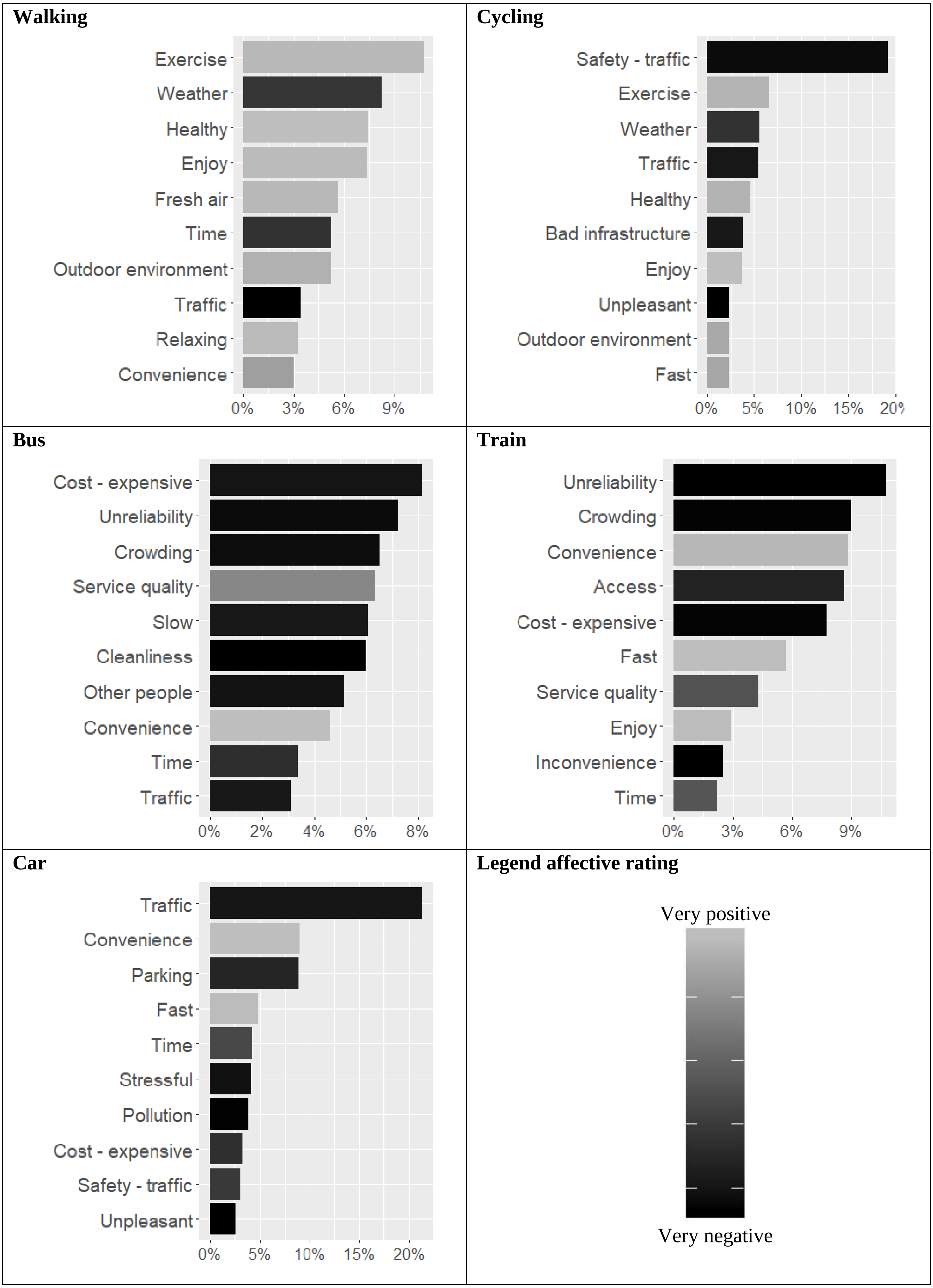


Figure 4-1 Ten most frequent association codes per mode (% of all associations with each mode),with an indication of the average affective rating for the association category

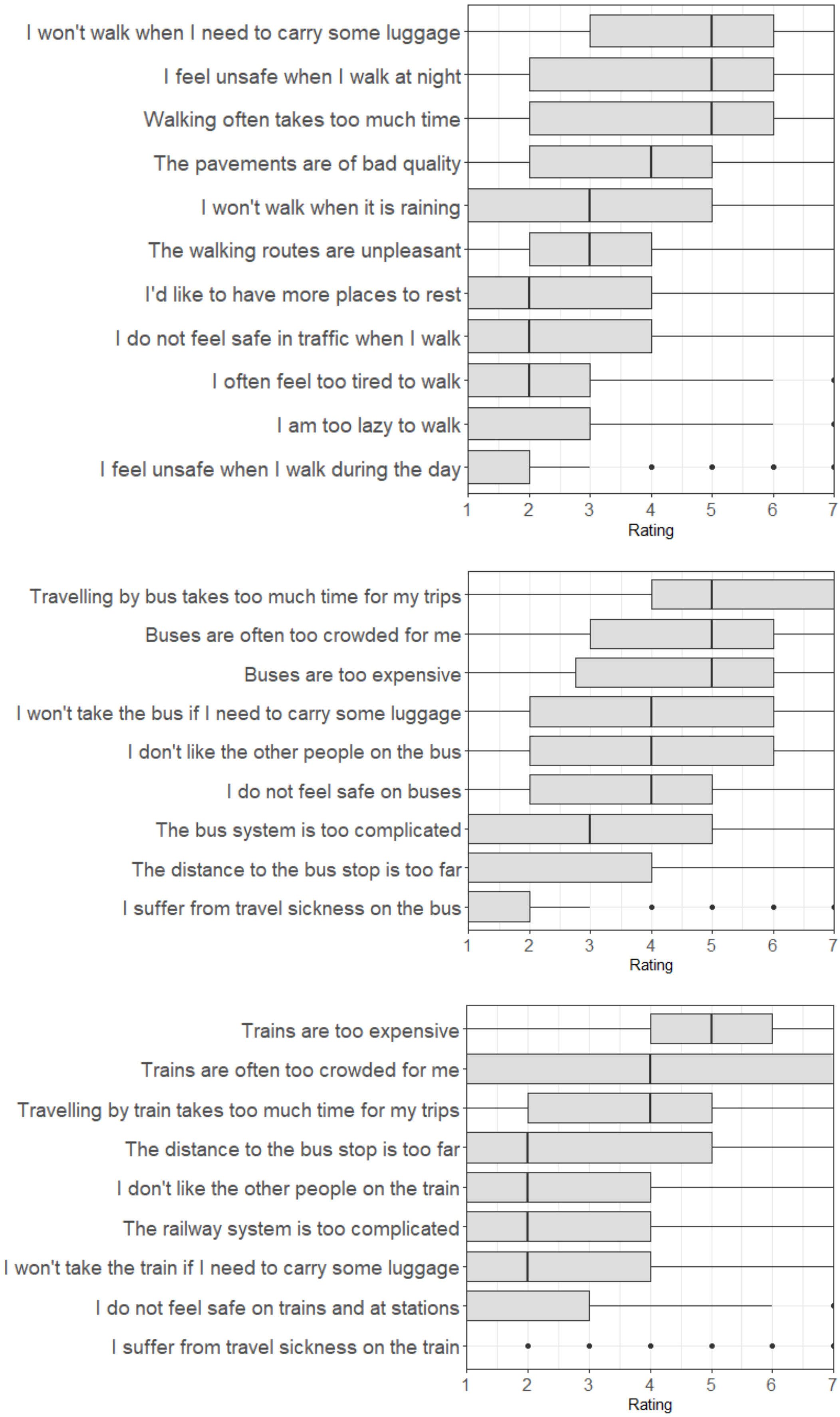


Figure 4-2 Boxplots for barrier ratings to walking, bus use and train use (1: disagree, 7: agree)

4.2.1 Environment

4.2.1.1 Associations

After considering the general results for the content and affective rating of free associations as well as the ratings of predefined barriers, the influence of the environment is explored. The results of the χ^2-tests for differences between the neighbourhoods in association codes are shown in Table 4-1. For all transport modes except the car, respondents in the different neighbourhoods came up with significantly different associations.

Table 4-1 Results for χ^2-tests for differences in frequency of association codes between neighbourhoods (bold: p<0.05)

Mode	χ^2	**df**	***p***	**Simulated *p***	**Number of codes**
Walk	87.76	51	**0.001**	**0.001**	18
Car	51.32	39	0.090	0.090	14
Train	179.23	51	**<0.001**	**<0.001**	18
cycle	84.12	51	**0.002**	**0.002**	18
Bus	113.72	54	**<0.001**	**<0.001**	19

For each of the transport modes with significantly differing associations across the neighbourhoods, the results of the correspondence analyses to study how the association content differed exactly are displayed in Figure 4-3. In correspondence analysis, usually the contingency table of two categorical variables is used as input, after which the categories are typically represented as points in a biplot (Beh and Lombardo, 2014). These biplots are generally difficult to read and are easily misinterpreted. Therefore, another type of visualisation is used in this study, called *moonplots* (Bock, 2017).

The plots consist of a circle in which the four neighbourhoods are depicted and on the outside there are association codes, of which the meaning can be traced back using the code book (see appendix C). The further a neighbourhood is placed from the centre of the circle, the more distinctive it is regarding the association content. So, if all neighbourhoods had completely similar associations, they would all be placed in the centre, without any distinctive associations around. The association codes have a bigger font size if they are more distinctive. If a neighbourhood is placed closer to a bigger code, it means there is a stronger association between them, meaning that associations with that particular code were relatively often mentioned in that neighbourhood, compared to the other neighbourhoods.

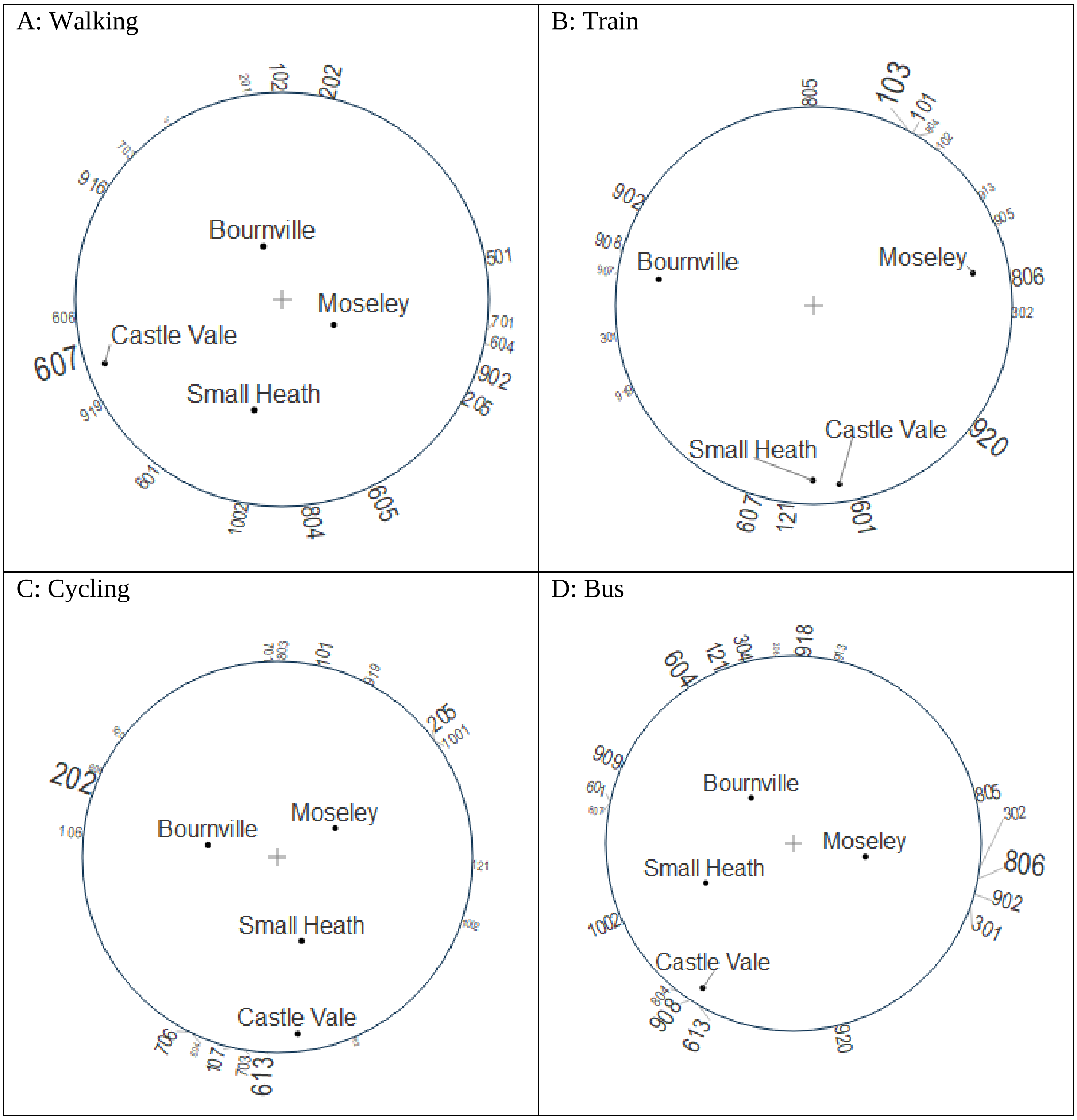


Figure 4-3 Moonplots of the correspondence analyses for four different transport modes (A: Walking, B: Train, C: Cycling, D: Bus)

From the plots, it can be deduced that the two deprived areas, and in particular Castle Vale, were overall the most distinctive neighbourhoods. Especially for trains; whilst respondents in Small Heath and Castle Vale had similar associations, they differed very clearly from the other two neighbourhoods. Overall, in the deprived areas the four modes seem to be more associated with various negative concerns compared to the less deprived areas. For walking, respondents in Castle Vale more often associated walking with crowding (607), speed (919) and weather concerns (606), whereas Small Heath residents referred more to concerns about cleanliness (804), traffic safety (1002), time (601), and weather (605). Cycling in these neighbourhoods was associated relatively often with concerns about (behaviour of) other people (613), statements of not using the mode (107), the effort it takes (703), but also exercise (706; which was generally perceived positively). In Bournville, on the other hand, residents referred more to relaxation (102), being in an outdoor environment (202) and the need for special clothing (916) for walking, and the outdoor environment (202) as well as concerns about weather (606) and notions of dislike (106) for cycling. In Moseley, pollution (205), convenience (902), healthiness (701) and concerns about traffic (604) were more often mentioned for walking, whilst cycling was relatively often associated with pollution (205), personal safety issues (1001) as well as speed (919) and enjoyment (101). The main difference for the two less deprived areas is that in Bournville the outdoor environment is appreciated more for active transport, whereas in Moseley pollution seems to be a larger hindrance and active transport is perceived more practically. This reflects the actual environment of both neighbourhoods, where Bournville has more green infrastructure available for active travel in contrast to Moseley, indicating that the physical environment can shape transport perceptions.

With regard to public transport perceptions, there were differences between the deprived and less deprived neighbourhoods too. For trains, responses from the two deprived areas, Small

Heath and Castle Vale, appeared to be very similar. Respondents relatively often associated trains with concerns about time (601), crowding (607) and notions of unpleasantness (121). Responses from Bournville, on the other hand, related more to convenience (902), both reliability (907) and unreliability (908; e.g. delays and cancellations), and notions about the payment system (301). In Moseley, trains were more associated with issues regarding access (806) and expense (302), but also comfort (905). Moreover, people in Moseley and Bournville expressed more a preference for using trains (103) and general notions of enjoyment (101). So, whilst the responses from the deprived areas again seem to be more critical towards trains, the residents in the less deprived areas were more inclined to appreciate the positive qualities of trains, although the responses from Moseley reflect the limited access that this neighbourhood has to the railway system. For bus use, the associations in all neighbourhoods tended to comprise rather negative aspects, except for Moseley, where some of its qualities were more appreciated. Respondents in Castle Vale were very distinctive, associating bus riding relatively often with concerns about other people (613), unreliability (908) and concerns about cleanliness (804), whilst for Small Heath traffic safety issues (1002) played a larger role. In Bournville, buses were comparatively often associated with concerns about traffic (604), unpleasantness (121), issues with the organisation of payments (304), waiting (909) and slowness (918). In Moseley, the bus was associated with the need for access transport (806), both expense (302) and money saving (301), as well as convenience (902) and notions about the service quality (805). The fact that Moseley is distinctive with more positive aspects compared to Bournville might relate to the public transport provision in these areas. In contrast to Moseley, Bournville has good train access, which make buses probably a less preferred form of public transport, partly with respect to the bus routes available.

4.2.1.2 Affective rating

Results of the binomial logistic regression models to study environmental influences on the affective rating of the free associations are presented in Table 4-2. In logistic regression, odds ratios are used to quantify the strength of the effects. The *odds* refers to the probability that something is true, in this case the probability that someone has a positive perception about a mode, divided by the probability that something is not true. For each factor, an odds ratio is computed, for instance for the factor *deprived*. In this case the odds ratio refers to the odds for those living in a deprived area divided by the odds for those living in a less deprived area. So, odds ratios below 1 mean that the variable has a negative influence on the odds of being positive about a transport mode, ratios above 1 have a positive effect on the odds. The models for car driving, cycling and bus use are significant at the 1% level, the model for walking at the 10% level ($p = 0.084$).

The role of neighbourhood deprivation beyond the socio-economic variables appears to be small. Only in the models for positivity about train use and bus use is deprivation a significant influence, with people in deprived areas being more positive about trains, but less positive about buses. Public transport supply had more impact, but mostly for walking and car driving. A higher convenience score for bus and train is associated with higher odds of being positive about walking, but lower odds of being positive about car driving. The availability of trains has a positive effect on the odds of being positive about train use, whereas a high train convenience is associated with lower odds of being positive about bus use. Remarkably, a higher bus convenience was not significantly associated with the positivity about buses. It does however have a big impact on the odds of being positive about cycling.

Table 4-2 Logistic regression results for positivity of walking, car driving, train use, cycling and bus use (bold: p < 0,05)

	Model 1 - Walking				**Model 2 – Car driving**				**Model 3 – Train use**				**Model 4 - Cycling**				**Model 5 – Bus use**			
Variable	**p-value**	**Odds-ratio**	**95% C.I. Odds ratio**		**p-value**	**Odds-ratio**	**95% C.I. Odds ratio**		**p-value**	**Odds-ratio**	**95% C.I. Odds ratio**		**p-value**	**Odds-ratio**	**95% C.I. Odds ratio**		**p-value**	**Odds-ratio**	**95% C.I. Odds ratio**	
Intercept	0.332	1.76	0.56	5.52	**<0.001**	6.76	4.33	10.56	0.081	0.38	0.13	1.13	0.163	0.28	0.05	1.69	0.121	0.21	0.03	1.50
Deprived	0.952	1.01	0.71	1.44	0.900	1.06	0.41	2.75	**0.036**	1.32	1.02	1.72	0.274	1.21	0.86	1.70	**<0.001**	0.79	0.70	0.89
Convenience bus 1	0.515	0.89	0.63	1.26	**<0.001**	0.46	0.42	0.51	0.215	1.42	0.82	2.47	**<0.001**	3.18	1.89	5.36	0.206	1.37	0.84	2.25
Convenience bus 2	**<0.001**	1.13	1.07	1.21	**<0.001**	0.63	0.53	0.74	0.489	1.18	0.74	1.90	0.060	0.85	0.72	1.01	0.629	0.90	0.59	1.38
Convenience train 1	**0.015**	1.68	1.10	2.54	0.210	0.73	0.45	1.19	**0.012**	1.51	1.10	2.09	0.111	1.46	0.92	2.33	0.071	0.55	0.29	1.05
Convenience train 2	0.075	0.73	0.51	1.03	**0.012**	0.72	0.55	0.93	0.269	0.84	0.61	1.15	0.151	0.72	0.46	1.13	**<0.001**	0.32	0.18	0.58
No PT	**<0.001**	0.47	0.43	0.51	0.716	0.88	0.45	1.73	0.934	0.99	0.73	1.33	0.918	1.04	0.52	2.07	**<0.001**	0.18	0.10	0.31
Female	0.919	1.02	0.65	1.60	**<0.001**	2.94	1.99	4.34	0.336	0.81	0.52	1.25	0.796	0.98	0.81	1.18	**0.001**	1.54	1.19	1.99
Income1	**0.001**	0.24	0.10	0.58	**<0.001**	0.15	0.10	0.23	0.574	1.48	0.38	5.86	0.446	0.68	0.25	1.83	0.324	2.90	0.35	24.06
Income2	**<0.001**	2.46	1.75	3.47	0.583	1.17	0.66	2.08	0.547	0.77	0.32	1.82	0.418	1.56	0.53	4.62	**0.003**	0.22	0.08	0.59
Income3	0.977	0.99	0.54	1.82	0.133	0.83	0.66	1.06	**<0.001**	0.55	0.45	0.67	0.706	0.86	0.40	1.85	0.813	0.96	0.71	1.31
Ethnicity	0.081	1.58	0.95	2.65	**0.027**	0.43	0.21	0.91	**0.014**	1.35	1.06	1.71	0.380	0.78	0.45	1.35	0.480	1.43	0.53	3.82
No car	0.229	0.76	0.49	1.19	0.979	0.99	0.50	1.96	0.712	0.93	0.63	1.37	**<0.001**	0.30	0.20	0.45	0.711	1.15	0.56	2.36
No bicycle	0.645	0.93	0.67	1.28	0.432	0.61	0.17	2.11	**<0.001**	0.49	0.35	0.67	**0.001**	3.68	1.75	7.75	0.243	1.18	0.89	1.56
p-value	*0.084*				***<0.001***				*0.311*				***<0.001***				***0.003***			

4.2.1.3 Ratings of predefined barriers

This section compares the ratings of the predefined barriers (Q21-Q23; on a scale of 1 (disagree) to 7 (agree)) across the four urban environments. Table 4-3 presents the median ratings for all predefined barriers for each of the four neighbourhoods, together with the Kruskal-Wallis test results (the *H*-statistic and *p*-value). Finally, the table also includes the results of the post-hoc Dunn tests, which tested how the neighbourhoods actually differed. These results are presented as letters (a, b, c); neighbourhoods with the same letter do not significantly differ in their ratings. If a neighbourhood has a double letter, it means it shares characteristics with two neighbourhood groups. The *p*-value of the Kruskal-Wallis test indicates whether the neighbourhood had a significant influence on the rating of the barrier (significance level α = 0.05). As can be observed, the neighbourhood played a significant role in six of the eleven walk barriers, only three of the bus barriers, and all of the train barriers.

Table 4-3 Median barrier ratings per neighbourhood and results for Kruskal-Wallis tests and the Post-hoc Dunn test (BO: Bournville, MO: Moseley, CV: Castle Vale, SH: Small Heath; bold: p < 0.05)

Barrier	**Median**				**Kruskal-Wallis**		**Post-hoc Dunn test Groupings**			
	BO	MO	CV	SH	*H*	*p*	BO	MO	CV	SH
Walking often takes too much time	5	5	4	5	2.131	0.546				
I do not feel safe in traffic when I walk	2	2	3.5	3.5	9.468	**0.024**	a	a	b	ab
I feel unsafe when I walk at night	4	5	6	6	21.313	**0.000**	a	a	b	b
I feel unsafe when I walk during the day	1	1	2	1	7.330	**0.062**	a	ab	b	ab
The walking routes are unpleasant	3	4	4	4	13.691	**0.003**	a	b	b	b
The pavements are of bad quality	4	4	4	5	19.551	**0.000**	ab	b	ac	c
I often feel too tired to walk	2	2	3	2	6.324	0.097				

Barrier	Median				Kruskal-Wallis		Post-hoc Dunn test Groupings			
	BO	MO	CV	SH	*H*	*p*	BO	MO	CV	SH
I am too lazy to walk	1	1	1	1	1.141	0.767				
I won't walk when it is raining	3	4	3	5	7.771	0.051				
I won't walk when I need to carry some luggage	4	5	4	5.5	10.678	**0.014**	a	b	ab	ab
I'd like to have more places to rest	2	2	4	4	24.782	**0.000**	a	a	b	b
The distance to the bus stop is too far	1	2	1	1	15.154	**0.002**	a	b	ab	ab
Travelling by bus takes too much time for my trips	6	5	5	4	13.574	**0.004**	a	b	ab	b
I do not feel safe on buses	4	3	4	4	4.511	0.211				
I won't take the bus if I need to carry some luggage	4	4	4	5	5.498	0.139				
Buses are often too crowded for me	5	4	4.5	5	6.156	0.104				
Buses are too expensive	5	4	4	5	2.428	0.488				
The bus system is too complicated	4	2	2.5	2	18.957	**0.000**	a	b	b	b
I don't like the other people on the bus	4	4	4	4	5.600	0.133				
I suffer from travel sickness on the bus	1	1	1	1	7.661	0.054				
The distance to the train station is too far	1	7	7	6	290.81	**0.000**	a	b	b	b
Travelling by train takes too much time for my trips	1	4	4	4	91.455	**0.000**	a	b	b	b
I do not feel safe on trains and at stations	1	1	4	4	27.551	**0.000**	a	a	b	b
I won't take the train if I need to carry some luggage	1	2	4	4	33.176	**0.000**	a	b	bc	c
Trains are often too crowded for me	4	4	4	4	9.509	**0.023**	a	a	b	ab
Trains are too expensive	4	5	5	6	17.984	**0.000**	a	b	b	b
The railway system is too complicated	1	2	4	4	32.212	**0.000**	a	c	b	b
I don't like the other people on the train	2	2	4	3	20.150	**0.000**	a	a	b	a
I suffer from travel sickness on the train	1	1	1	1	21.342	**0.000**	a	a	ab	b

With regard to the potential walking barriers, time was one of the barriers that on average was rated highest by respondents and consistently so across the neighbourhoods. Safety feelings during the day, tiredness, laziness and rain also scored similarly across the four areas. The other barriers all showed significant differences across the neighbourhoods. The three safety-related barriers tended to be more of influence in the two deprived areas. Especially in Castle Vale people feel more unsafe during both the day and night. Safety at night has a larger influence on walking than safety feelings during the day. The unpleasantness of routes and pavement quality played a smaller role in Bournville than in the other areas. Regarding luggage and the need for places to rest there seemed to be a difference between the deprived and the less deprived areas.

For trains, the experience differed significantly across neighbourhoods for all potential barriers, while for buses only access distance, time and understandability of the system were significantly different. Expense, distance, crowding and time are the barriers respondents agreed with most overall for trains. For buses distance was perceived to be much less of an issue, whilst luggage and the presence of other people in public transport acted more as a barrier.

The distance to bus stops was considered too great slightly more in Moseley, which is understandable since the average bus distance to the closest bus stop is about one and a half times as high as in the other neighbourhoods. In Bournville people more often found that bus journeys take too much time, while in Small Heath this was less common. The understandability of the bus system was more of an issue in Bournville, whilst for trains understandability acted least as a barrier in this neighbourhood. Furthermore, for trains, safety, luggage, complicatedness and travel sickness are rated highest in the two deprived areas. Crowding, expense and the presence of other people were all perceived more as a barrier in Castle Vale.

To get a deeper insight into potentially influencing variables, logistic regression models were estimated, for which the results are shown in Figure 4-4 to Figure 4-6. The results are presented graphically instead of using tables, as there are a large number of models, which would otherwise be hard to compare. Odds ratios below 1 mean that the variable has a negative influence on the odds of being positive, ratios above 1 have a positive effect on the odds. Parameters that were significant ($p < 0.05$) are coloured red in the plots. The plots are limited to ratios of maximum 10 for visibility purposes.

Overall, for barriers to walking, the convenience score for trains, neighbourhood deprivation and ethnicity seem to be the most influential on the ratings. The train convenience seems to show a U-shaped relationship with walking barriers. People who have no trains at all available nearby have higher odds of agreeing with the walk barriers than those with a minimum train convenience, whilst a higher train convenience generally leads to higher odds too. The level of neighbourhood deprivation has a clear positive influence on the odds of agreeing with walk barriers (except for luggage, rain and safety feelings during the day). For ethnicity, most odds ratios are below 1, meaning that people of white ethnicity tend to experience less barriers to walking than those of other ethnicities.

The convenience scores for both bus and train transport also seem to have some influence on barriers to public transport, particularly to bus use. A higher train convenience score tends to lead to a larger experience of barriers to buses and a smaller experience of barriers to train use. The higher the bus use convenience score, the smaller the experience of bus barriers generally, except for expense and travel sickness. Also for trains the barriers tend to be smaller for higher bus convenience, with a few mixed results. In contrast to the walk barriers, the influence of neighbourhood deprivation and ethnicity on the barriers to public transport is limited. On the barriers to bus use these two factors have no significant influence at all.

The availability of a car is found to lead to a higher odds of finding trains too expensive, but lower odds of not liking other people on the train or finding the railway system too complicated. Regarding bus use, there are higher odds of finding that the bus takes too much time, are too crowded, or that luggage or safety act as a barrier. People who have a bicycle available have higher odds of finding trains too expensive, too crowded and not liking other people on the train. Those with bicycles experience crowding and safety more as a barrier to bus use, whilst expense is less of an issue.

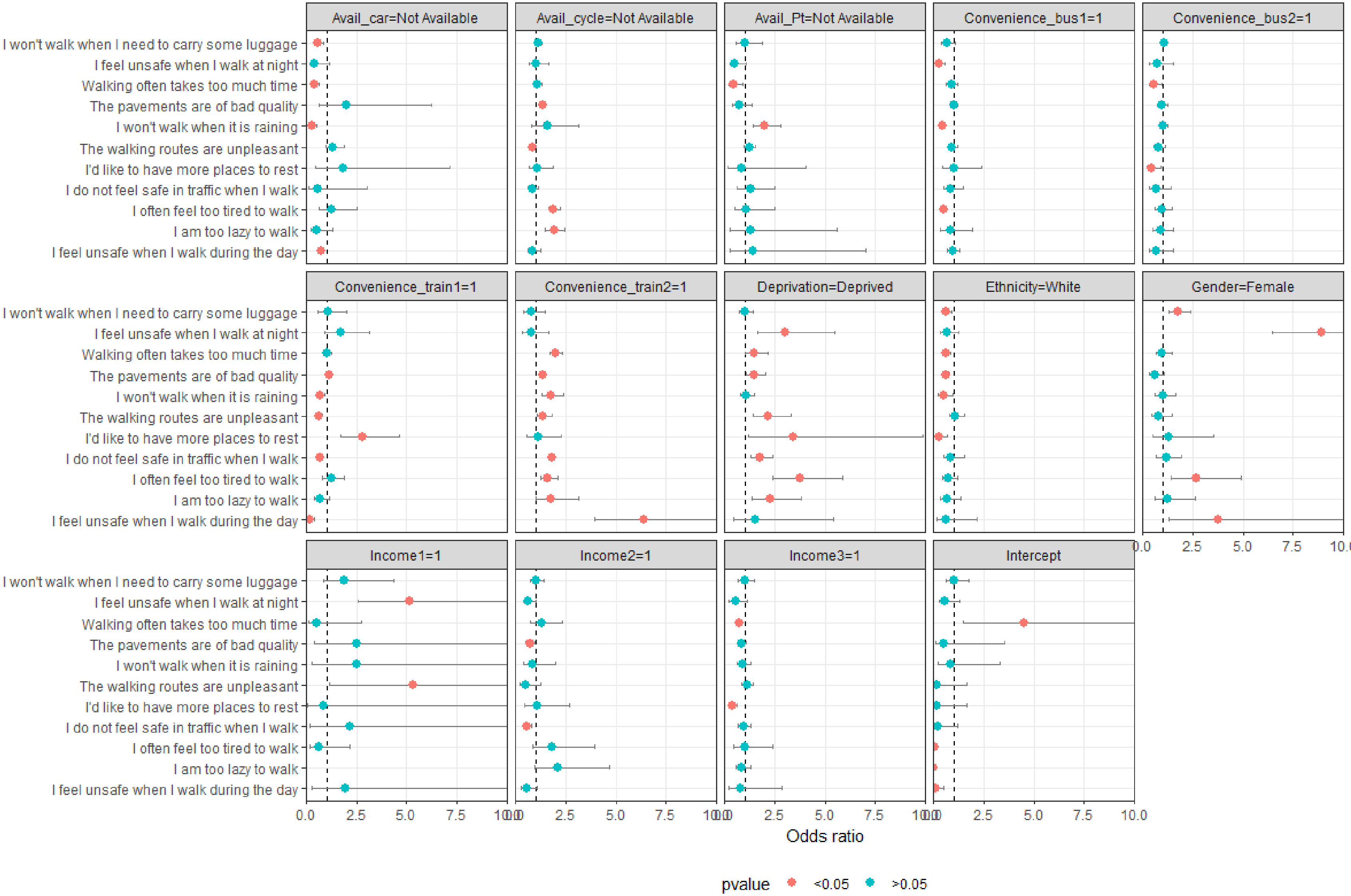


Figure 4-4 Odds ratio plots for walk barrier ratings

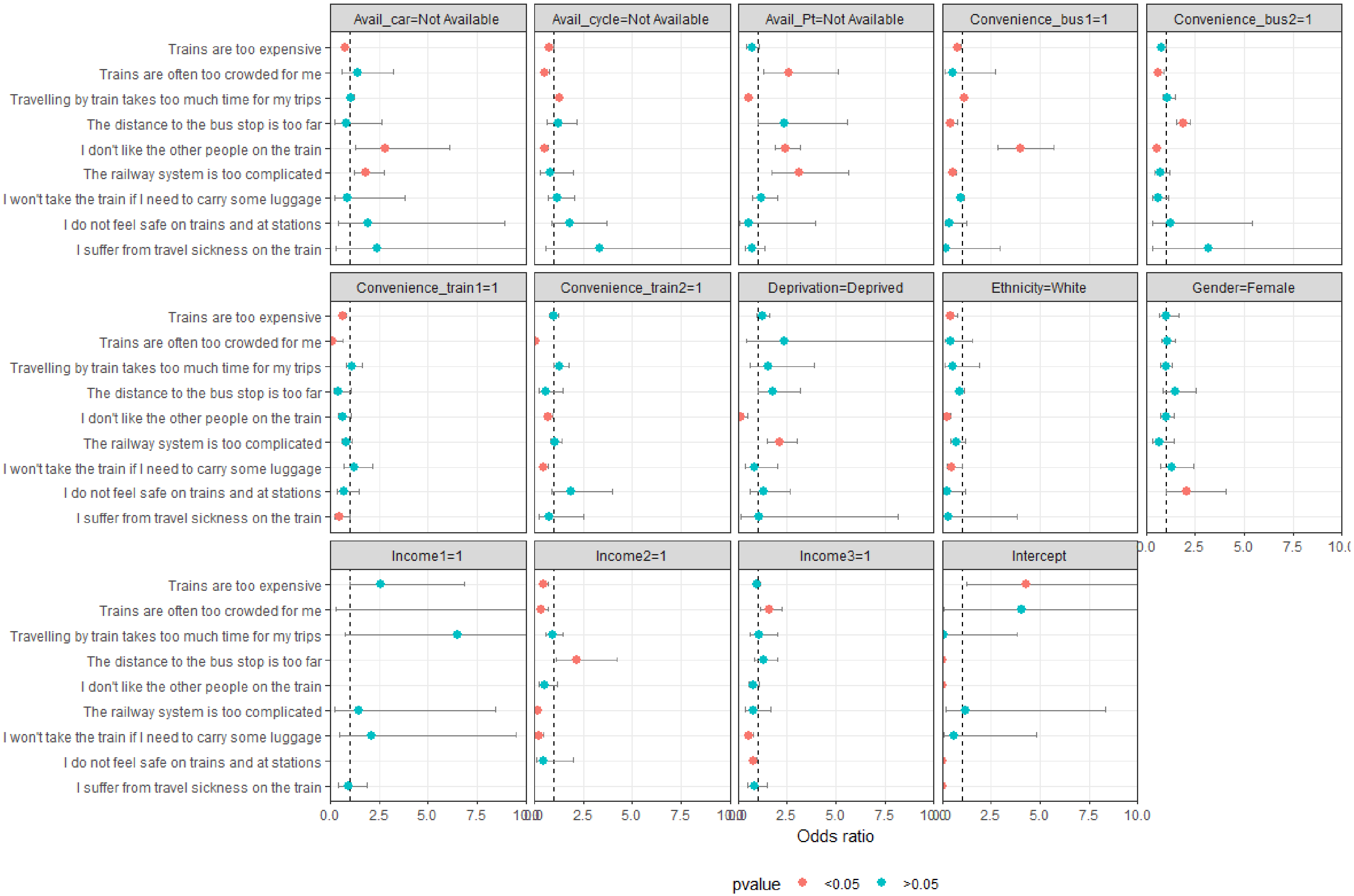


Figure 4-5 Odds ratio plots for train barrier ratings

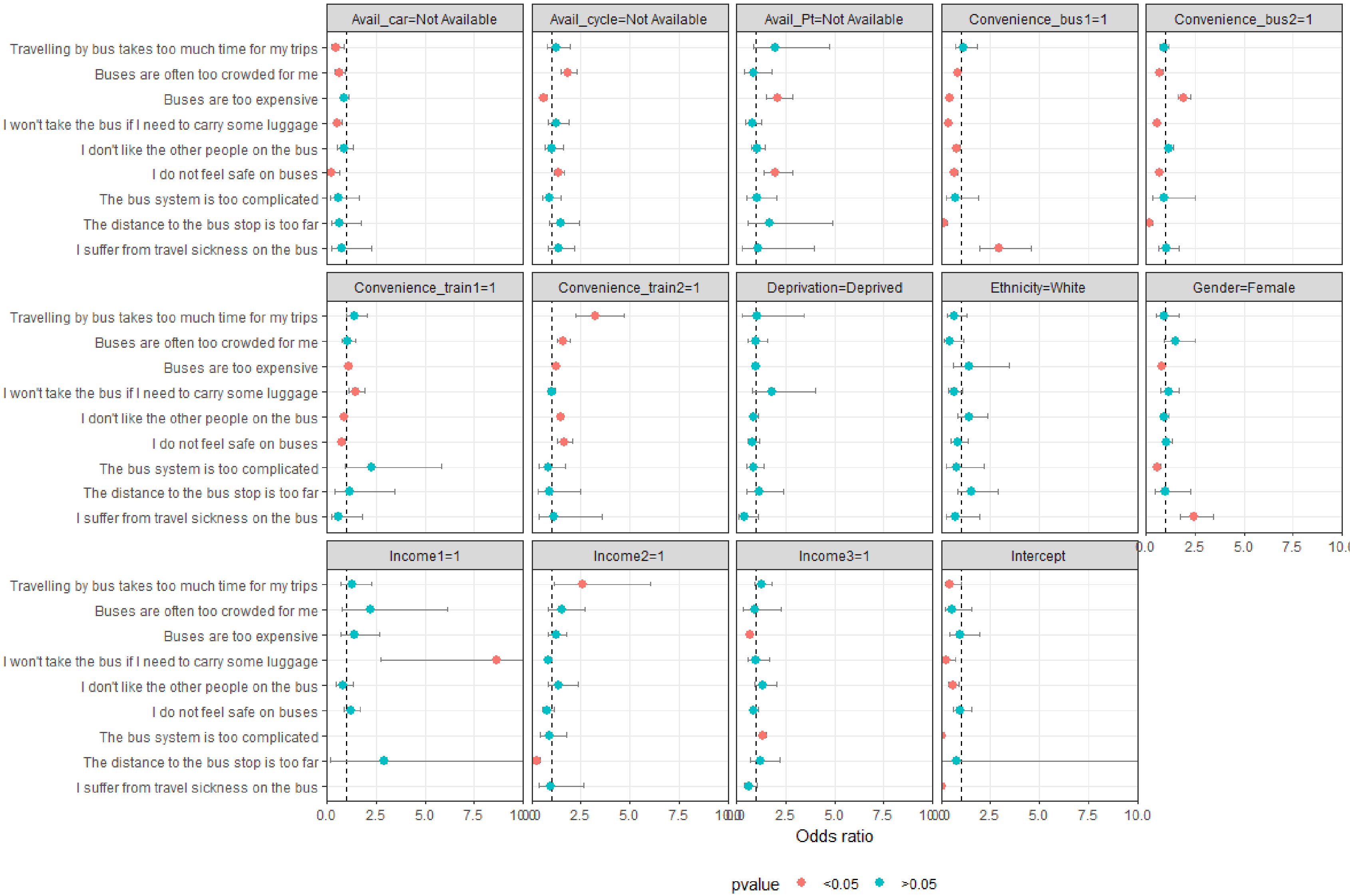


Figure 4-6 Odds ratio plots for bus barrier ratings

4.2.2 Relationship with behaviour

4.2.2.1 Associations and affect

After getting insights into the differences in perceptions of five transport modes, and how the environment influences these, it is of interest to investigate to what extent these free associations relate to actual mode use behaviour. In this section, the way in which the frequency of mode use is related to the associations that people gave with certain modes is presented. Results for the χ^2-tests to compare the content of associations and the Kendall's tau correlations for affective rating are presented in Table 4-4.

As might be expected, the content of the associations with each of the five modes appeared to be significantly related with the use of the respective mode. The people who use a mode often associate that mode much more with its positive qualities, whilst the people who rarely or never use it think much more about negative aspects. This is also reflected in the positive correlations between the affective rating and mode use frequency. For instance, regular bus users are distinctive by referring to 'saving money', the perception that travelling by bus is a relatively cheap mode of transport. People who never use buses refer to safety issues, waiting, unpleasantness and information provision. For other modes, a similar pattern appeared. Frequent cyclists perceive cycling to be convenient, healthy, enjoyable and fast, whereas those who never cycle find it inconvenient, do not like it and find it unsafe. Frequent walkers referred to the outdoor environment, convenience and enjoyment; those who never or rarely walk think about the need for special clothing or gear, about traffic and about weather, but also that it is healthy. For trains and car driving, the frequent users also distinctively associate the respective modes with some negative aspects, such as the need for petrol or the behaviour of other drivers in the case of car driving, or cleanliness issues and unreliability for train users.

Moreover, there appeared to be various significant relationships between the perceptions of a mode and the usage frequency of other modes. In terms of affect, car driving is the most distinctive mode: a higher positivity about cars is related to a lower usage frequency of the other modes. Related to this, opposite observations can be made on other modes, where a higher positivity about those modes is related to a lower car driving frequency. Because the main interest is to eventually establish a modal shift from car travel to public transport, it is not favourable that car drivers think less positively about alternative modes. Frequent car users associate buses more often with unsafety, issues around paying and information provision, which points at their unfamiliarity with the services. Cycling is more often associated with the negative aspects weather, safety, traffic and pollution. For trains, however, frequent or regular car drivers refer often to the fact that you can relax and the cheapness (although some found trains expensive instead), along with time and access issues and inconvenience. This suggests that there can be groups of car users who have positive perceptions about trains and who might be willing to use trains more if a reasonable service is offered, for instance by reducing the access barrier.

Table 4-4 Test results for the relationships between associations and mode use – Shaded rows show the results of the relationships between perceptions and usage of the same mode

Perception	Behaviour (frequency of use)	Content					Affective rating	
		χ^2	df	*p*	simulated *p*	# codes	Kendall's Tau	*p*
Walking	Walking	71.799	51	**0.029**	**0.029**	18	0.123	**0.001**
	Car driving	61.618	51	0.147	0.141	18	-0.072	**0.042**
	Train riding	60.711	51	0.166	0.164	18	0.079	**0.027**
	Cycling	31.602	32	0.487	0.487	17	0.044	0.243
	Bus riding	29.967	34	0.666	0.667	18	0.007	0.845
Driving	Walking	32.017	39	0.778	0.786	14	-0.115	**0.001**
	Car driving	72.396	39	**0.001**	**0.001**	14	0.150	**<0.001**
	Train riding	39.002	39	0.470	0.468	14	-0.108	**0.003**
	Cycling	31.627	26	0.206	0.201	14	-0.086	**0.023**
	Bus riding	31.558	26	0.208	0.201	14	-0.078	**0.033**
Train use	Walking	72.996	48	**0.012**	**0.012**	17	0.081	**0.021**
	Car driving	89.272	48	**<0.001**	**<0.001**	17	-0.017	0.621
	Train riding	145.164	48	**<0.001**	**<0.001**	17	0.179	**<0.001**
	Cycling	47.661	32	**0.037**	**0.039**	17	0.062	0.100
	Bus riding	36.060	32	0.284	0.278	17	0.014	0.710
Cycling	Walking	50.135	48	0.389	0.387	17	0.022	0.551
	Car driving	70.811	48	**0.018**	**0.018**	17	-0.117	**0.001**
	Train riding	54.671	48	0.236	0.237	17	0.019	0.596
	Cycling	151.921	30	**<0.001**	**<0.001**	16	0.404	**<0.001**
	Bus riding	26.815	32	0.727	0.733	17	0.016	0.664
Bus use	Walking	64.976	54	0.146	0.136	19	0.063	0.080
	Car driving	85.987	54	**0.004**	**0.004**	19	-0.061	0.084
	Train riding	57.384	54	0.351	0.342	19	-0.088	**0.015**
	Cycling	34.198	36	0.555	0.557	19	0.058	0.125
	Bus riding	101.492	36	**<0.001**	**<0.001**	19	0.280	**<0.001**

4.2.2.2 Predefined barriers

Table 4-5 displays the Kendall correlation values and p-values for the relationships between mode use and the ratings of pre-defined barriers. The number of walking trips per week is significantly negatively correlated with most of the barriers against walking, except for the two barriers related to the environment and infrastructure. Furthermore, all train barriers show significant negative correlations and some of the barriers to bus use. Similarly, bus use is significantly negatively correlated with most of the bus barriers, and positively with the train barrier ‘distance to the station’, which indicates that those who do not have a train station nearby travel more by bus. There are also a few walk barriers which are negatively correlated with bus use (time, laziness, rain and luggage). Train use is significantly negatively correlated with most train barriers and several bus barriers, although the bus barriers ‘time’ and ‘too complicated’ show a positive correlation with train use. There are also some negative correlations with walk barriers.

Cycling and driving also both show various correlations with the barriers to walking, bus use and train use. For cycling, all significant correlations are negative, except for the access distance to the train station. For driving, all significant correlations are positive, which reflects its position as the most commonly used transport mode for which public transport is an alternative.

Table 4-5 Correlation values for barrier ratings and mode use (bold: $p < 0,05$)

		Walking		Bus		Train		Cycling		Driving	
	Barrier	**Kendall's Tau**	***p***	**Kendall's Tau**	***p***	**Kendall's Tau**	***p***	**Kendall's Tau**	***p***	**Kendall's Tau**	***p***
Walking	Time	-0.221	**0.000**	-0.136	**0.000**	-0.065	0.076	-0.003	0.940	0.143	**0.000**
	Traffic safety	-0.087	**0.019**	0.016	0.673	-0.057	0.132	-0.081	**0.042**	-0.038	0.306
	Safety night	-0.161	**0.000**	-0.051	0.176	-0.112	**0.002**	-0.121	**0.002**	0.098	**0.006**
	Safety day	-0.162	**0.000**	-0.043	0.273	-0.029	0.461	-0.097	**0.018**	0.093	**0.014**
	Unpleasant routes	-0.045	0.214	0.072	0.056	-0.035	0.340	-0.018	0.638	-0.027	0.457
	Bad pavements	-0.038	0.292	-0.031	0.403	-0.009	0.797	-0.064	0.097	-0.031	0.381
	Tired	-0.229	**0.000**	-0.047	0.228	-0.044	0.242	-0.111	**0.006**	0.069	0.064
	Lazy	-0.288	**0.000**	-0.142	**0.000**	-0.049	0.198	-0.062	0.126	0.150	**0.000**
	Rain	-0.321	**0.000**	-0.197	**0.000**	-0.141	**0.000**	-0.157	**0.000**	0.264	**0.000**
	Luggage	-0.273	**0.000**	-0.147	**0.000**	-0.180	**0.000**	-0.093	**0.016**	0.226	**0.000**
	Rest places	-0.078	**0.040**	0.000	0.998	-0.093	**0.015**	-0.076	0.058	0.024	0.522
Bus	Access distance	-0.112	**0.003**	-0.095	**0.016**	-0.098	**0.012**	-0.022	0.594	0.067	0.080
	Time	-0.172	**0.000**	-0.283	**0.000**	0.088	**0.018**	-0.024	0.542	0.173	**0.000**
	Feel unsafe	-0.134	**0.000**	-0.145	**0.000**	-0.052	0.156	-0.088	**0.023**	0.131	**0.000**
	Luggage	-0.144	**0.000**	-0.180	**0.000**	-0.091	**0.013**	-0.108	**0.005**	0.218	**0.000**
	Crowding	-0.150	**0.000**	-0.192	**0.000**	0.011	0.772	-0.148	**0.000**	0.127	**0.000**
	Expensive	-0.052	0.150	-0.131	**0.001**	0.011	0.758	0.004	0.924	0.077	**0.033**
	Complicated	-0.036	0.327	-0.203	**0.000**	0.095	**0.011**	-0.030	0.436	0.089	**0.015**
	Other people	-0.057	0.118	-0.141	**0.000**	0.038	0.306	-0.068	0.080	0.002	0.950
	Travel sickness	-0.042	0.285	-0.070	0.083	0.034	0.400	-0.010	0.815	-0.003	0.947
Train	Access distance	-0.125	**0.001**	0.150	**0.000**	-0.488	**0.000**	0.090	**0.024**	0.114	**0.002**
	Time	-0.218	**0.000**	-0.030	0.434	-0.421	**0.000**	-0.003	0.930	0.155	**0.000**
	Feel unsafe	-0.084	**0.027**	-0.020	0.610	-0.166	**0.000**	-0.152	**0.000**	0.078	**0.041**
	Luggage	-0.131	**0.001**	-0.054	0.167	-0.207	**0.000**	-0.066	0.101	0.143	**0.000**
	Crowding	-0.083	**0.022**	-0.010	0.796	-0.023	0.525	-0.106	**0.006**	-0.020	0.578

	Walking		Bus		Train		Cycling		Driving	
Barrier	**Kendall's Tau**	***p***	**Kendall's Tau**	***p***	**Kendall's Tau**	***p***	**Kendall's Tau**	***p***	**Kendall's Tau**	***p***
Expensive	-0.087	**0.018**	-0.018	0.637	-0.141	**0.000**	-0.024	0.536	0.003	0.938
Complicated	-0.128	**0.001**	-0.039	0.320	-0.200	**0.000**	-0.069	0.086	0.034	0.372
Other people	-0.077	**0.041**	-0.010	0.799	-0.026	0.498	-0.158	**0.000**	-0.005	0.899
Travel sickness	-0.123	**0.002**	-0.033	0.427	-0.096	**0.019**	-0.058	0.171	0.065	0.103

4.2.3 Relationships between modes regarding associations and barriers

4.2.3.1 Predefined barriers

A visualisation of the Kendall Tau correlations (Figure 4-7) between the barrier ratings reveals that the great majority of barriers are positively correlated with each other, meaning that if someone stated that he or she experienced a certain barrier, it is likely that that person experienced other barriers as well. Correlations appear to be stronger between barriers towards the same mode. There is also a clear diagonal visible between the bus and train barriers. These two sets of barriers were essentially the same, and people tended to experience them on both modes, except for the distance to the stop/station and the time it takes to travel with that mode. Furthermore, there appears to be some relationship between the walking barriers and the experience of safety, luggage and crowding as a barrier on buses and trains as well as the experience of understandability of the train system and the presence of other people on trains.

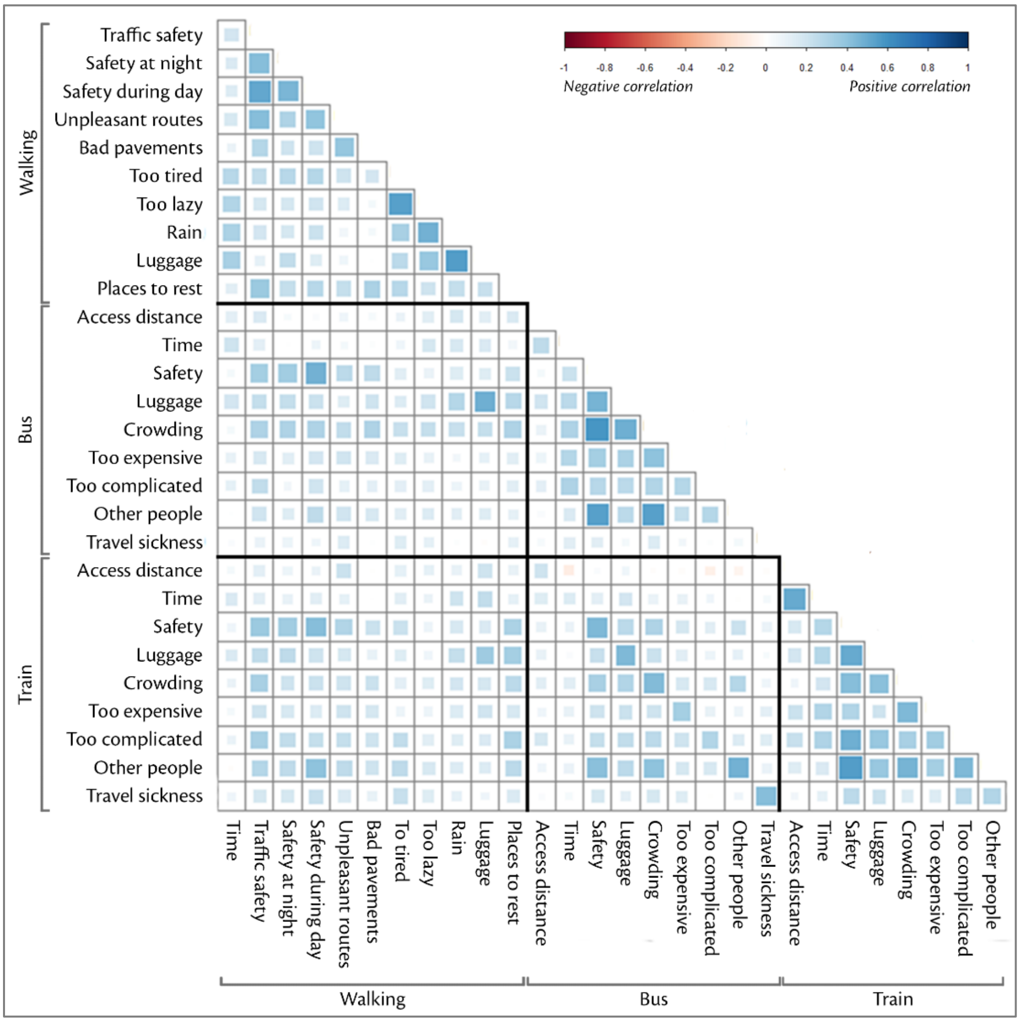


Figure 4-7 Visual correlation matrix for predefined barriers

4.2.3.2 Associations

Using a series of χ^2-tests, it was assessed whether the content of the associations with a mode differs significantly for people who agree, disagree or are neutral about the influence of a certain barrier. The results for the pre-defined walking barriers are shown in Table 4-6. This shows the experience of most barriers to urban walking is significantly related to the content of the associations with walking ($\alpha = 0.05$). There are only a few significant relationships with the images of public transport. People for whom traffic safety is a barrier to walking, or who would like to see more rest places, think differently about bus use. People for whom laziness or luggage form a barrier to walking think differently about train use.

Table 4-6 χ^2-test results for walking barriers and free associations [χ^2-statistic (degrees of freedom); p-value] (bold: p < 0,05)

Barrier to walking	**Walk**	**Bus**	**Train**
Takes too much time	**52.632 (34); 0.022**	23.148 (36); 0.953	30.297 (30); 0.455
Not feel safe in traffic	**75.714 (34); <0.001**	**52.096 (36); 0.040**	41.463 (30); 0.079
Unsafe at night	**71.430 (34); <0.001**	41.029 (36); 0.255	29.367 (28); 0.394
Unsafe during day	**87.754 (34); <0.001**	50.380 (36); 0.054	41.308 (30); 0.081
Unpleasant routes	**82.249 (34); <0.001**	38.270 (36); 0.367	39.578 (30); 0.113
Bad pavements	**56.514 (34); 0.009**	48.445 (36); 0.080	29.760 (30); 0.478
Often too tired	39.975 (34); 0.222	37.093 (36); 0.418	36.690 (30); 0.186
Too lazy	**65.935 (34); <0.001**	49.993 (36); 0.061	**47.600 (30); 0.022**
Rain	**55.746 (34); 0.011**	36.484 (36); 0.446	34.668 (30); 0.255
Luggage	27.418 (34); 0.781	28.249 (36); 0.818	**52.902 (30); 0.006**
Need for places to rest	34.289 (32); 0.358	**51.113 (36); 0.049**	35.486 (30); 0.225

Respondents who experienced traffic safety as a barrier to walking referred more to access issues when thinking about the bus, along with crowding and smelliness. People who desired more places to rest referred more often to waiting issues when thinking about buses and smelliness. The respondents who said they were often too lazy to walk referred more to access issues and unpleasantness when thinking about trains. Those for whom luggage is a barrier to walking associated trains more with expensiveness, access issues, inconvenience and relaxation. These results suggest that some barriers to walking also relate to how people think about using public transport, especially since access issues tend to be relatively often present in their public transport imagery.

The relationships with the predefined barriers to bus use are presented in Table 4-7. As expected, most barriers are significantly related to free associations with bus use. People who do not feel safe on the bus, or for whom luggage is a barrier, think differently about walking too. People for whom buses are too crowded or who do not like the presence of other people on the bus think differently about trains.

Table 4-7 χ^2-test results for bus barriers and free associations [χ^2-statistic (degrees of freedom); p-value] (bold: p < 0,05)

Barrier to bus	**Walk**	**Bus**	**Train**
Distance to stop	36.673 (32); 0.261	**69.542 (36); <0.001**	26.759 (28); 0.531
Takes too much time	32.493 (32); 0.442	**68.891 (36); <0.001**	26.070 (30); 0.672
Not feel safe	**54.519 (32); 0.008**	**160.561 (36); <0.001**	33.254 (28); 0.227
Luggage	**46.800 (32); 0.044**	**67.502 (36); 0.001**	39.075 (28); 0.080
Too crowded	36.263 (32); 0.276	**149.842 (36); <0.001**	**64.180 (30); <0.001**
Too expensive	43.311 (32); 0.088	**172.354 (36); <0.001**	38.683 (30); 0.133
Too complicated	41.887 (32); 0.113	**55.501 (36); 0.020**	33.829 (28); 0.207
Don’t like other people	44.031 (32); 0.076	**121.195 (36); <0.001**	**58.556 (28); <0.001**
Suffer from travel sickness	44.927 (32); 0.064	30.538 (36); 0.726	24.659 (28); 0.646

Respondents who do not feel safe on the bus associate walking relatively often with issues regarding cleanliness, traffic, time and pollution. Those for whom luggage is a barrier to bus use refer more to the need for special gear and concerns about cleanliness, traffic, time and traffic safety when thinking about walking. People for whom crowding is an issue on buses associate train use also relatively often with crowding, along with cleanliness issues and inconvenience. The respondents for whom the presence of other people is a barrier to bus use referred relatively often to cleanliness, expensiveness, and crowding, as well as relaxation.

The relationships with the predefined barriers to train use are presented in Table 4-8. The experience of all barriers to train use is not only significantly related to the imagery about trains, but also to bus imagery. The respondents who experienced certain barriers to trains tended to associate bus use also with those issues. People who experience the distance to the stop/station to be too far, for whom trains are too crowded, or who see luggage as a barrier think significantly differently about walking too, and associate walking relatively often with concerns about time, cleanliness, weather, traffic and the need for special clothing. This shows that the experience of some barriers to bus and train use is related to a more negative image about walking, in which certain concerns play a larger role.

Table 4-8 χ^2-test results for train barriers and free associations [χ^2-statistic (degrees of freedom); p-value] (bold: p < 0,05)

Barrier to train	**Walk**	**Bus**	**Train**
Distance to station	**53.571 (34); 0.018**	**59.974 (36); 0.007**	**157.301 (30); <0.001**
Takes too much time	43.374 (32); 0.086	**54.529 (36); 0.025**	**139.199 (30); <0.001**
Not feel safe	38.514 (32); 0.199	**76.048 (36); <0.001**	**63.796 (30); <0.001**
Luggage	**55.028 (32); 0.007**	**56.335 (36); 0.017**	**56.965 (28); 0.001**
Too crowded	**48.847 (32); 0.029**	**60.232 (36); 0.007**	**130.168 (30); <0.001**
Too expensive	21.087 (30); 0.885	**61.636 (36); 0.005**	**117.947 (30); <0.001**
Too complicated	35.609 (30); 0.221	49.033 (36); 0.072	**65.854 (28); <0.001**
Don't like other people	44.395 (32); 0.071	**75.082 (36); <0.001**	**114.208 (30); <0.001**
Suffer from travel sickness	41.565 (32); 0.120	35.064 (36); 0.513	**45.324 (30); 0.036**

4.3 Summary

Different transport modes were shown to be perceived differently by the public. Walking seemed to be much more positively perceived than the other modes. Bus and train were associated with similar concepts, although the bus was perceived more negatively. For the trains, unreliability and crowding were the most important negative aspects. For buses these aspects were also important as well as expense.

For all modes the perceptions were significantly different across neighbourhoods, except for car driving. These perceptions were found to be influenced by the level of neighbourhood deprivation, the physical environment of the neighbourhood, and the public transport provision. When considering the affective rating, the role of neighbourhood deprivation seemed to be mostly related to differences in socio-demographic characteristics.

Plenty of predefined barriers were rated differently across the neighbourhoods as well, especially barriers to train use. Also here public transport provision and the level of deprivation seemed to play a role. The regression models confirmed this for the barriers to walking. For the barriers to bus and train use, the level of neighbourhood deprivation had very little effect, however, although for train barriers income and ethnicity tended to have some effect.

The perceived barriers also showed relationships with the actual mode use behaviour. The content of the associations appeared to be related to the use of the respective mode, in which the users of a mode refer more often to positive qualities and those who never or rarely use the mode associate it much more with negative aspects. There were also cross-relationships between the perceptions of a mode and the use of other modes, in which car driving was the most distinctive. A more positive perception of this mode is related to lower usage of the other modes.

These relationships between modes were explored further. The ratings of predefined barriers were found to be related to each other, mostly within modes, but also to those of other modes. Especially for bus and train the ratings were strongly related. Barriers experienced to walking also appeared to correlate with some specific barriers to bus and train use. The ratings were found to be related to the content of the free associations as well. Again, this was mostly within the same mode, but especially for the experience of barriers to train use the content of associations with bus usage differed significantly too. These results are discussed in more detail in Section 6.2.

5. RESULTS AND ANALYSIS: TRACKING SURVEY

5.1 Introduction

This chapter presents the results and analysis of the data obtained through the smartphone tracking survey, which primarily aimed at addressing Objectives 4 and 5. The major analytical steps taken in this chapter were outlined in Section 3.7.2 (Chapter 3: Methods). This chapter consists of four subsections, besides this introduction. Firstly, some additional comments are provided on the analyses and the measures used. Then some characteristics of the dataset that was gathered are described. The main body of the chapter is Section 5.4, which describes the actual results of all analyses. This section contains two main subsections. The first one presents the analysis of the walk stages to and from PT trips, whereas the second subsection deals with the analysis of car trips. Finally, the chapter is summarised in Section 5.5.

5.2 Overview of analysis and measures

The two main types of trips that are of interest regarding the objectives of the current research are the PT trips and the car trips. For trips undertaken by PT, the aim is to analyse the access and egress walk stages. Of major interest is the amount of walking that occurs for different PT trips. The influence of PT provision on these walk distances is currently underexplored. Car trips are of interest as this is the most prevalent alternative mode to PT travel, with many adverse effects to the urban community. Regarding a potential modal shift towards PT use, which would offer benefits to society as well as the individual (e.g. health benefits as a result of increased walking), it is to be explored how much walking is omitted by these car trips and the role walking plays in the decision to not use PT.

The distance walked to and from PT is basically measured by calculating the distance between all subsequent recorded location points, between the origin point where the walk started to the point at the PT stop (in case of an access walk). This seems to be a simple straight-forward measure, but it is not in all cases clear where the walk starts or stops. For example, a traveller can visit a shop while walking to the station. Strictly speaking, this would mean the traveller undertakes two walk trips: from home to the shop and from the shop to the station, of which only the latter is a walk to access PT. One could also argue, however, that both walks should be counted together as a PT access walk. Similarly, when someone travels to a high street for some leisure shopping, the person does not necessarily have a specific destination in mind. He or she can walk along several stops, perhaps while doing some window shopping, and eventually pop into a store, after which he or she walks to a next shop, etc. It is disputable how much of this walking should be considered as part of the egress trip stage related to the PT trip. To avoid confusions, especially since it is hard to infer the thought processes underlying the behaviour observed from the raw data, the analyses are based on the directly linked walk stages only.

In the next section, firstly some general descriptive statistics for the PT-related walks are studied. This is followed by an investigation of some potential influences on these walk distances. These include the people's attitudes, geographical location and PT service provision. The attitude is measured through the clustering of responses to attitudinal questions in the questionnaire. PT provision is defined using various measures related to the convenience of PT near the home location.

5.3 Data

In total, 120,698 location points were registered by the participants. All the location points obtained were processed following the steps outlined in section 3.3. After annotating the trips in Microsoft Access databases, the tables with trips and destinations were exported to plain table files, which could then be loaded and merged into R. This resulted into a unified table with all trip legs registered for all users. There were 827 trip legs in total; the distribution across modes is displayed in Table 5-1. Overall the distribution of trip legs between the two areas is similar to the distribution of participants (63% of trip legs in Moseley versus 64% of the participants). As can be derived from the percentages, participants living in Bournville registered relatively high proportions of PT trips (both the percentage of bus trip legs and train trip legs is significantly higher than 37%).

Table 5-1 Number of trip legs inferred per mode and distribution between the two neighbourhoods

Mode	**n**	**Moseley**		**Bournville**	
Bus	37	20	*54%*	17	*46%*
Car	291	199	*68%*	92	*32%*
Cycle	93	62	*67%*	31	*33%*
Train	43	11	*26%*	32	*74%*
Tram	2	2	*100%*	0	*0%*
Walk	351	219	*62%*	132	*38%*
NA	10	8	*80%*	2	*20%*
Total	**827**	**521**	***63%***	**306**	***37%***

The phones collected data for different durations. Participants were asked to let the app run for at least a day, but preferably a week. In many cases, there are however temporal gaps in the data, which can be due to various reasons. Figure 5-1 shows the distribution of the number of days about which data is collected per participant. As can be seen, there are nine participants with data about only one day, but the majority provided multiple days of data (on average 4 days per participant). Ideally, all participants covered a full week of travel behaviour and all for the same duration. Since some people tracked themselves for more days than others, their behaviour will be 'overrepresented' in this dataset. Likewise, Figure 5-2 provides the distribution for the number of trips recorded per participant. There are several participants for whom just a few trips were recorded. It is not in all cases possible to know whether no other trips have happened on the days tracked or whether there is missing data, i.e. that some trips that took place have not been recorded by the app.

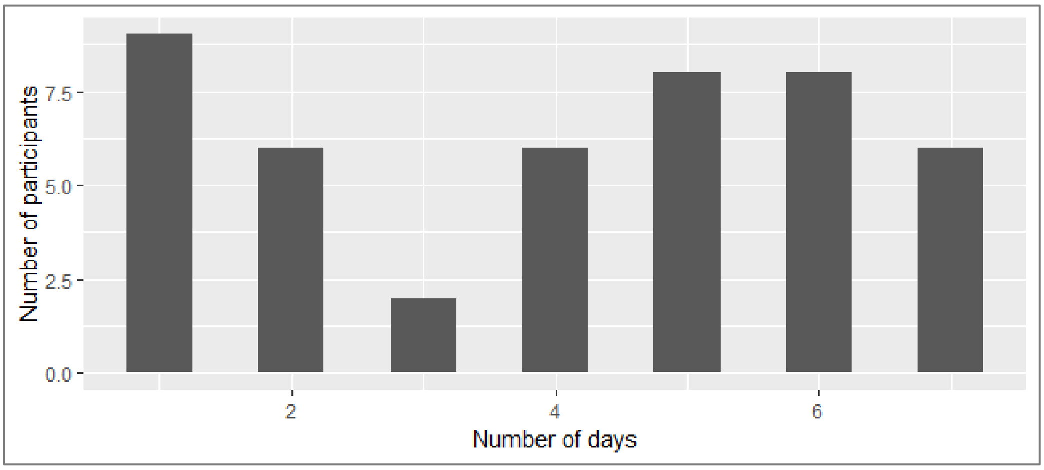


Figure 5-1 Distribution of number of tracking days with recorded trips per participant

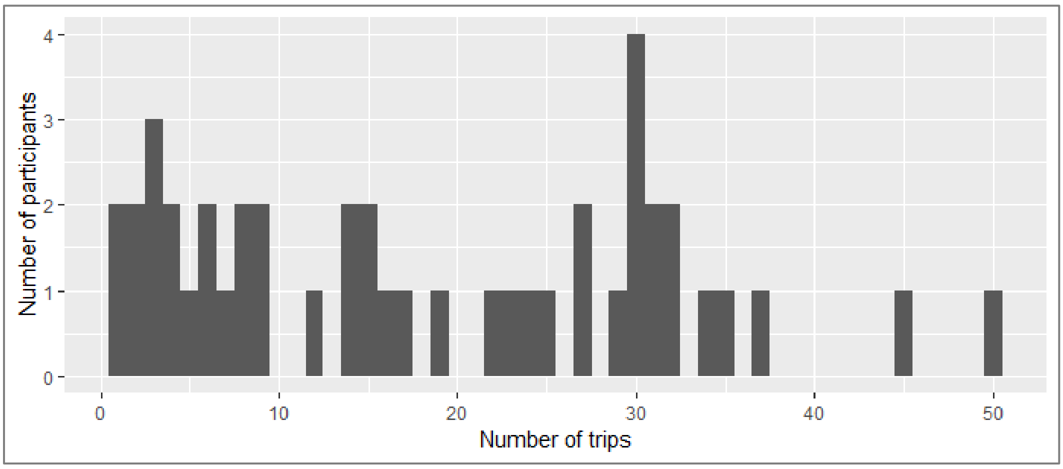


Figure 5-2 Distribution of number of trips recorded per participant

5.4 Analysis

5.4.1 Walk stages to and from public transport

Of the 45 participants, there were 15 people who registered at least one trip by PT. For most of these trips, a walk to or from the PT mode was registered as well, 81 walks in total (excluding transfer walks, such as between a bus stop and a railway station). Table 5-2 gives an overview of some descriptive characteristics of all these walks. It needs to be noted, however, that not all these walks are independent cases. A large proportion of the trips included are return trips, with similar walks both ways, or repetitive over multiple days. Hence, besides analyses of all trips, analyses are also performed on a part of the dataset, solely including the ‘unique trips’ (e.g. if someone walked from home to the home railway station and vice versa on two days, thus having walked four access/egress trips, only one of these trip legs is counted as a unique trip. These additional analyses are meant to reduce some of the potential bias that is in the dataset due to different tracking durations for different participants. I.e. if two people go to work every day via the same route, but the first person tracked for 5 days and the second person tracked for one day only, the trips of the first person would weight much more in the analyses).

Table 5-2 Characteristics of access and egress walks for bus, train and tram trips

	Mode	***n***	**Distance (metres)**				**Time (minutes)**	
			Mean	St. dev.	Min	Max	Mean	St. dev.
All trips	**Bus**	30	516	444	55	1590	7.91	6.52
	Train	49	639	374	50	1957	11.5	8.61
	Tram	2	626	356	375	878	15.5	0.212
Unique trips	**Bus**	18	492	419	63	1590	7.80	7.17
	Train	24	707	456	50	1957	12.2	10.1
	Tram	2	626	356	375	878	15.5	0.212

5.4.1.1 Walk distances

The plots in Figure 5-3 show the cumulative distribution of walks per distance to/from buses and trains. A typical inverted S-curve pattern appears, although the first concave section is not very apparent for the bus. The two dashed lines indicate the conventional 400m and 800m walking distance thresholds for respectively bus and train often used in transport planning (Canepa, 2007). For trains, this 800m threshold appears to be quite accurate and cover most of the walks registered. About 15% are significantly longer. In contrast, for buses there is actually a large proportion of walks longer than 400m (around 40%), up to almost four times as long (1590m). There are no clear differences between the characteristics measured over all trip legs versus those for unique trip legs, although especially for buses there seem to be fewer long walks when considering unique trips legs only.

The difference in mean distance between walks to and from buses and trains is not significant (t = -1.2362, df = 50, p = 0.222 [considering all trips]; t = -1.6112, df = 40, p = 0.115 [considering unique trips only]). This might partly be due to the small sample size, but also reflects the finding that the walk distances related to bus trips are relatively long. Likewise, differences in walk distances between participants living in Moseley and Bournville are not statistically significant (t = 1.2024, df = 26, p = 0.240 [considering all bus trips]; t = -0.17211, df = 16, p = 0.866 [unique bus trips only]; t = -1.4004, df = 11, p = 0.1882 [all train trips]; t = -1.0993, df = 14, p = 0.290 [unique train trips only]).

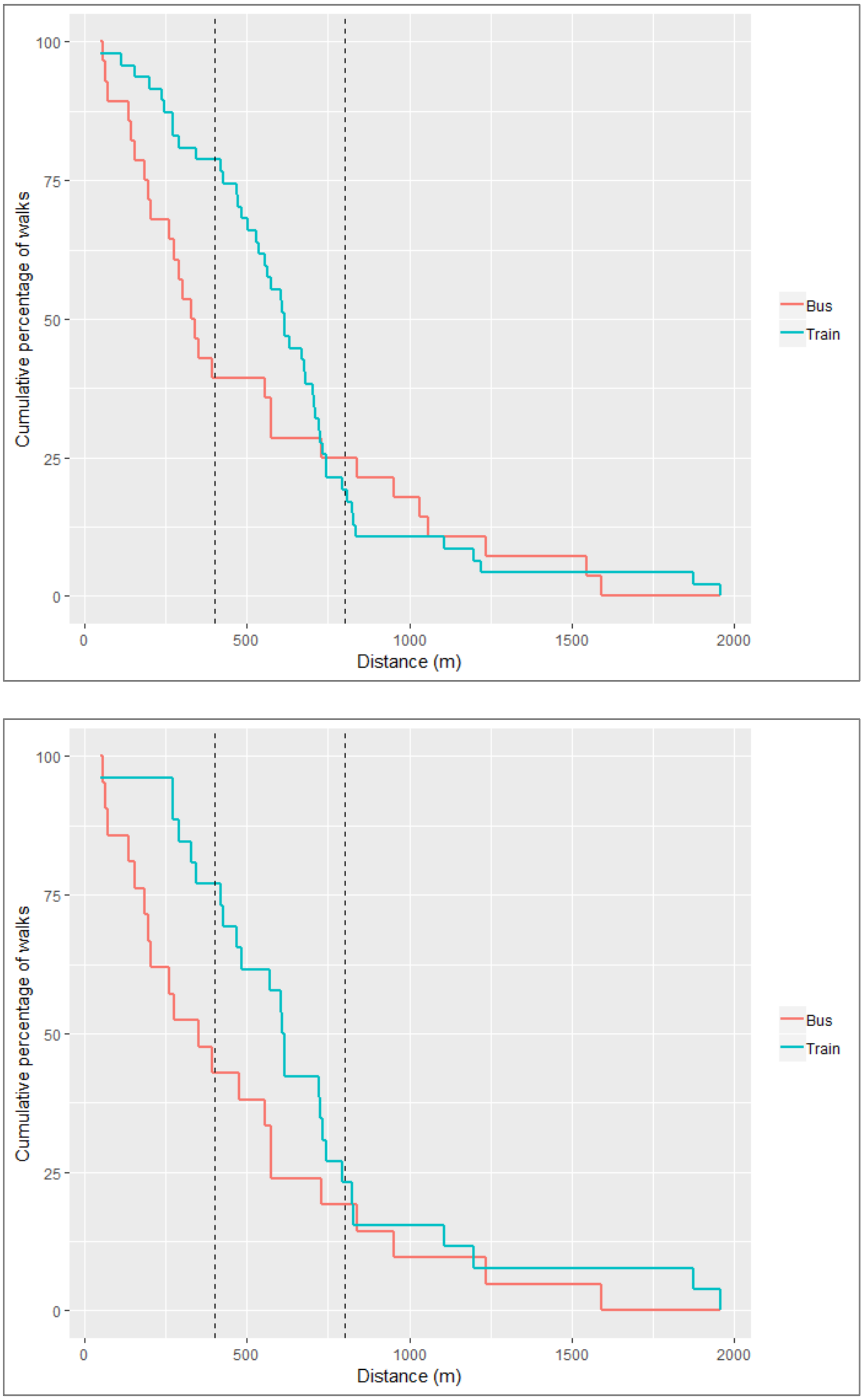
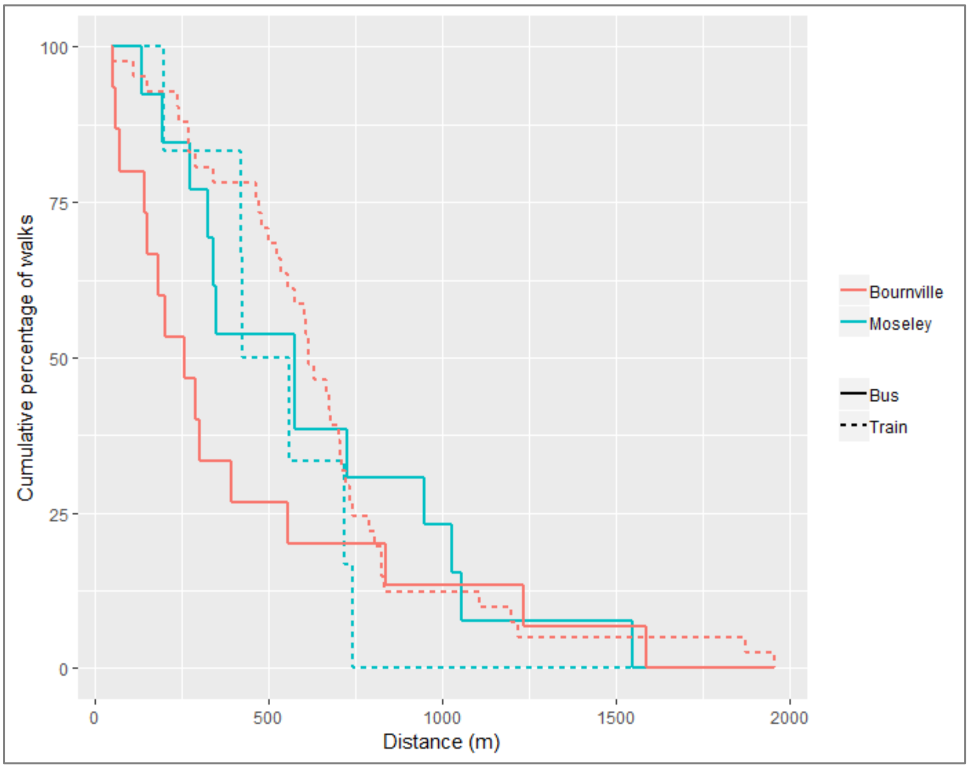


Figure 5-3 Cumulative distribution of walk distances to/from bus and train (top: all trips, bottom: unique trips); the dashed lines indicate the conventional 400m and 800m thresholds for walking to respectively bus and train



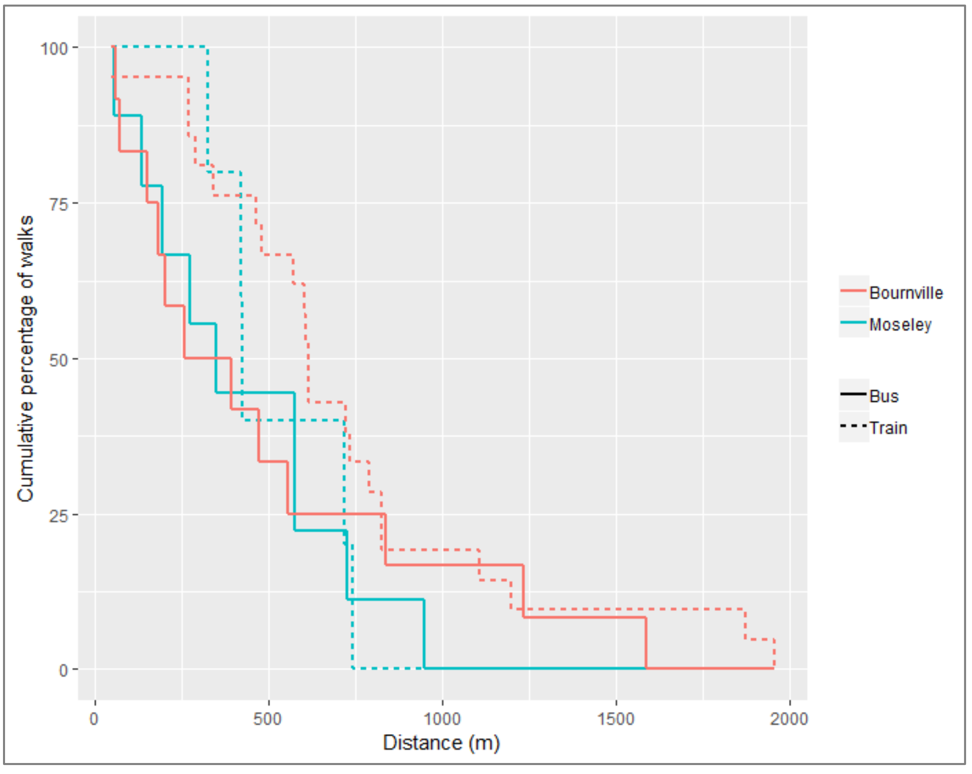


Figure 5-4 Cumulative distribution of walk distances to/from bus and train (top: all trips, bottom: unique trips), for both neighbourhoods

5.4.1.2 Public transport provision

The fact that the walk distances related to bus trips in Birmingham generally appear to be longer than what would be expected based on the conventionally used 400m-threshold might be due to the layout of bus routes in Birmingham in relation to where people live. Figure 5-5 shows the distribution of walk distances to the nearest bus stop (with at least 6 services per day) for all questionnaire participants with a known home location in Bournville and Moseley. As can be seen, virtually all questionnaire participants living in Bournville are able to reach a bus stop within 400m, whereas a large proportion of those living in Moseley need to walk substantially further to reach the nearest stop. So, there seems to be a large difference in access to bus stops between the two areas. However, the difference between the tracked walk distances in the two areas was not significant. The few PT users in the sample all lived less than 400m from their closest bus stop, except for one participant in Moseley (758m).

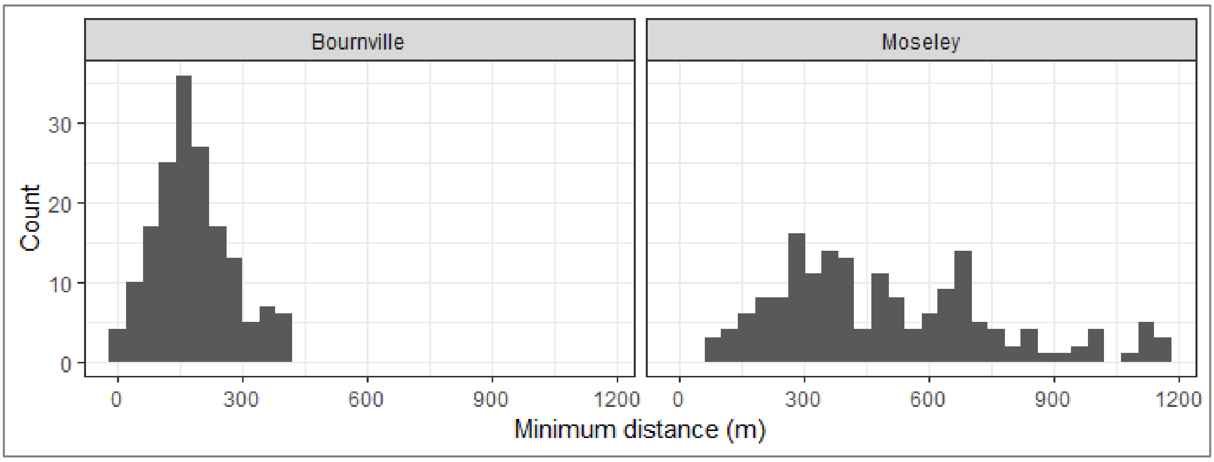


Figure 5-5 Distributions of walk distances to the nearest bus stop in Bournville and Moseley

When considering the home-based walks to or from buses only, it appears that the tracking participants do not use the nearest bus stop in many cases, but instead walk further to another bus service, for instance because this stop has a higher service frequency and better connections to the final destination. All in all, for a significant proportion of Birmingham residents, bus stops are relatively far away (more than 400m) and for those with a bus stop close to home it often does not offer the service desired for the trips made.

To dig deeper into this, each respondent was assigned a PT convenience score (on a scale of 1 – least convenient to 5 – very convenient), based on his or her home location. Table 5-3 presents some statistics about the access and egress walk distances related to people with different PT convenience scores. An interesting pattern appears, with participants having convenience score 4 walking shorter distances than those with convenience scores 3 or 5. When solely considering the access/egress trips at the home side of the trip, the convenience score is based on the home environment after all, the people with the highest convenience score walk the shortest distances. The highest convenience score refers to the fact that there is a PT stop with a very high frequency nearby the home, so it can be expected that these people walk shorter distances, at least at the home side. The fact that they walk further distances when considering non-home related trips as well indicates that these people tend to walk further at the activity side of the trip. This observation indicates that travellers might have a kind of total walk distance budget for a PT trip, which implies a dependence between the length of the access and that of the egress walk. Figure 5-6 displays a scatterplot for the access distance versus the egress distance for all PT trips with complete information about both the access and egress walks. Although there is no very clear pattern due to the limited number of data points, a hyperbolic shape appears (as sketched in blue in the plot), pointing at this budget (i.e. a long access walk is accompanied with a relatively short egress walk and vice versa).

Table 5-3 Descriptive statistics for access and egress walk distances per main mode and convenience score

A: For all modes

Mode	**Convenience score**	***N***	**Distance**			
			Mean	St. dev.	Min	Max
All	3	23	660	415	135	1548
	4	36	534	353	50	1957
	5	22	621	457	55	1876

B: For all modes, trips to/from home only

Mode	**Convenience score**	***N***	**Distance**			
			Mean	St. dev.	Min	Max
All	3	7	726	427	153	1199
	4	16	633	400	144	1957
	5	8	485	367	55	834

C: Per mode

Mode	**Convenience score**	***N***	**Distance**			
			Mean	St. dev.	Min	Max
Bus	3	17	644	429	135	1548
	4	6	315	172	144	575
	5	7	366	550	55	1590
Train	3	6	704	412	201	1199
	4	28	568	371	50	1957
	5	15	749	360	344	1876
Tram	4	2	626	356	375	878

D: Per mode, trips to/from home only

Mode	**Convenience score**	***N***	**Distance**			
			Mean	St. dev.	Min	Max
Bus	3	6	647	408	153	1057
	4	4	343	185	144	575
	5	3	63.3	8.5	55	72
Train	3	1	1199	-	1199	1199
	4	12	738	410	474	1957
	5	5	738	148	482	834

E: Per mode, unique trips only

Mode	Convenience score	*N*	Distance			
			Mean	St. dev.	Min	Max
Bus	3	13	504	374	56	1237
	4	4	358	166	202	575
	5	5	477	644	63	1590
Train	3	6	725	383	273	1199
	4	12	614	474	50	1957
	5	8	770	480	344	1876
Tram	4	3	497	337	238	878

F: Per mode, unique trips to/from home only

Mode	Convenience score	*N*	Distance			
			Mean	St. dev.	Min	Max
Bus	3	3	485	416	153	951
	4	3	409	159	259	575
	5	2	67.5	6.36	63	72
Train	3	1	1199	-	-	-
	4	3	1060	777	608	1957
	5	2	654	243	482	825

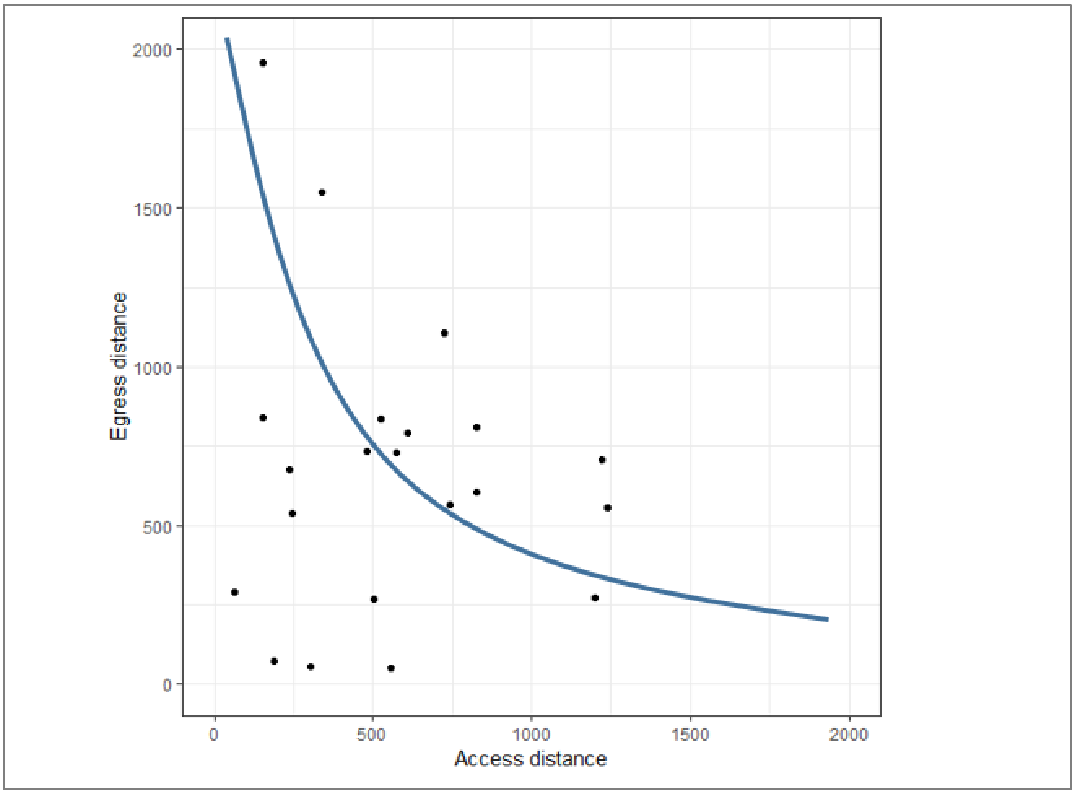


Figure 5-6 Access versus egress distance scatterplot

(the blue curve represents a manually drawn indication of a hyperbolic trend in the data)

The correlation values between the walk distances and the distance to the best bus stop or closest train station are displayed in Table 5-4, for all trips and home based trips only. It seems that the further the best bus stop or closest train station, the further people walk to/from the bus. For train trips, the opposite seems true, which might indicate that people who live closer use the train more often, but can also be a phenomenon related to the small sample size (leading to larger error margins). The longer walk distances related to further stops can be due to captivity to PT, i.e. people were forced to walk a longer distance. Of the 15 PT users in the sample, five could be considered PT captive (measured by whether someone had no car available for his/her trips according to the questionnaire responses). However, when comparing the walk distances between people who were PT captive and those who were not, there were no significant differences (t = -0.683, df = 94, p = 0.497 [all train trips]; t = 0.841, df = 39, p = 0.406 [all bus trips]).

Table 5-4 Correlation values between walk distances and the distance to the closest train station and best stop

Mode	**Distance to bus stop**	**Distance to railway station**	**Distance to bus stop, home based trips**	**Distance to railway station, home based trips**
Bus	0.256	0.217	0.199	0.796
Train	-0.001	-0.183	0.163	-0.185
Bus, unique trips	0.204	-0.067	-0.0116	0.780
Train, unique trips	0.081	-0.169	0.369	0.019

Table 5-5 Descriptive statistics for access and egress walk distances per main mode and PT captivity

Mode	**Captive**	***N***	**Distance**			
			Mean	**St. dev.**	**Min**	**Max**
Bus	No	11	493	526	55	1590
	Yes	19	528	407	135	1548
Train	No	23	700	331	201	1876
	Yes	26	586	408	50	1957
Tram	No	2	626	356	375	878

5.4.1.3 Spatial distribution

Figure 5-7 shows the spatial distribution of the origins of access and egress walks in the city. The colour indicates the length (yellow is shortest, black is longest). There is no clear spatial pattern of a particular area where more long or short walks occur. The statistics indicate that people tend to walk shorter distances for buses at the home side of a trip than at the activity side, whilst they walk longer distances for trains at the home side. The differences are not statistically significant, however (bus: $t = -1.8309$; $df = 43$, $p = 0.074$ [all trips]; $t = -1.150$, $df = 19$, $p = 0.2644$ [unique trips]; train: $t = -0.1588$, $df = 28$, $p = 0.875$ [all trips]; $t = 1.395$, $df = 7$, $p = 0.2086$ [unique trips]).

Table 5-6 Descriptive statistics for walks at the home and activity side

A: all trips

Mode	**Side**	***n***	**Distance**			
			Mean	St. dev.	Min	Max
Bus	Activity	17	599	495	135	1590
	Home	13	419	371	55	1057
Train	Activity	31	568	374	50	1876
	Home	18	765	351	474	1957

B: unique trips

Mode	**Side**	***n***	**Distance**			
			Mean	St. dev.	Min	Max
Bus	Activity	14	543	461	56	1590
	Home	8	352	298	63	951
Train	Activity	20	609	389	50	1876
	Home	6	948	555	482	1957

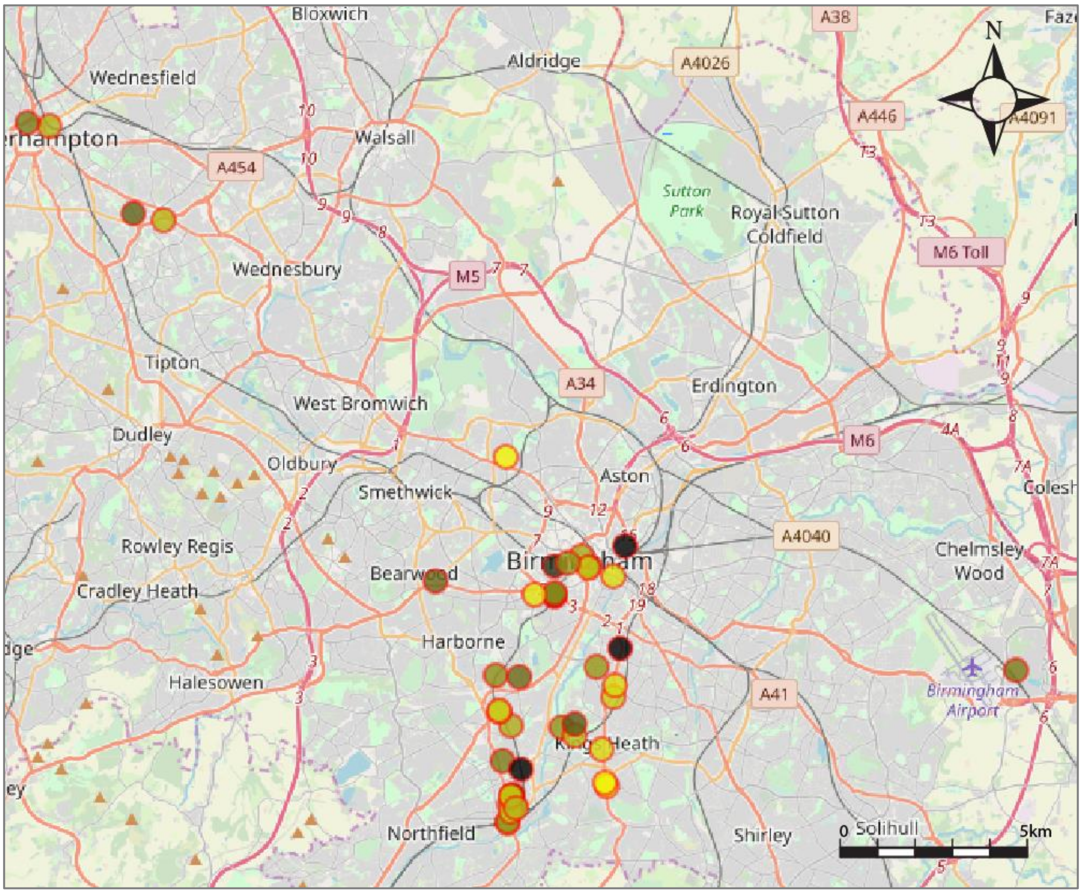


Figure 5-7 Spatial distribution of access/egress walks (starting points).
The colour indicates the walk distance (yellow is shortest, black is longest)

5.4.1.4 Routes

The walk distance is eventually determined by the route someone chooses to walk to or from a PT stop, together with the choice for the stop or station. A closer look at the tracked routes revealed that the large majority of walks were undertaken via the most direct and shortest route. In case of train journeys, also the closest station was used in most cases. There were a few instances in which a participant chose a station that required a slightly longer walk, but this was in the direction of travel, leading to a shorter overall travel distance. In the case of walks related to buses, the closest bus stop was not necessarily used, but very much dependent on which bus lines operate where.

The comparison of characteristics of feasible alternative routes, as obtained through Google Maps, is presented in Table 5-7. There is complete data about 30 different PT trips including the origin and destination. When comparing the chosen options (shaded in the table) with their alternatives, it becomes clear that in many cases the amount of walking is not absolutely minimised.

An example is displayed in Figure 5-8, for a trip from Bournville to Brindleyplace in the centre of Birmingham, in which Google Maps identified four possible travel alternatives. The green option on the map takes 31 minutes, of which 22 minutes of walking. The route uses only one mode (train) and contains 0 transfers. The second alternative takes 36 minutes, just five minutes more, but involves only 7 minutes of walking. However, this option uses two buses (so one transfer). When the traveller chose the first option, it means he or she did not minimise their walking, but instead walked significantly more than necessary. This extra walking was probably undertaken due to the higher perceived status of the train, the avoidance of the transfer on the bus and a little bit of less travel time.

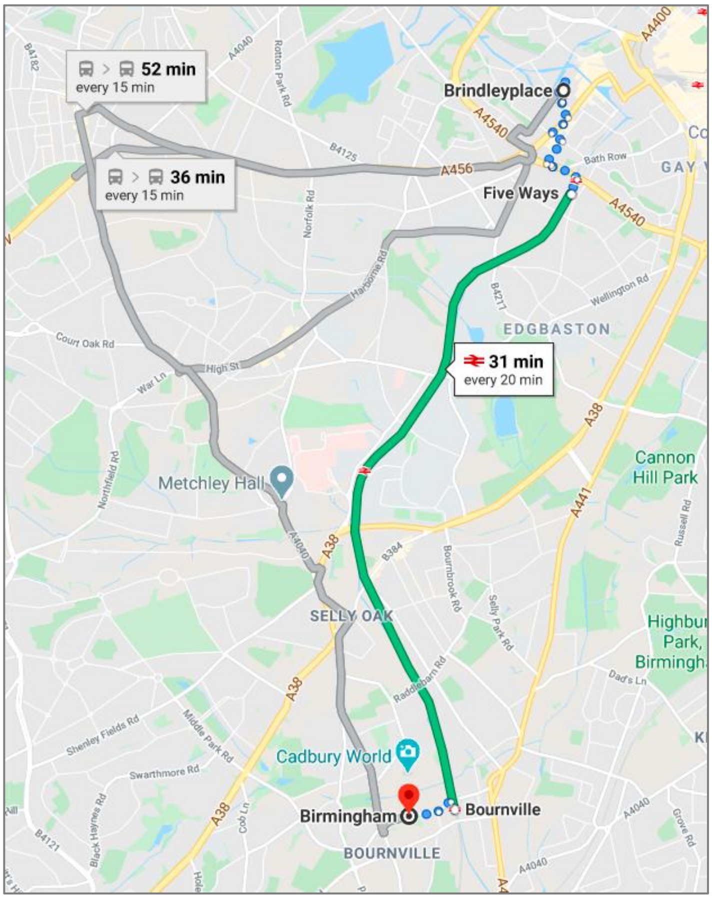


Figure 5-8 Example of multiple route options

Some of the chosen routes were the only available alternative (trips 10, 13, 23, 24), or the most optimal alternative both in terms of travel and walking time (16, 20, 21, 25, 27, 29). For the other trips a choice had to be made for options that included either more or less walking. In only a few cases was the amount of walking minimised (4, 7, 9, 11). For trip number 4 this only led to a slight increase in travel time compared to the fastest alternative. For the other trips (7, 9, 11), a car was used as main access/egress mode. For trip 7, this did not reduce the travel time, but reduced the amount of walking by 8 minutes (from 26 to 18). For trip 9, this led to only a slight decrease in walking time, but a significant reduction in total travel time (at least 10 minutes saved). For trip 11, walking and total travel time were both minimised too.

For all other trips, the participant chose to walk further than the minimum necessary when taking PT. In many cases this longer walk distance simply resulted in a shorter overall travel time (1, 3, 6, 14, 26, 30) due to the availability of a faster and/or more direct service. For some other trips the travel time remained similar to the alternatives (5, 18, 22), although in some cases the longer walk avoided a transfer (2, 8, 12, 15, 28). For trips 17 and 19, the longer walks led to respectively longer and similar travel times, but it allowed the trip to be undertaken by train instead of bus.

These seven different 'PT walking strategies' are investigated further ((1) only alternative; (2) most optimal; (3) walk minimisation; (4) walking further to reduce travel time; (5) walking further without influencing total travel time; (6) walking further to avoid a transfer; (7) walking further to use a train instead of bus). Table 5-8 displays the free associations with transport as provided by the participants that applied each of the strategies in their trips. However, for each strategy a similar pattern of associations appears. The participants tend to think positively about walking, apart from some weather or traffic-related concerns. Trains are generally perceived positively as well, except for issues mainly related to reliability. Bus and car use are perceived negatively, although their convenience is acknowledged, particularly for cars. About cycling the feelings tend to be mixed, but mostly negative due to its perceived danger. So, whilst perceptions were found to be related to mode use frequency in general, they do not seem to significantly influence the walking strategy that is applied when using PT.

Table 5-7 Characteristics of travel alternatives (minutes of total travel time, minutes of walking time, number of transfers, modes involved (B: Bus, M: Metro/tram, T: Train)) – green shading: chosen alternative, yellow shading: chosen alternative, but not included as an option in the results of Google Maps

	Alternative 1				Alternative 2				Alternative 3				Alternative 4			
Trip	Minutes	Walk	Transfers	Modes	Minutes	Walk	Transfers	Modes	Minutes	Walk	Transfers	Modes	Minutes	Walk	Transfers	Modes
1	35	27	0	T	44	19	1	B-B	56	12	1	B-B				
2	34	13	1	B-B	34	15	1	B-B	41	16	1	B-B	35	24	0	B
3	32	21	0	T	35	11	1	B-B	46	12	1	B-B				
4	62	16	1	B-B	54	24	1	M-T	61	14	1	B-T	77	13	0	B
5	59	12	0	B	62	18	1	T-B	52	13	2	T-B-B	63	16	1	B-B
6	43	12	1	T-T	76	8	1	B-B								
7	74	26	1	T-B	60	26	1	T-B	70	18	1	T-T-Car				
8	40	13	0	B	41	14	1	T-M	35	14	1	T-B	35	20	0	T
9	37	8	1	T-B	49	11	1	T-B	27	7	0	T-Car				
10	38	9	0	T												
11	64	35	1	B-T	88	16	1	B-B	51	16	1	Car-T-T				
12	47	19	0	B	47	11	1	B-B	49	12	1	B-B				
13	26	3	0	B												
14	146	21	2	B-T-B	134	27	1	B-T								
15	26	6	1	B-B	30	17	0	B	25	20	0	T				
16	59	19	1	T-T	120	23	1	B-T								
17	22	9	1	B-B	28	23	0	T								
18	18	13	0	T	21	12	0	B	19	16	0	T				
19	18	13	0	T	21	12	0	B								
20	27	14	0	T	40	14	0	B								
21	34	10	0	B	51	10	1	B-B								
22	31	12	0	B	36	13	1	B-B	31	13	0	B				

23	36	5	0	M												
24	77	17	1	M-B												
25	15	9	0	B	30	21	0	B	31	9	1	B-B				
26	22	8	0	B	43	6	1	B-B								
27	30	6	0	B	46	18	1	B-B								
28	53	24	1	B-B	55	28	1	B-M	52	33	0	B				
29	28	6	1	B-B	30	7	1	B-B	40	7	1	B-B				
30	43	17	1	T-B	48	15	1	B-B	45	27	0	B	42	29	1	B-B

Table 5-8 Associations per walking strategy (the affective rating is presented between square brackets, 1: very negative - 7: very positive)

Strategy	Mode	Associations
1: Only available alternative *Users 40, 42, 65*	Walk	Pollution [1], Traffic [1], Pavements [4], Long [3], Healthy [7], Polluted [1], Healthy [6], Unintuitive (cars come first) [1], Relaxing [6]
	Bus	Cramped [1], Slow [1], Long [1], Expensive [1], Unenjoyable [2], Slow [2], Expensive [1], Swift card not good enough [2], Noisy [2]
	Train	Fast [6], Efficient [6], Easy [6], Quick [7], Easy [7], Only possible from a few areas [2], Expensive [1], Unreliable [1], Overcrowded [2]
	Car	Tight/narrow [2], Slow [2], Boring [3], Expensive [3], Convenient [6], Bad for the environment/ air quality [1], Stressful [1], Congested [1], Cheaper than pub transport [5]
	Cycling	Canal [7], Long [4], Sweaty [1], Healthy [7], Scenic along canals [7], Dangerous on roads [1], Dangerous [1], Healthy [6], Fun [6]
2: Most optimal for walking and travel time *Users 50, 52, 74, 76*	Walk	Canal [5], Health [6], Trees [5], Healthy [7], Reliable [7], Stress-free [7], Enjoyable [7], Time to reflect [7], Good exercise [7], Pavement [4], Traffic [2], Road [3]
	Bus	Waiting [3], Not clean [2], Cheap [4], Dirty [1], Slow [2], Expensive [2], Free bus pass [7], Slow [3], Sociable [5], Late [2], No seats available [2], Long way to walk [3]
	Train	Relaxation [5], Unreliability [2], Much better than the car [6], Fast [7], Frequent [7], Warm [7], Better than cars [6], Fast [6], Regular [6], Sitting down [6], Fast [6], Schedule [3]

	Car	Supermarket [5], Congestion [3], Risk [3], Busy [1], Stressful [1], Expensive [1], Traffic [1], Pollution [1], Parking [1], Cars [5], Traffic light [2], Parking [3]
	Cycling	Rare [3], Health [6], Canal [6], Fast [7], Reliable [7], Healthy [7], Need more cycle routes [5], Good exercise [7], No parking or congestion problems [7], Quick [6], Dangerous traffic [1], Healthy [6]
3: Minimising walking *Users 4, 33, 40, 41*	Walk	Pollution [1], Traffic [1], Pavements [4], Easy [7], Enjoyable [7], Cold [2], Relaxing [7], Get to see more [7], Good exercise [7], Means of travel [6], Local shopping [6], Exercise [6]
	Bus	Cramped [1], Slow [1], Long [1], Inconvenient [1], Slow [1], Full [1], Necessary & convenient [6], Overcrowded and dirty [1], Delays [2], Choice-regular [6], Swift card [6], Local – good price [6]
	Train	Fast [6], Efficient [6], Easy [6], Quick [7], Cost effective [7], Not always reliable [3], Convenient [6], Crowded [2], Delays [2], Choice of times [6], Parking at station [2], Able to buy tickets pre-travel [6]
	Car	Tight/narrow [2], Slow [2], Boring [3], Quick [7], Parking [4], Congested [2], Stressful [1], Not efficient [2], Traffic [1], Traffic [4], Convenience [6], Parking [5]
	Cycling	Canal [7], Long [4], Sweaty [1], Challenging [2], Dangerous [2], Non-existent [2]
4: More walking for shorter travel time *Users 1, 4, 42, 76*	Walk	Long [3], Healthy [7], Polluted [1], Pavement [4], Traffic [2], Road [3], Relaxing [7], Get to see more [7], Good exercise [7], Busy [2], Traffic [2], Relaxing [6]
	Bus	Expensive [1], Unenjoyable [2], Slow [2], Late [2], No seats available [2], Long way to walk [3], Necessary & convenient [6], Overcrowded and dirty [1], Delays [2], Dirty [1], Busy [2], Expensive [1]
	Train	Quick [7], Easy [7], Only possible from a few areas [2], Sitting down [6], Fast [6], Schedule [3], Convenient [6], Crowded [2], Delays [2], Good [7], Unreliable [2], Packed [2]
	Car	Expensive [3], Convenient [6], Bad for the environment/ air quality [1], Cars [5], Traffic light [2], Parking [3], Stressful [1], Not efficient [2], Traffic [1], Traffic [2], Slow [2], Fumes [1]
	Cycling	Healthy [7], Scenic along canals [7], Dangerous on roads [1], Quick [6], Dangerous traffic [1], Healthy [6], Challenging [2], Dangerous [2], Non-existent [2], Freedom [6], Fast [7], Relaxing [6]
5: More walking for similar travel time *Users 4, 36, 51, 65*	Walk	Healthy [6], Unintuitive (cars come first) [1], Relaxing [6], Relaxing [7], Get to see more [7], Good exercise [7], Fresh air [6], Weather [3], Healthy [7], Exercise [7], Raining [3], Rucksack [5]
	Bus	Expensive [1], Swift card not good enough [2], Noisy [2], Necessary & convenient [6], Overcrowded and dirty [1], Delays [2], Slow [2], Smokers at bus stops [1], Uncomfortable [3], Noisy [1], Feet on seats [1], Slow [1]
	Train	Expensive [1], Unreliable [1], Overcrowded [2], Convenient [6], Crowded [2], Delays [2], Germs [1], Simple [6], Time to consume media [6], Litter [1], Dirty seats [1], Constant announcements [2]

	Car	Stressful [1], Congested [1], Cheaper than pub transport [5], Stressful [1], Not efficient [2], Traffic [1], Stress [2], Jams [2], Parking [2], Congestion [2], Parking [2], Easy [5]
	Cycling	Dangerous [1], Healthy [6], Fun [6], Challenging [2], Dangerous [2], Non-existent [2], Danger [1], Exercise [6], Rain [2], Congestion [1], Distracted drivers [1], Bike theft [1]
6: More walking to avoid a transfer *Users 1, 42, 50, 76*	Walk	Long [3], Healthy [7], Polluted [1], Canal [5], Health [6], Trees [5], Busy [2], Traffic [2], Relaxing [6], Pavement [4], Traffic [2], Road [3]
	Bus	Expensive [1], Unenjoyable [2], Slow [2], Waiting [3], Not clean [2], Cheap [4], Dirty [1], Busy [2], Expensive [1], Late [2], No seats available [2], Long way to walk [3]
	Train	Quick [7], Easy [7], Only possible from a few areas [2], Relaxation [5], Unreliability [2], Much better than the car [6], Good [7], Unreliable [2], Packed [2], Sitting down [6], Fast [6], Schedule [3],
	Car	Expensive [3], Convenient [6], Bad for the environment/ air quality [1], Supermarket [5], Congestion [3], Risk [3], Traffic [2], Slow [2], Fumes [1], Cars [5], Traffic light [2], Parking [3]
	Cycling	Healthy [7], Scenic along canals [7], Dangerous on roads [1], Rare [3], Health [6], Canal [6], Freedom [6], Fast [7], Relaxing [6], Quick [6], Dangerous traffic [1], Healthy [6]
7: Longer walk and travel time, but by train *Users 50, 51*	Walk	Canal [5], Health [6], Trees [5], Exercise [7], Raining [3], Rucksack [5]
	Bus	Waiting [3], Not clean [2], Cheap [4], Noisy [1], Feet on seats [1], Slow [1]
	Train	Relaxation [5], Unreliability [2], Much better than the car [6], Litter [1], Dirty seats [1], Constant announcements [2]
	Car	Supermarket [5], Congestion [3], Risk [3], Congestion [2], Parking [2], Easy [5]
	Cycling	Rare [3], Health [6], Canal [6], Congestion [1], Distracted drivers [1], Bike theft [1]

5.4.1.5 Route quality

Apart from PT characteristics, people might have chosen a longer walking route due to the pleasantness of the route itself. The distances of the PT related walks are plotted against the pleasantness index (calculated based on the link-place framework) in Figure 5-9. It shows that more longer walks occur on routes with a higher pleasantness index, which suggests that more pleasant routes have a positive influence on the distance people are willing to walk for PT (Pearson correlation $r = 0.379$, $t(81) = 3.682$, $p < 0.001$). Due to feelings of personal safety, the opposite of the pleasantness index could be expected sometimes, especially at night (i.e. people prefer to walk along streets with more traffic). However, there were only five walks in the dataset after 20:30 and none before 05:30 (the approximate hours of sunset and sunrise in Birmingham around May), which did not show any divergent trends.

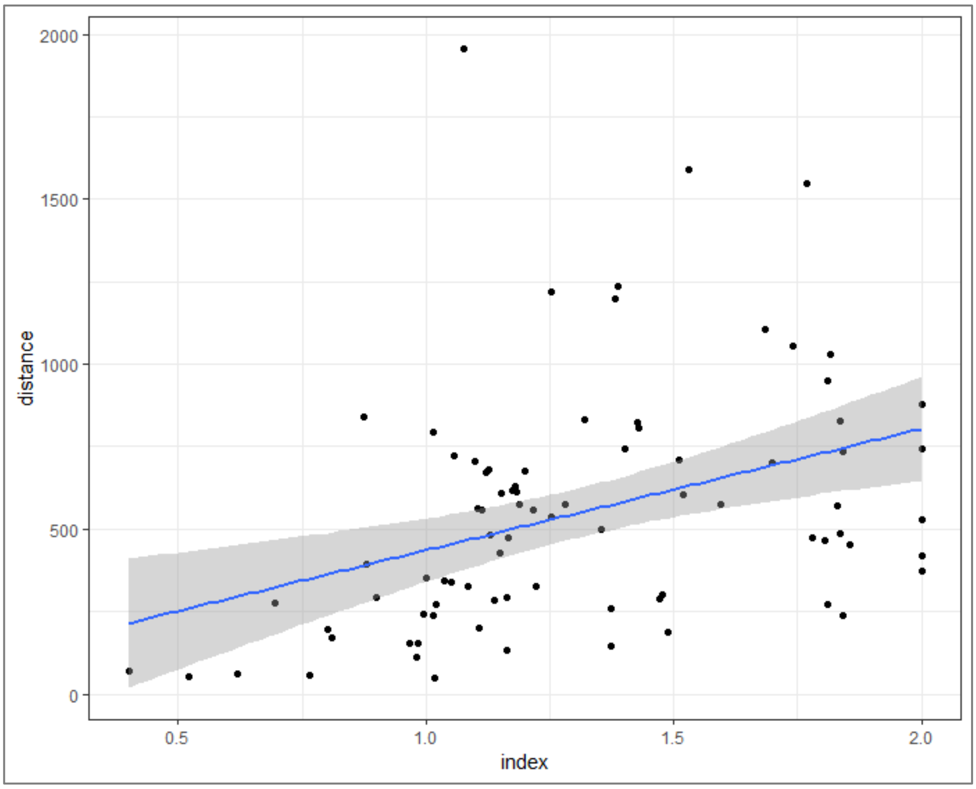


Figure 5-9 Plot of pleasantness index versus walk distance

5.4.2 Car trips

There were 246 car trips with complete information about their origin and destination. For each of these car trips, it was examined how likely the trip would have been if the person had chosen to use PT instead. As described in Section 3.7.2.2, this was done by retrieving a travel plan for a trip between the coordinates of the origin and the destination of the car trip via an online PT planning engine (transportapi.com). The trip planning engine is probably conservative in its assumptions of willingness to walk and do not account for some of the walk strategies identified in Section 5.4.1.4. Some car trips also included walk access or egress trips (e.g. from a parking garage to the final destination), in this case the origin and destination of the complete trip were used. Similar to the PT trips, analyses are done for the set of unique car trips as well to reduce potential dependency between trips. For car trips that were made repeatedly between the same origin and destination by a particular user, only the first trip is used for the analysis of unique trips. From the selection of PT routes available, two routes were selected for further analysis: the fastest one (the first available route with the shortest total duration) and the most direct one (the route with the least transfers, and in case there were multiple, the fastest option of these).

5.4.2.1 Overview of car trips

The car travel times were simulated using the Microsoft Bing Maps API, as stated in section 3.7.2.2, to obtain more reliable travel times. The simulated car travel times for all car trips are compared between the two neighbourhoods in Figure 5-10, with and without accounting for traffic conditions. Although the car trips are on average slightly longer in Moseley, there are no real noticeable differences between the two areas ($t = -0.235$, $p = 0.815$ [with traffic]; $t = 0.539$, $p = 0.591$ [without traffic]).

Figure 5-11 and Figure 5-12 show scatter plots and boxplots which compare the travel time by PT with the travel time by car. The diagonal lines in the scatterplot indicate an equal travel time by car and PT. As the plots clarify, PT is a slower mode for all of the trips, apart from two or three cases (on average about 2.23 times slower when comparing the most direct PT route with car travel time in traffic; 1.93 times slower when comparing fastest PT route with car time in traffic). However, in contrast to what might be expected based on the differences in PT provision, there are no clear differences between the two neighbourhoods when comparing the total travel times of PT in relation to the travel times by car. The boxplots clarify this better by comparing the travel time ratios for both neighbourhoods; the differences are statistically insignificant ($t = 0.962$; $p = 0.338$ [all trips, most direct]; $t = -0.689$, $p = 0.492$ [all trips, fastest]).

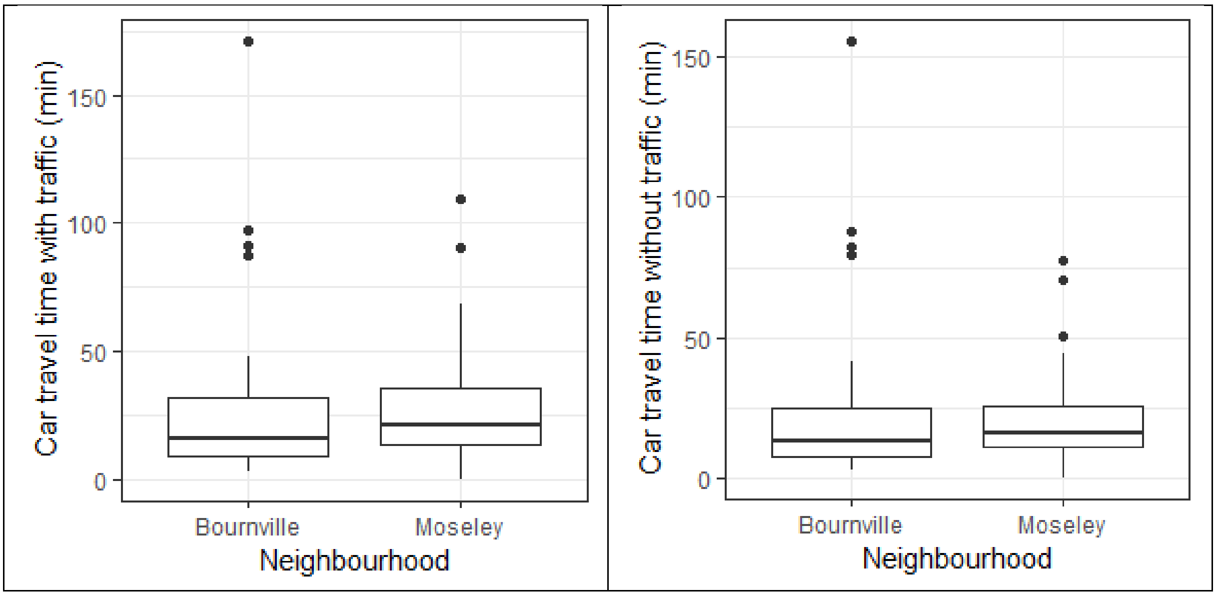


Figure 5-10 Comparison of car travel times for the trips in the two neighbourhoods (left: accounting for traffic conditions, right: without traffic)

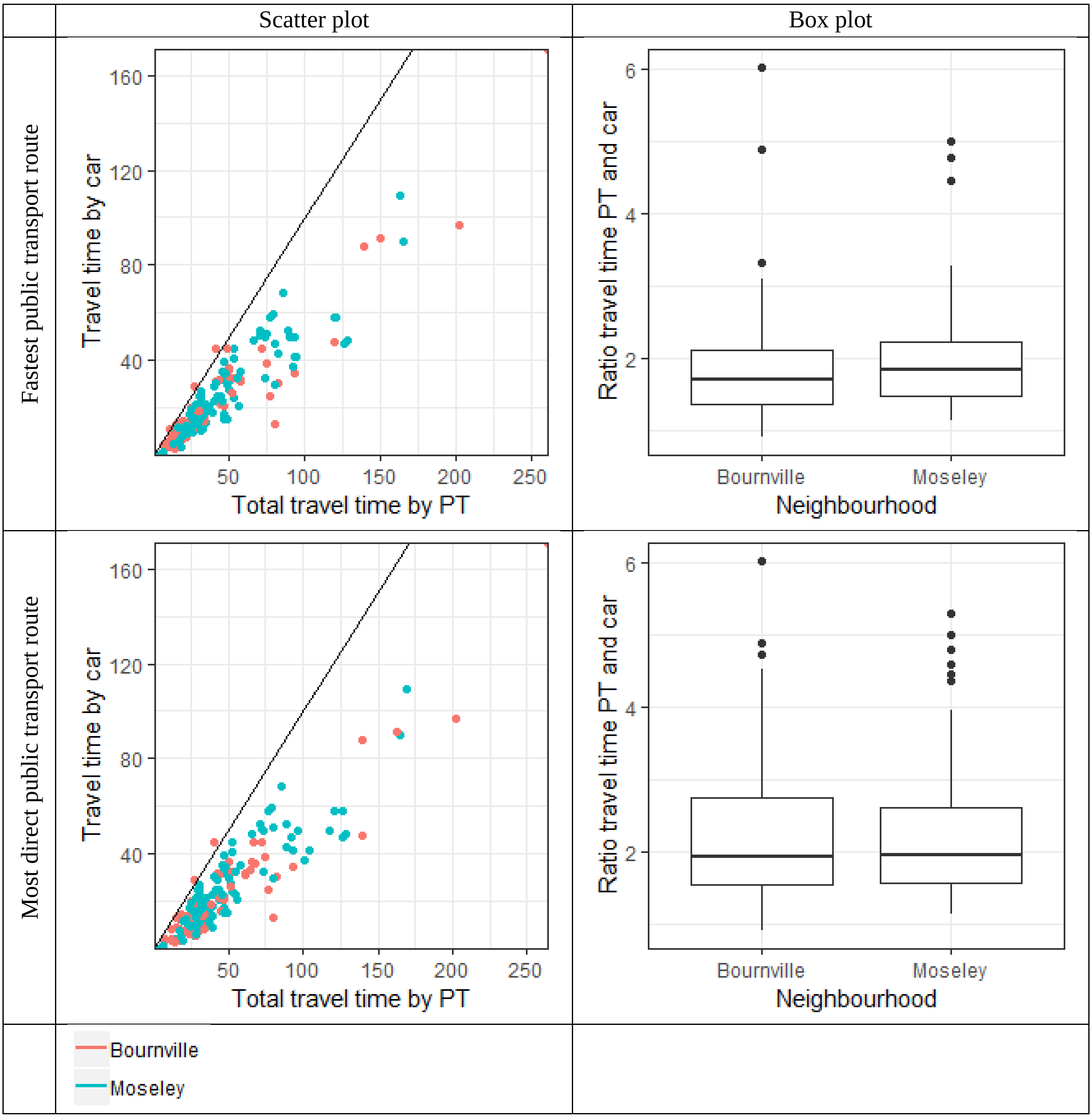


Figure 5-11 Scatter plots and boxplots for travel time (minutes) by public transport and car in both areas (all car trips)

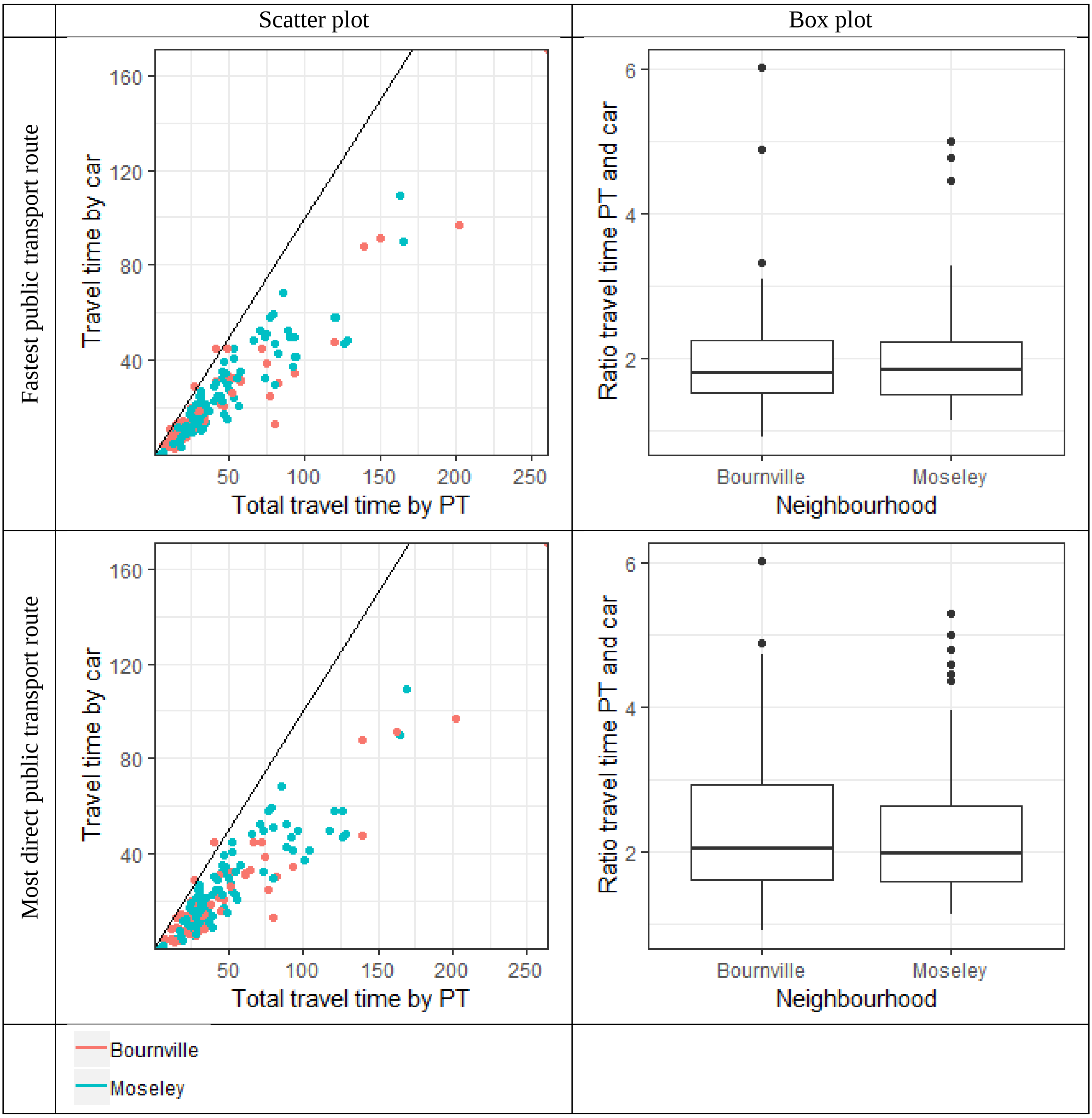


Figure 5-12 Scatter plots and boxplots for travel time (minutes) by public transport and car in both areas (unique car trips)

5.4.2.2 Potential walks to and from public transport

Figure 5-13 displays the cumulative distance distributions for potential access and egress walks if the car trips had been undertaken by PT, for the two areas. Despite the similar potential total travel times by PT, there is a significant difference, with Moseley residents requiring longer walks if they would use PT more often (t = 5.3098, df = 216, p = < 0.001 [all trips, fastest]; t = 5.0119, df = 178, p = < 0.001 [unique trips, fastest]; t = 4.4556, df = 179, p = < 0.001 [all trips, most direct], t = 3.5288, df = 152, p = < 0.001 [unique trips, most direct]). About 70% of the car trips by Moseley residents would require more than 1000m of walking if made by PT (both access and egress), whilst for the participants in Bournville this is approximately 40%.

Also when the ratio of time spent on walking versus the actual in-vehicle PT time is considered (Figure 5-14), it shows that the trips by Moseley residents require relatively more walking, although the difference is not significant when considering the most direct alternatives for unique trips only (t = 3.2308, df = 220, p = 0.001 [all trips, fastest]; t = 2.6989, df = 185, p = 0.008 [unique trips, fastest], t = 2.0748, df = 139, p = 0.040 [all trips, most direct]; t = 1.3034, df = 117, p = 0.195 [unique trips, most direct]).

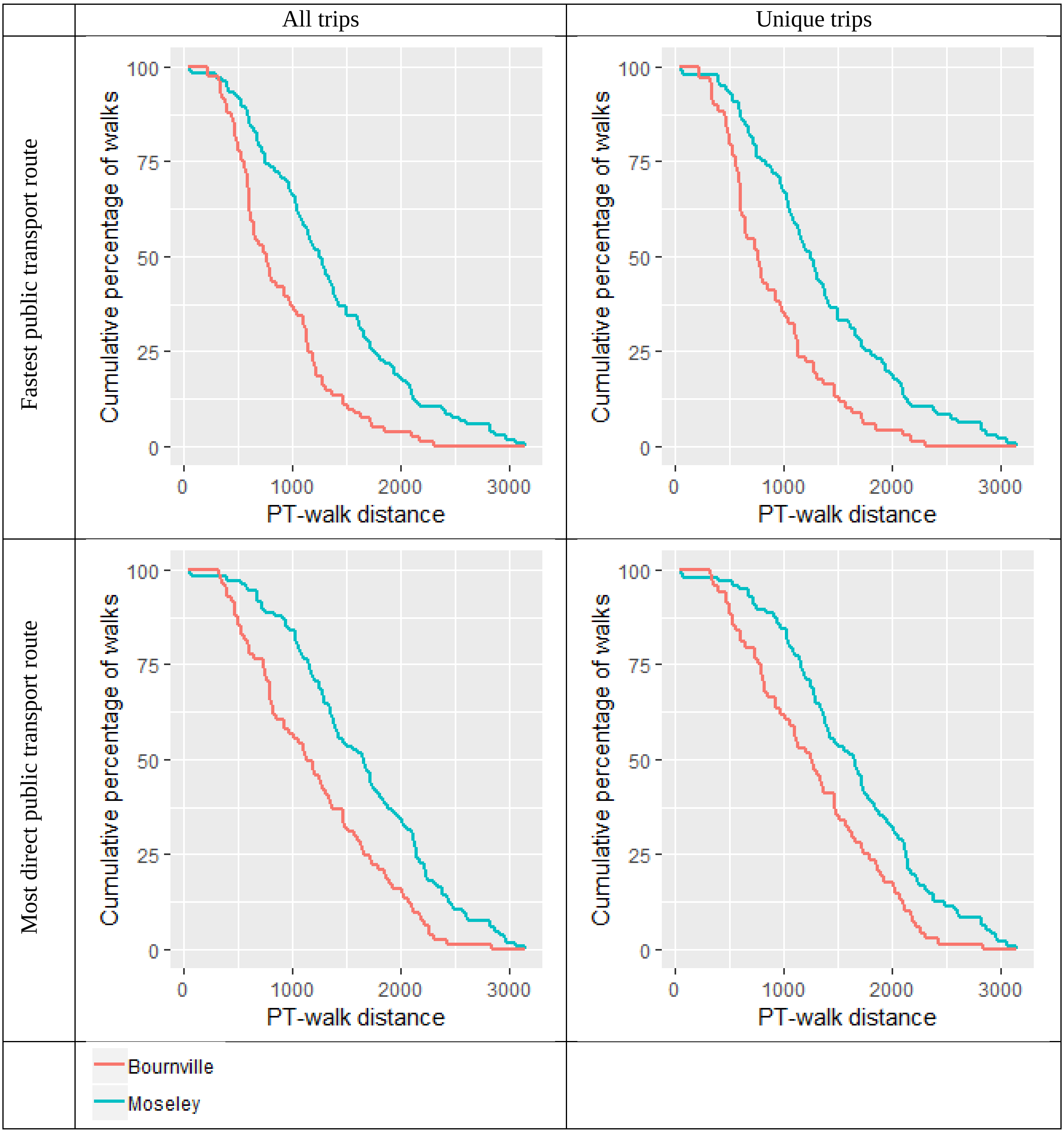


Figure 5-13 Cumulative distribution for PT-walk distances (both access and egress) in alternative PT trips, for both neighbourhoods (top: fastest public transport route, bottom: most direct public transport route)

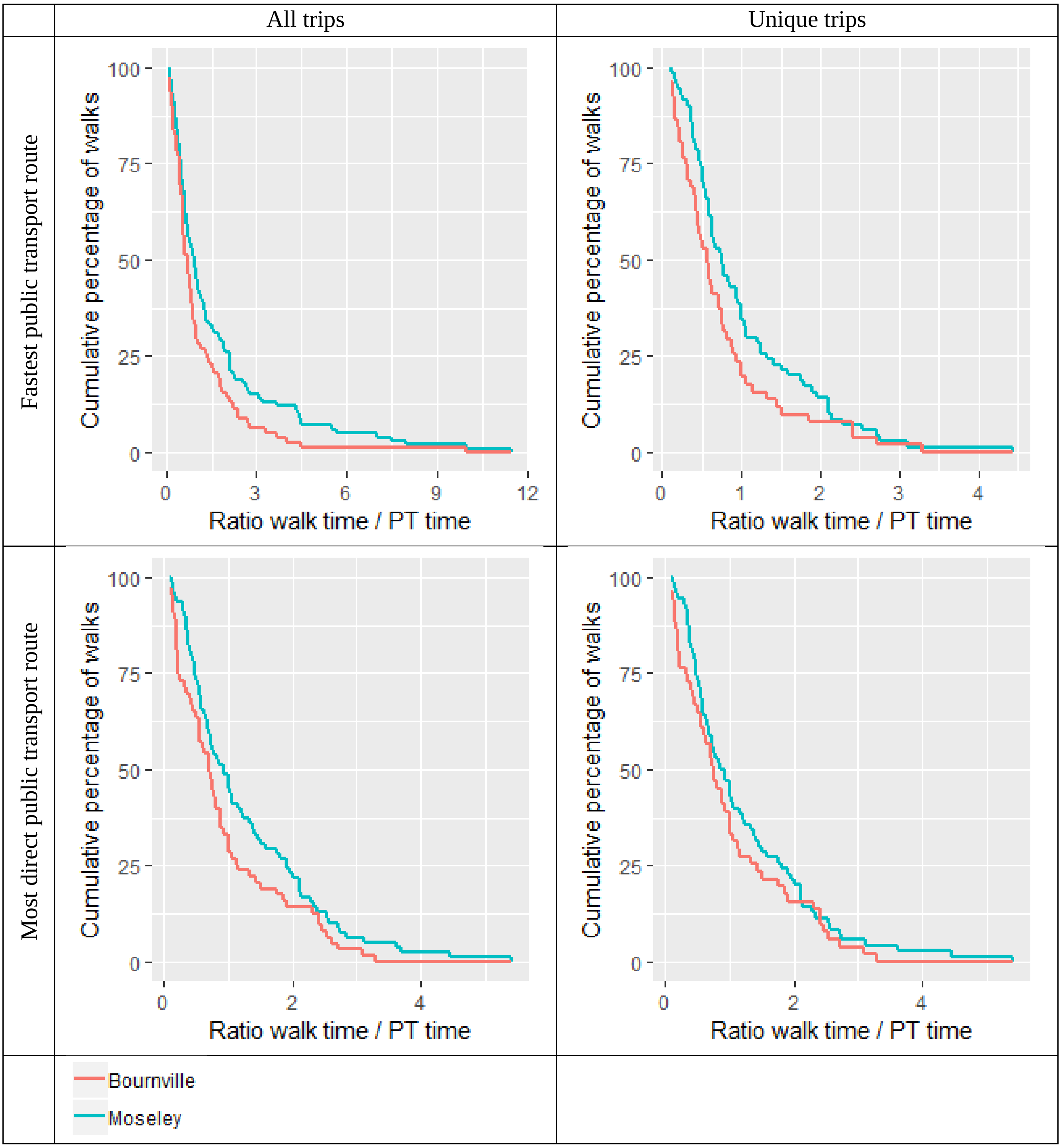


Figure 5-14 Ratio of walk time versus public transport time for both neighbourhoods (top: fastest public transport route; bottom: most direct public transport route)

5.4.2.3 Public transport provision

Table 5-9 shows the statistics for walk distances according to the PT convenience score at the home location of participants. Generally a higher convenience score led to shorter walk distances as part of the potential PT trips, although this trend is less strong when considering the most direct PT options.

Table 5-9 Potential public transport walk distances per PT convenience score

A: all trips, fastest PT route

Convenience score	**Neighbourhood**	***n***	**Distance**				**Time**	
			Mean	St. dev.	Min	Max	Mean	St. dev.
2	*General*	13	1626	680	572	25553	23.6	9.2
	Moseley	13	-	-	-	-	-	-
3	*General*	108	1333	730	36.6	4119	20.2	10.4
	Moseley	68	1509	817	36.6	4119	22.5	11.5
	Bournville	40	1029	399	223	2110	16.2	6.5
4	*General*	80	1084	545	231	2367	16.2	7.7
	Moseley	75	1118	537	231	2367	16.7	7.5
	Bournville	5	579	418	329	1312	8.6	5.4
5	*General*	39	824	547	212	2317	12.8	8.0
	Moseley	1	719	-	-	-	11	-
	Bournville	38	827	554	212	2317	12.8	8.1

B: all trips, most direct PT route

Convenience score	**Neighbourhood**	***n***	**Distance**				**Time**	
			Mean	St. dev.	Min	Max	Mean	St. dev.
2	*General*	8	1827	796	572	2965	26.6	11.0
	Moseley	8	-	-	-	-	-	-
3	*General*	89	1483	696	36.6	3158	22.3	9.66
	Moseley	50	1726	737	36.6	3158	25.5	9.99
	Bournville	39	1171	494	500	2173	18.2	7.54
4	*General*	50	1554	625	333	2619	23.1	9.02
	Moseley	46	1562	615	389	2619	23.2	8.89
	Bournville	4	1465	841	333	2263	22	11.9
5	*General*	39	1231	724	318	2849	18.8	10.6
	Moseley	1	719	-	-	-	11	-
	Bournville	38	1245	729	318	2849	19.0	10.6

C: Unique trips, fastest PT route

Convenience score	**Neighbourhood**	***n***	**Distance**				**Time**	
			Mean	St. dev.	Min	Max	Mean	St. dev.
2	*General*	12	1714	629	677	2553	24.8	8.42
	Moseley	12						
3	*General*	95	1349	760	36.6	4119	20.4	10.8
	Moseley	62	1526	832	36.6	4119	22.6	11.7
	Bournville	33	1007	435	223	2110	15.9	7.07
4	*General*	70	1104	559	272	2367	16.5	7.82
	Moseley	65	1146	549	272	2367	17.1	7.66
	Bournville	5	579	418	329	1312	8.6	5.37
5	*General*	33	883	574	212	2317	13.6	8.43
	Moseley	1	719	-	-	-	11	-
	Bournville	32	889	583	212	2317	13.7	8.55

D: Unique trips, most direct PT route

Convenience score	**Neighbourhood**	***n***	**Distance**				**Time**	
			Mean	St. dev.	Min	Max	Mean	St. dev.
2	*General*	7	2007	663	1158	2965	29.1	8.99
	Moseley	7	-	-	-	-	-	-
3	*General*	79	1517	698	36.6	3158	22.8	9.61
	Moseley	47	1707	747	36.6	3158	25.2	10.1
	Bournville	32	1238	513	500	2173	19.3	7.79
4	*General*	45	1530	606	333	2619	22.9	8.88
	Moseley	41	1536	592	389	2619	23.0	8.72
	Bournville	4	1465	841	333	2263	22	11.9
5	*General*	33	1286	706	318	2849	19.5	10.3
	Moseley	1	719	-	-	-	11	-
	Bournville	32	1303	709	318	2849	19.8	10.4

When this is considered in the context of the car trip lengths, the differences become less clear. Figure 5-15 shows the differences in the ratio of total PT travel time and car travel time for the different PT convenience scores and Figure 5-16 shows the same for the potential PT related walk time versus car travel time. Based on the observations above, where a higher convenience score leads to shorter walks, one would expect that it also leads to a lower PT/car travel time ratio (as walking can take up a significant proportion of the travel time by PT). However, those with a rather low convenience score (2) surprisingly show a lower travel time ratio (which is stronger when looking at the walk time / car time ratio). Across convenience scores 3 to 5, there seems to be a decreasing trend, as expected, but this is relatively weak.

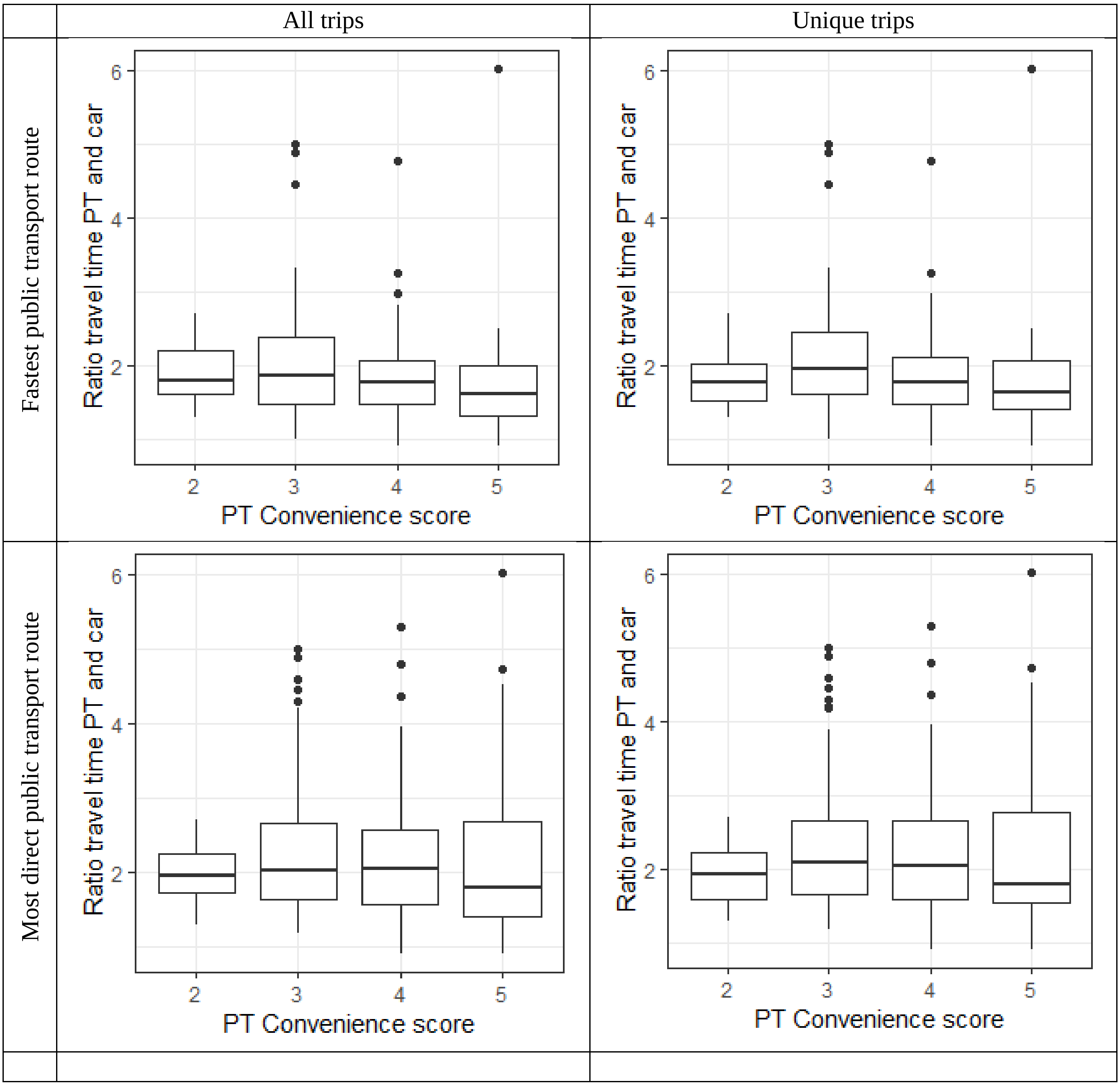


Figure 5-15 Boxplots comparing the travel time ratio for public transport and car per PT convenience score

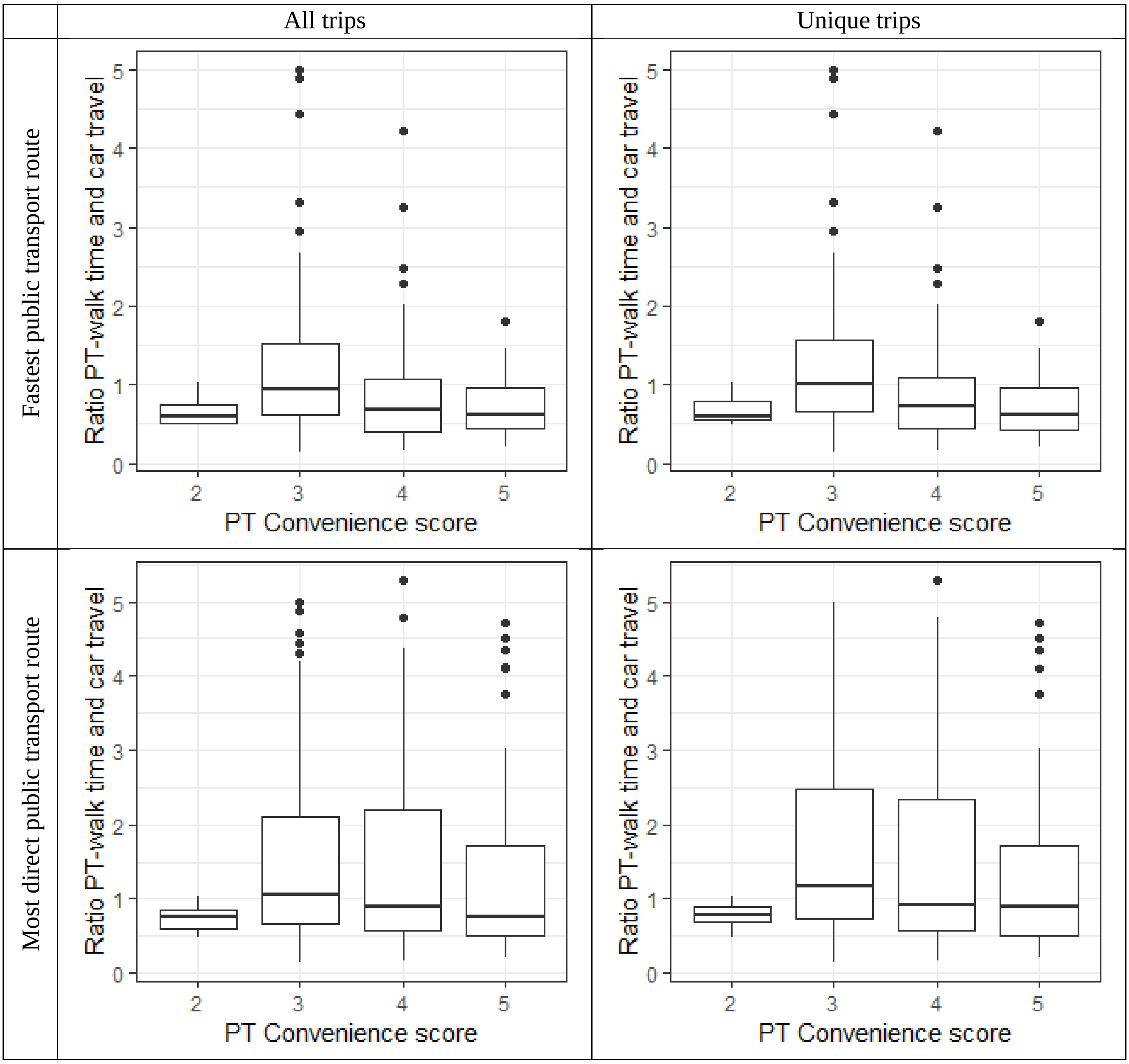


Figure 5-16 Boxplots comparing the travel time ratio for public transport and car per PT convenience score

5.4.2.4 Public transport users versus non-users

Public transport users are defined as the participants who stated in the questionnaire that they used PT at least sometimes (less than once a week), versus those who never use PT. Regular users are those who use PT at least once a week. The differences were mostly statistically insignificant differences between either PT users and non-users or regular and non-regular users (*t* = 0.653, *df* = 51, *p* = 0.517 [all trips, fastest routes, users vs. non-users]; *t* = 2.646, *df* = 52**, *p* = 0.011** [all trips, direct routes, users vs. non-users]; *t* = -0.027, *df* = 140, *p* = 0.979 [all trips, fastest routes; regular users vs. non-regular users]; *t* = 0.674, *df* = 156, *p* = 0.501 [all trips, direct routes; regular users vs. non-regular users]; *t* = 0.586, *df* = 44, *p* = 0.561 [unique trips, fastest routes, users vs. non-users]; *t* = 1.717, *df* = 43**,** *p* = 0.093 [unique trips, direct routes, users vs. non-users]; *t* = -0.295, *df* = 143, *p* = 0.768 [unique trips, fastest routes; regular users vs. non-regular users]; *t* = 0.017, *df* = 152, *p* = 0.986 [unique trips, direct routes; regular users vs. non-regular users]). This implies that the walking requirement for the trips of those who never use PT is similar to the walking requirement of those who do use PT, which indicates that walking does not play a major role in the decision to use PT or car.

Table 5-10 Potential public transport walk distances according to PT usage

A: All trips, fastest PT route

	n	**Distance**				**Time**	
		Mean	St. dev.	Min	Max	Mean	St. dev.
Users	154	1157	670	36.6	3158	17.4	9.39
Non-users	32	1084	557	297	2186	16.4	8.03
Regular users	74	1143	710	74.8	3158	17.1	9.90
Non regular users	112	1146	612	36.6	2828	17.2	8.68

B: All trips, most direct PT route

	n	**Distance**				**Time**	
		Mean	St. dev.	Min	Max	Mean	St. dev.
Users	154	1411	709	36.6	3258	21.2	9.96
Non-users	32	1720	577	389	2619	25.9	8.36
Regular users	74	1507	701	74.8	3158	22.6	9.69
Non regular users	112	1436	696	36.6	2965	21.6	9.98

C: Unique trips, fastest PT route

	n	Distance				Time	
		Mean	St. dev.	Min	Max	Mean	St. dev.
Users	137	1179	682	36.6	3158	17.6	9.55
Non-users	27	1109	537	389	2186	16.7	7.75
Regular users	73	1150	712	74.8	3158	17.2	9.93
Non regular users	91	1181	617	36.6	2828	17.7	8.74

D: Unique trips, most direct PT route

	n	Distance				Time	
		Mean	St. dev.	Min	Max	Mean	St. dev.
Users	137	1460	699	36.6	3158	21.9	9.80
Non-users	27	1675	574	389	2619	25.3	8.46
Regular users	73	1496	700	74.8	3158	22.4	9.66
Non regular users	91	1494	674	36.6	2965	22.5	9.71

5.4.2.5 Attitudinal Clusters

Finally, people were clustered based on their transport attitudes, which might partly explain their use of PT. The clustering process and characteristics of the four clusters obtained were described in Section 3.7.2.2:

- Cluster 1 (135 people): Positive attitude to all modes, except for bus
- Cluster 2 (61 people): Relatively positive to buses, less positive about car driving, positive about walking, cycling and trains.
- Cluster 3 (144 people): Relatively negative to cycling and bus use, whilst positive about walking, car and train use.
- Cluster 4 (42 people): A bit less positive about walking, negative attitude towards buses and trains, moderately negative about cycling and most positive about car driving.

Differences in walk distances between the four clusters are shown in Table 5-11, Table 5-12 and Figure 5-17. Cluster 4, those who had a less positive attitude towards PT and walking, was significantly different from the other clusters in case of the fastest PT alternative. When considering the most direct PT connections there were no significant differences in walk distances between the attitudinal clusters.

Overall, people in cluster 4 required longer walk distances to and from PT when replacing all car trips, implying that the PT accessibility for their trip demand is worse than for others. The difference in comparing the most direct and fastest PT connections indicates that people in cluster 4 tend to have less options in terms of faster connections that involve less walking than those in clusters 1, 2 and 3.

Table 5-11 T-tests to compare the mean walk distances for attitudinal clusters

A: Fastest PT route (top: all trips, bottom: unique trips; bold: p<0,05)

Cluster	**2**	**3**	**4**
1	*t* = 0.951 *df* = 23.314 *p*-value = 0.351 *t* = 0.193, *df* = 18.071, *p*-value = 0.849	*t* = 0.711 *df* = 119.92 *p*-value = 0.478 *t* = 0.7459, *df* = 112.67, *p*-value = 0.457	***t* = -2.311** ***df* = 27.808** ***p*-value = 0.028** ***t* = -2.481,** ***df* = 27.639,** ***p*-value = 0.019**
2		*t* = 0.564 *df* = 26.476 *p*-value = 0.577 *t* = 0.149, *df* = 19.283, *p*-value = 0.883	***t* = -2.442** ***df* = 41.864** ***p*-value = 0.019** *t* = -1.904, *df* = 33.827, *p*-value = 0.065
3			***t* = 2.583,** ***df* = 31.291,** ***p*-value = 0.015** ***t* = -2.804,** ***df* = 29.815,** ***p*-value = 0.009**

B: Most direct PT route (top: all trips, bottom: unique trips)

Cluster	**2**	**3**	**4**
1	*t* = -0.372 *df* = 23.018 *p*-value = 0.714 *t* = -0.510, *df* = 18.186, *p*-value = 0.6162	*t* = -0.782 *df* = 110.04 *p*-value = 0.436 *t* = 0.092, *df* = 99.031, *p*-value = 0.927	*t* = -1.762 *df* = 29.195 *p*-value = 0.089 *t* = -1.810, *df* = 28.765, *p*-value = 0.081
2		*t* = 0.756 *df* = 28.008 *p*-value = 0.456 *t* = -0.533, *df* = 21.76, *p*-value = 0.599	*t* = -1.535 *df* = 40.155 *p*-value = 0.133 *t* = -0.830, *df* = 32.411, *p*-value = 0.4125
3			*t* = -1.209, *df* = 36.765, *p*-value = 0.234 *t* = -1.7514, *df* = 36.091, *p*-value = 0.088

Table 5-12 Descriptive statistics for potential PT-walk trips per attitudinal cluster

A: All trips, fastest PT route

	n	**Distance**				**Time**	
		Mean	St. dev.	Min	Max	Mean	St. dev.
1	81	1129	522	36.6	2828	17.2	7.41
2	20	953	784	212	3064	14.4	11.3
3	61	1061	592	297	2614	16.0	8.80
4	24	1571	893	74.8	3158	22.5	11.7

B: All trips, most direct PT route

	n	**Distance**				**Time**	
		Mean	St. dev.	Min	Max	Mean	St. dev.
1	81	1402	561	36.6	2849	21.2	7.96
2	20	1326	873	333	3064	20.0	12.5
3	61	1489	721	318	2924	22.4	10.5
4	24	1726	849	74.8	3158	25.2	11.1

C: Unique trips, fastest PT route

	n	**Distance**				**Time**	
		Mean	St. dev.	Min	Max	Mean	St. dev.
1	71	1128	547	36.6	2828	17.1	7.76
2	16	1086	827	212	3064	16.2	12.0
3	54	1053	562	318	2614	16.0	8.44
4	23	1614	887	74.8	3158	23.1	11.6

D: Unique trips, most direct PT route

	n	**Distance**				**Time**	
		Mean	St. dev.	Min	Max	Mean	St. dev.
1	71	1441	560	36.6	2849	21.8	7.9
2	16	1552	832	333	3064	23.2	12.0
3	54	1430	704	318	2924	21.6	10.4
4	23	1777	831	74.8	3158	25.9	10.8

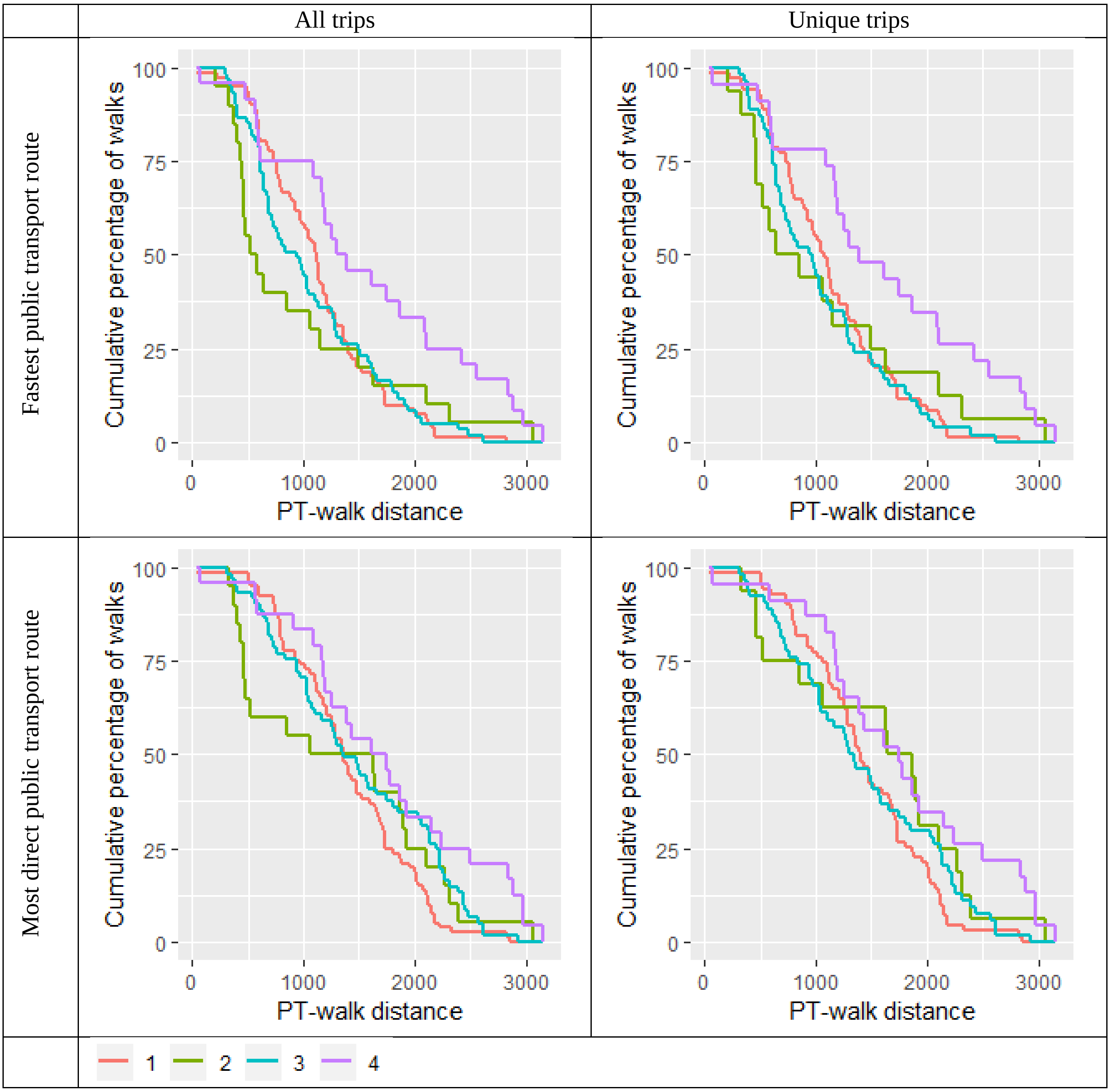


Figure 5-17 Cumulative distribution for potential PT-walk trips per attitudinal cluster

5.5 Summary

This chapter presented the results of the analyses of the smartphone tracking survey. The analyses comprised of two main sections: the analysis of PT trips and related walks and the analysis of car trips. The main focus was on the walk distances in relation to several aspects of the PT service provision. With regard to the car trips, the PT alternatives were examined and similar analyses were done for the potential walk distances.

Because of the small sample size and the fact that not all walks in the sample were independent observations, analyses were done for both the entire sample and for unique trips only to control for potential biases (if the same trip was made multiple times, it was only counted once, for instance when someone travels from home to work and from work to home via the same route, or did this trip on multiple days).

Walks to and from buses were found to be on average much longer than expected, making the difference with walks to and from trains smaller than usually assumed. These relatively long distances related to bus trips can partly be attributed to the layout of bus services in Birmingham, with especially long access distances to bus stops in Moseley. However, in many cases people were also found to not just walk to the closest bus stop but use a further stop with better services instead. People were found to walk further to avoid transfers, to get a faster connection or to use a train instead of bus. Moreover, the results indicated that the access and egress distances in PT trips were related to each other, and that people might have some walk distance budget. If the access distance is longer, the egress distance will likely be shorter, and vice versa. The route quality was also found to be related to the walk distances. Longer walks more often occurred on routes with a higher ‘pleasantness index’, which is mostly based on the link or place function of a street. So streets on which there are more activities taking place and which carry less traffic tend to cater for longer walks.

In the second part of the analysis, the car trips in the dataset were considered, together with their PT alternative by planning the same trips via an online route planning engine. The car trips did not appear to differ much in duration between the two areas. For almost all trips the PT alternative would have been significantly slower. However, despite the clear difference in PT supply between the two areas, there was also no significant difference in the ratio of PT travel time and car travel time.

The potential walk distances related to PT did differ significantly, though, if all car trips were replaced by PT. This was partly related to PT convenience, as a higher score on this attribute generally led to shorter walk distances. The PT usage frequency did mostly not have significant relationships with the walk distances. The attitudes, however, were of influence, as people in the attitudinal cluster that was most negative towards PT and walking had to walk significantly longer than other groups if they were to switch to PT for all their car trips.

6. DISCUSSION

6.1 Introduction

The previous two chapters presented the results of the two main parts of this research: the questionnaire survey and the smartphone tracking survey. This chapter builds on these by critically discussing the findings, in order to be able to draw conclusions and address the research objectives in Chapter 7. The findings are critically discussed in two sections, referring to the questionnaire and the tracking survey.

Like any study, this research has a range of limitations, which are acknowledged and discussed as well in the two following sections. A limitation of the research in general is that the focus was solely on walking, whilst cycling (or perhaps other active modes such as scooters) to or from PT can also offer the intended public health benefits. The use of cycling as an access mode can significantly increase the service area of PT; the combination of cycling and train use has for instance been proven to be a successful multimodal option in the Netherlands (Jonkeren, Kager and Harms, 2019). The effect of this research limitation in the study context of Birmingham is limited, however, since the majority of PT access is undertaken on foot (Centro, 2013, 2014) and cycling forms only a relatively small proportion of travel in the UK.

6.2 Discussion questionnaire survey[7]

The perceived barriers to PT and walking were studied using two different methods in a postal questionnaire. Respondents firstly provided three free associations with five different transport modes and rated the affect with each association on a 7-point scale. As a second method, a

[7] Part of this section has been already published in Van Soest et al. (2019b). Dennis van Soest wrote the major parts of the paper, while Miles Tight and Christopher Rogers contributed with reviewing, editing and supervising the paper.

range of predefined barriers to walking and bus and train use were presented, of which respondents rated the importance on a 7-point scale as well.

Each mode was shown to be perceived very differently. Whereas walking was associated to many positive aspects, the other modes were perceived rather negatively. For bus and train the most mentioned negative associations were related to its cost, unreliability of the service, crowding problems and, in case of trains, access issues. Likewise, the car was perceived very negatively, despite the fact that the mode is widely used. Traffic and parking problems were often mentioned, as well as time issues and stress or pollution, though it was also regarded as a convenient and fast mode. These association findings are in accordance with existing findings around travel satisfaction. In studies on travel satisfaction, active travellers tend to be the most satisfied with their trips, car travellers are moderately satisfied and PT users are the least satisfied with their trips (De Vos, 2018). The ease of use of a certain mode has been found to be an important aspect in the affective appraisal of travel modes, in which particularly car and public transport can be regarded as stressful (Gatersleben and Uzzell, 2007).

Although for most of the predefined barriers there was a wide range of ratings, there were clear trends concerning the relevance of some potential barriers. The barriers that received the highest ratings did not necessarily come up in the free association task. For walking, luggage, safety at night and time were rated as most relevant barriers. For bus use these were time, crowding and expense and for train use expense, crowding and time, respectively. Whilst time was one of the three most associated barriers to walking, feelings of unsafety at night or luggage as a barrier were not often mentioned in the free associations. Instead, weather and traffic were the two other most associated barriers. This is perhaps due to the hypothetical character of both luggage and safety at night as barriers. People might never or rarely walk with some luggage or during night time (whether or not due to these factors being a serious barrier to walking), and therefore not associate walking with these aspects. The most associated barriers to bus and train however align well with the highest rated predefined barriers. The discrepancy between the predefined barriers to walking and the associated barriers to walking shows how the free association technique could add richness to the conventional rating approach of predefined barriers; it gives more insights into what negative aspects are predominant in the image of walking.

The analysis of both the content of the associations and the affective rating has shown that there were significant differences in perceptions between the neighbourhoods for all transport modes except car driving. These differences were investigated further using binomial logistic regression models for the affective rating of the associations. Whilst controlling for various socio-demographic variables, the influence of neighbourhood deprivation appeared to be limited. The availability of PT, albeit measured through three different indicators, showed significant effects on the positivity for all modes, especially car driving and walking. A higher convenience of PT was related to a lower odds of being positive about car driving, and a higher odds of being positive about walking. The availability of trains had a positive effect on the odds of being positive about trains, as might be expected, whilst the bus convenience score did not influence the odds of being positive about bus use. A high train convenience was associated with lower odds of being positive about buses, however, pointing at the general preference for trains over buses in case of PT trips (Scherer and Dziekan, 2012; Anderson, Nielsen and Ingvardsson, 2016).

The limited influence of the level of neighbourhood deprivation indicates a limited place-related effect beyond controlling for other socio-economic variables. However, since income level, for instance, is part of the definition of deprivation and had a significant influence on the affect for all modes except cycling, the differences in perceptions between neighbourhoods with different levels of deprivation are larger in practice. This was also apparent in the analysis of the contents of the free associations, and likewise observed by Gebel et al. (2009), where people of lower economic status showed a larger discrepancy between perceived and objectively assessed walkability. These deprivation differences are, therefore, mostly attributable to differences in socio-demographic characteristics, and only to a limited extent to factors on the neighbourhood-level (e.g. differences in available social support to engage in physical activity and investments in the street environment (McNeill, Kreuter and Subramanian, 2006)). However the physical neighbourhood environment, such as the level of greenery and the provision of PT services, did have an important impact on the way transport modes were perceived.

Generally, in the less deprived areas, people tended to perceive public and active transport more positively than in the areas with high deprivation, whilst car transport was perceived more positively in the highly deprived areas. Based on the content analysis, these differences can be attributed to problems around crowding, safety, time and concerns about (the behaviour of) other people in the deprived areas. The usually lower incomes in more deprived areas can also lead to PT being perceived as more expensive, although this did not come forth in the content analysis. Moreover, the car might act more as a status symbol, as has been observed particularly within some migrant populations (Ashmore, Christie and Tyler, 2017), which can explain some of the more positive affect for this mode. Furthermore, the more limited disposable income in these areas can impact the freedom to choose the residential location and preferred means of transport. This increases the possibility of being a “dissonant traveller”, someone who does not travel with his or her preferred mode, leading to lower levels of travel satisfaction (De Vos, 2018), and probably more negative perceptions.

The level of deprivation also formed a limitation to the research, as the sample was skewed towards the two less deprived areas. The relatively small sample sizes in the two most deprived areas limited the comparisons among the different neighbourhoods. This limits the opportunities for analysis and potentially biases results in case there is unmeasured variance between the neighbourhoods. Future research might be able to address this by using different approaches to collect data in deprived areas, where willingness to participate in research tends to be lower. Especially in Small Heath, language barriers might have contributed to the small sample size as well. Also the quality of the responses was more often doubtful in the deprived areas. For example, sometimes the responses to the questions seemed rushed, after which the person took the opportunity to complain about all transport problems in the open comment section at the end.

Following the analyses of the free associations, a similar analysis was done for the predefined barriers. The neighbourhoods tended to show significantly different barrier ratings too, especially for train use. For walking and bus use only several of the full range of barriers rated differed significantly across neighbourhoods. Similar to the affective rating, the level of neighbourhood deprivation did not seem to influence the barriers to bus and train use much. However, for most of the barriers to walking, neighbourhood deprivation tended to have a significant and large effect on the ratings. In all these cases, people living in deprived neighbourhoods had a higher rating of the barriers. For train barriers, deprivation-related indicators such as income and ethnicity still showed moderate influence, whereas also these influences were very small for bus barriers. Perhaps this is again related to the higher status of trains, which is appreciated by some people, mainly in less deprived areas, whereas the vast majority have a rather negative perception about buses, across both deprived and less deprived communities. The low status of bus use can lead to the situation that some people would not even consider it as an option for travelling, although they might reject suggestions that status is a reason (Fitt, 2018).

While neighbourhood deprivation seems to play a role in the transport perceptions and barriers generally, the fact that its influence was rather small for various barriers indicates that not all attributes are necessarily experienced more as a barrier by respondents in deprived areas compared to those in less deprived areas. In other words, they do not necessarily feel more negatively towards walking or PT in general, suggesting that it might be possible to reduce the adverse experiences of environmental barriers, which are modifiable through urban or transport planning, in deprived areas. Improvements of the infrastructure quality in these areas might also offer wider wellbeing benefits, as a poor quality environment can have a reinforcing effect on the level of deprivation (Atkinson and Kintrea, 2001).

This discussion on perceived transport barriers and how they are influenced leads to the question whether the transport perceptions and barrier ratings also relate to actual travel behaviour. To test this, χ^2-tests were performed for the content of the free associations, whilst Kendall's tau correlations were calculated for both the affective ratings and the ratings of the predefined barriers.

The results showed that both the content and affective rating of associations with a particular mode as well as the barrier ratings to a mode were significantly related to its usage frequency. Generally it was found that people who never or rarely use a mode tend to associate that mode with more negative aspects, whilst frequent users acknowledged more positive qualities. The barrier ratings were negatively related with the mode use frequency, as could be expected. A major limitation of the current study is that the causality of these relationships could not be assessed. A positive view on a particular transport mode might result in an increased usage of that mode, but more usage might also result in a more positive view. Likewise, a more frequent use of a mode might lead to a lower experience of potential barriers. There is some evidence, though, that positive views can positively influence the satisfaction with a transport mode and eventually the loyalty and usage (Minser and Webb, 2010; Lai and Chen, 2011; Zhao, Webb and Shah, 2014; Şimşekoğlu, Nordfjærn and Rundmo, 2015). It has however been found that it is very difficult to improve negative perceptions by marketing campaigns, especially when people have no interest in using PT (Beale and Bonsall, 2007).

Therefore, perceptions can give insights in the predispositions to change modes (Hasiak, Hasiak and Egea, 2016), and thus highlight opportunities where change is most possible. It was shown that the use of a transport mode was not always only associated with the content and affect of the associations with that particular mode, but also with the views on other modes. These interactions between modes indicate that it is worth studying perceptions in a context of multiple modes instead of a single one. Car use frequency appeared to be negatively related to perceptions of other modes, although train perceptions contained positive aspects as well. There might, consequently, be more potential to stimulate a modal shift from cars to trains than to buses. The higher status of trains is also indicated by the fact that an increased train use is negatively associated with the perceived positivity of buses, while an increased bus use shows no relation with the perception of trains.

Similarly, most barrier ratings were positively correlated with each other, which indicates that a barrier is usually not experienced in isolation but that two or more barriers are experienced at the same time. The relationship between the experience of a barrier to using a certain mode and other modes was assessed by comparing the free associations of the three modes between people who agreed that a barrier played a role and people who were neutral or who disagreed that a barrier played a role. For most barriers, there were significant differences in associations for the mode to which the barrier was experienced, but sometimes of other modes as well. This strong relationship indicates that it might be possible to influence the perception of using a certain transport mode by addressing barriers people experience to using that mode. These findings are in line with Hickman and Vecia (2016), who observed that perceptions about PT or car use were related to someone's willingness to walk from PT.

There are a few further observations that should be made with regard to this research. A problem with the selection of Small Heath as one of the study areas is related to its selection as a neighbourhood with railway access. However, in the selection of the streets within the neighbourhood there was perhaps too much attention on the opportunity of different walk routes to and from the station, with as a result that some of the selected streets have a rather long walk distance to the station (e.g. more than 800m, the conventional threshold). In the interest of studying differences between areas with good railway access and without railway access, it would have been better to choose residents living closer to a railway station. Yet, the study was able to define some differences between a neighbourhood with or without railway access, as most respondents were living in Bournville and Moseley, which are very distinctive on this characteristic.

The questionnaire itself targeted travel in general, and there was no distinction between travel purposes, which might have led to different views on using a certain mode and different effects on mode use (Feuillet *et al.*, 2016). Making the hypothetical travel scenarios that people had to think about more specific could reveal sharper contrasts in the free associations. It can however also reduce the freedom in associations, and limit the responses in case the scenarios become too irrelevant to the respondent. Some people already appeared to have difficulties with the current approach, e.g. not understanding that one can still have associations with a certain mode even when one never uses it.

The free association technique specifically has some drawbacks too. The interpretation of the associations was not always straight forward, due to the limited context provided to the associations. It can be questioned to what extent the free associations cover a person's full perception of using a certain mode. Free associations probably do not address the rational assessment of transport modes (Slovic *et al.*, 2004), which might also be important with regard to travel preferences and behaviour. However, the predefined barriers that were used as a second method aimed to compensate this to some extent.

Overall, the analyses were limited by the cross-sectional nature of the study, which makes it harder to infer causal relationships between variables. Future work could adopt more qualitative methods, such as interviews or focus groups, to add to the questionnaire findings, providing more in-depth insights into the experience of PT and walking. Longitudinal studies, using similar questionnaires over a longer time period, can also provide a better view on changes over time and causal mechanisms.

6.3 Discussion smartphone tracking survey

The analyses of the smartphone tracking survey focused mostly on the recorded PT trips and their related walks on the one hand and the car trips on the other. For the PT trips, the main focus was on the distances people walked to and from the PT mode, whilst for car trips the PT alternative was examined, of which the walk characteristics were then explored further.

When examining the actual walk distances recorded in the sample, firstly the average distances were compared for bus and train trips. Based on existing conventions (e.g., Murray and Wu, 2003; Zhao *et al.*, 2003; Canepa, 2007), it could be expected that most walks related to buses would be under 400m and those related to trains under 800m. It had however already been observed in various studies that these conventions are not always in accordance with reality (e.g., Canepa, 2007; Badland *et al.*, 2014; El-Geneidy *et al.*, 2014). This seemed to be the case in the current study as well. Although the majority of the train-related walks were recorded to be under 800m, a large proportion of the bus-related trips was longer than 400m, with an average of about 500m. Also in contrast to many other studies, the difference between bus and train-related walk distances was statistically insignificant, although this can partly be attributed to the small sample size in the present research.

Several further analyses were employed to attempt to understand why particularly the bus-related walk distances were relatively long in this study. Participants in this study were living in either Moseley or Bournville, two areas with a big difference in PT supply. Whereas the Bournville area has good train access via two stations and almost everyone can reach a bus stop within 400m from home, Moseley residents do not have a train station nearby and a significant proportion need to walk further than 400m from home to reach a bus stop. Despite these differences, there were no significant differences in walk distances between Bournville and Moseley residents, which probably reflects the fact that most people who lived further than 400m from their closest stop did not use PT. The distance to the closest bus stop was however not found to be very important in relation to the distances people walk for PT, as in many cases a stop further from home was chosen to board or alight a bus. The PT connection with the final destination, in terms of quality, travel time and directness, appeared to be one of the most important aspects. In this consideration, some dependence was observed between the access and egress walk in a trip, in that a longer access walk generally means that the egress walk will be shorter. This latter finding also aligns with other studies, that observed longer access trips than the conventional thresholds, provided that the PT service brings the traveller closer to their destination (Badland *et al.*, 2014). The evidence is too limited to be very conclusive about to what extent people do consider a specific walk distance budget, or whether this is an observation following from the fact that people tend to have an overall trip time budget (Milakis *et al.*, 2015).

When the chosen PT routes were compared to potential alternatives, several ‘walking strategies’ came forth. For some of the trips there was only one optimal option in terms of walking and total travel time, which was chosen in that case. However, often multiple routes were available with different travel times and walk distances. People were regularly found to walk further, either to avoid transfers, to get a more direct connection and reduce the total travel time or to travel by train instead of bus. In a few cases no particular reason for the further walks could be attributed. The pleasantness of the walking routes could play a role, as this was found to be related to the choice to walk further distances, also confirming earlier research (Jiang, Zegras and Mehndiratta, 2012; Park, Deakin and Jang, 2015).

Besides this analysis of PT-related walk trips, the car trips were studied, in particular with regard to the potential for a switch to PT (in combination with walking). This was done by considering how each car trip might have looked like if it were undertaken by PT instead. This data was obtained by planning a PT route with the same origin and destination as the car trip, using an online route planning engine. For each trip, two alternatives were considered: the fastest (least total travel time) and the most direct alternative (least number of transfers), which in some cases might be the same. The car trips were also reconsidered to obtain better estimates of the car travel time, as the times recorded were not always reliable due to earlier or later registration at respectively the origin and destination as a result of missing data points.

It is important to note that in this analysis of the PT alternatives, it is assumed that the car trip can potentially be converted, as long as instrumental differences (such as travel time and walking time) are acceptable. Someone might however use a car to carry heavy goods or have other unknown reasons which would make it more difficult to use PT (e.g., Mackett, 2003; Beckx *et al.*, 2013; Mattioli, Anable and Vrotsou, 2016). Moreover, it is assumed that the destination of the car trip is a fixed entity, while destinations can in some cases be flexible, depending on the availability of transport means. For instance, in case someone went to a supermarket, he or she could choose to visit another one which is more accessible by PT if the person were to avoid the car as a travel mode. If more data were available, it would have been of interest to differ more by purpose of the trip, and for instance also explore alternative shopping locations when considering the public transport alternative to a car trip.

Although there were clear differences in the PT provision between the two areas, the total travel time by PT if all car trips were replaced did not differ significantly. When examining the potential walk distances, however, significant differences appeared between the two areas Bournville and Moseley with regard to the PT accessibility of the car trips. There was also a negative relationship between the PT convenience score for the people's home locations and the walk distance, meaning that a closer, more frequently served PT access point at home generally led to shorter total walk distances for PT trips. This finding, although logical, might however be mediated by the algorithms used to plan the PT routes. As found in the analysis of the walk stages to and from PT, people regularly used options that were not offered by planning engines (although different planners were used in both analyses; transportapi.com and Google Maps). The algorithms likely do not consider the preference of a walk distance budget, as was suggested by the previous analysis of walk stages.

Thus, despite the much better walk access to PT in Bournville, this did not result in a better overall PT accessibility when considering the trip demand. The current PT system could therefore be considered relatively slow for the trips people want to undertake. To some extent this is due to a lack of direct connections, as the travel time ratio between PT and car increases more in Bournville than in Moseley, when comparing the fastest with the most direct PT routes.

A comparison was also made between people who (regularly) use PT and those who do not, based on their questionnaire response. These comparisons did not reveal any clear trends, which initially seems to point at a small role of walking in the decision to use PT. However, under the assumption that walking does play a big role in this decision, one would expect that PT users have a higher mean of potential walk distances (since the trips with shorter walk distances would then already be undertaken by PT instead of by car). Since no clear difference is observed, it can also indicate that the walking acceptability of non-users is lower, which would align with the intermodal relationships found in Chapter 4 (see discussion in Section 6.2).

Part of the difference between PT users and non-users can lie in different attitudes towards these transport modes. Therefore, participants were divided into attitudinal clusters using a clustering technique, which resulted in four clusters based on attitude responses in the questionnaire. After comparing the four clusters, it was found that the cluster that was less positive towards walking and PT also had significantly longer walk distances if all car trips were to be replaced. So the walk accessibility for their trips by PT is worse than for other people. This can be caused partly by residential self-selection (living in an area that is more accessible by their preferred mode, the car), the attitudes can have become more negative as a result of bad experiences with PT due to the bad accessibility, or the destinations they choose to travel to may be less accessible by PT (i.e. they might be on average more flexible in their location choices, paying less attention to reduction of the derived transport demand).

The most prevalent disadvantage of the smartphone tracking approach adopted in this study was probably that it was very difficult to get a sufficient number of people to download an app and provide detailed travel data. This has resulted in a small sample size (n = 45), none of whom lived in the two most deprived areas. The method can be considered quite intrusive, since it gathers sensitive confidential data about a person. The participants do not know the researcher, so they need to have sufficient trust and willingness to participate in the research when deciding to take part. This leads also to further bias in the sample towards more highly educated people and people working in education, who tend to have more experience with university research and have a deeper understanding of the need of data gathering and/or a higher inclination to contribute to such a project.

Another limitation was related to the times at which the surveys were conducted. Although it can be considered a strength that the questionnaire and smartphone survey were connected to each other, creating a very rich dataset, there was a rather large time gap between the two studies. The tracking study was carried out about 16 months after the questionnaire survey, mainly related to delays in arranging a server for the data collection system with the university's IT Services. By connecting the two datasets to each other, it was assumed that the responses to the questionnaire survey were still valid for the person at the time of the tracking study, which might not always be the case in practice. A related discrepancy is that the questionnaire was conducted in winter time (January), whilst the tracking happened in spring (May), which can have implications for people's willingness to use active transport modes, for which weather is an important consideration.

Besides this, there were several technical limitations. By using people's smartphones as a data collection sensor, in contrast to providing the participants with a device, there is no control over the quality of the equipment. For a few participants the smartphone did not provide any data or very little data. Furthermore, the battery of a smartphone can die and participants can close the app, whether or not intentionally, which stops the collection of data. The data collection was continuously monitored and if no data had been uploaded for a while, the participant was informed and asked about the app. In most cases the app was indeed closed, for instance due to a reboot, dead battery or accidental closure of the app. These app closures led to temporal gaps in the data collected. There was also a flaw in the app related to this, because after restarting the app, the app was restored to its previous state. This made it look like it was still gathering data, whilst this was not the case. In such situations, the participant had to press the button to stop data collection and manually start it again, which was not always clear to all participants. This is all related to a larger limitation of this research approach: the technical complications involved, which were rather challenging for a researcher with solely a transport planning background. The tracking system is based on various technologies and software, which ideally should be understood at least at some basic level. Some of the aspects included: the principles of communicating with a server via a command terminal using an *SSH* connection, installing software on an *Ubuntu* server, working with *Node.js* and *tmux*, accessing *PostgreSQL* databases using *pgAdmin*, compiling Android app code (*Java*) and iOS app code (*Objective C*), debugging the apps, and the processes of publishing in the relevant app stores. Although the study worked out eventually, it was not particularly time-efficient to find the way through this unknown field without much guidance, and it involved some risks, as it could be difficult to resolve potential unexpected technical errors without deep knowledge or ample experience.

Lastly, the temporal gaps in the data collected could also be caused without closing the app. In some areas the phone might lose position information (such as GPS signals) or there could also be cases that the phone does not continuously provide location data to the app due to energy saving algorithms in the operating system or likewise.

7. CONCLUSIONS

7.1 Introduction

This last chapter of the thesis summarises the findings of the research project. Firstly, a section outlines how the different research objectives are addressed. Then the key findings of the research project are listed, drawing together the findings of the two main studies. Finally, the chapter concludes with recommendations for transport research, policy and practice and some ideas for potential future research strands related to walking to and from PT.

7.2 Research objectives

In Section 1.2, five research objectives were stated, which will now be addressed. Each objective is discussed individually on how it has been addressed and achieved.

Objective 1: *To identify which barriers people perceive towards using public transport and walking.*

In Chapter 4, barriers to PT were explored using two techniques: predefined potential barriers that had to be rated on a 7-point scale and free associations, which included an affective rating. For walking, luggage, safety at night and time were found to be the highest rated barriers, followed by the poor quality of pavements. When looking at free associations, weather, time and traffic were the most mentioned barriers, whilst overall walking was perceived positively.

Bus and train were associated with many barriers, of which unreliability, crowding and expense were the most prevalent ones. In the predefined barriers section, these findings were confirmed. Expense, crowding and time were rated highest across both transport modes (unreliability mainly affects time or time uncertainty).

Objective 2: *To explore if and how these perceived barriers vary across neighbourhoods.*

This objective was also addressed in Chapter 4, by analysing the influence of the neighbourhood and other characteristics on the ratings of barriers, the free associations given and the affective ratings of these. Overall the experience of barriers and perceptions of transport modes in general tended to differ across the four neighbourhoods studied. Both the levels of PT provision and neighbourhood deprivation appeared to influence the barriers people perceived. For walking, deprivation was very influential on the barrier experience, whilst for PT only for some barriers did there seem to be a clear distinction according to neighbourhood deprivation and, if so, the effect of neighbourhood deprivation was small beyond differences in socio-demographic characteristics such as income.

Objective 3: *To study to what extent these perceived barriers are related to each other and the actual travel behaviour.*

This objective was addressed in Sections 4.2.2 and 4.2.3. Both the content and affective rating of the free associations were strongly related to the mode use of the respective modes. Car driving tended to be very distinctive, in which people with a more positive perception about car driving used the other modes less, and vice versa. Also for the predefined barriers, there were strong negative relationships between the rating and the mode use frequency of the respective modes. A larger experience of barriers towards bus and train was, moreover, associated with a lower frequency of walking. People who cycled more generally experienced smaller barriers to walking and PT, whilst more frequent drivers experienced larger barriers. It remained however uncertain how exactly the barriers to walking and public transport interact and to what extent these might work synergistically or not.

Objective 4: *To investigate how public transport related walks are influenced by public transport provision.*

This objective was achieved by examining walk stages to and from PT as recorded in the smartphone tracking study. Some differences were found between train and bus-related walks, but less than expected. The people in the sample walked relatively far to the buses in Birmingham. The results showed that this was partly due to a low density of bus stops in some areas, but also to the layout of bus routes. Participants often walked more than the minimum to reach a better transport connection.

Objective 5: *To explore the potential for the use of public transport and walking for current car trips.*

This last objective was addressed in Section 5.4.2 in Chapter 5. In this section, the PT potential was explored by planning the recorded car trips using an online route planning engine. The walk distances involved were analysed, as well as the total travel time by PT in relation to the travel time by car. It became clear that in almost all cases, PT trips would take significantly longer. The differences in walk accessibility between the two neighbourhoods studied for this objective did not result in differences in overall PT accessibility for the car trips. Yet, people who never or rarely use PT seemed to have a lower acceptability of walking.

7.3 Key findings

The main aim to address in this research is to develop the understanding of the variability in walk distances to and from public transport across urban areas. The study is unique, as it took a more personal approach to understanding the distances people walk to and from public transport, in contrast to most earlier work focussing on specific public transport stops or services. It also addressed more social dimensions in urban planning, such as the level of deprivation, which can influence travel behaviour beyond the often-studied spatial indicators.

After an extensive, systematic review of the literature (Chapter 2), the walk distance to and from public transport was conceptualised as an interaction between the demand for travel and using public transport and walking, and the provision of public transport services and walk infrastructure in the built environment. The study was shaped around this concept, examining both sides in further detail.

With regard to the demand side, the perceived barriers towards public transport and walking were investigated using a postal questionnaire survey in four different areas of Birmingham. The perceived barriers were questioned in two different ways: by rating sets of predefined barriers and using an open approach based on free associations. The analysis of these data led to the following main findings:

- Whereas walking was associated with many positive aspects, public transport was perceived much more negatively and associated with various barriers. Travel time, the unreliability of the service, expense and access issues were the most prevalent barriers to public transport usage. Time was also an important barrier to walking, along with the weather conditions, the presence of traffic, concerns about personal safety (especially at night) and the need to carry luggage.
- People living in different neighbourhoods were shown to perceive transport modes differently, except for car driving. The availability of public transport in the neighbourhood was found to significantly influence the perceived barriers towards public transport, showing a connection between the supply and demand sides of the framework. Alongside public transport provision, the differences in deprivation also

tended to affect the perceptions, although this effect was mostly attributable to certain differences in socio-demographic factors such as income and ethnicity, rather than place-related deprivation effects. More widely, it was shown that the context people are living in, at different levels, has a strong influence on how transport modes are perceived. Understanding how modes are perceived, and in particular the barriers to using them, is important with regard to the design of effective interventions to bring about a shift in modes of transport that better aligns with the carbon reduction and health agendas.

- The barriers to walking and public transport were found to be connected to each other and also strongly related to mode use behaviour. People who experienced a certain barrier to a mode tended to experience multiple barriers to the same mode as well as other modes. The experience of barriers to one mode can influence how other modes are perceived. Therefore, attempts to overcome a certain barrier to, for instance, train use might not always have the desired impact, because people can have a different image of walking too. This highlights the importance of considering the surrounding built environment in public transport planning and calls for an integrated consideration and planning approach. By addressing barriers to multiple modes, the entire trip chain involving public transport and walking can become more attractive, which might have synergistic effects on the predisposition to choose public transport as a mode of travel.

The supply side was studied using a smartphone tracking study that gathered detailed travel data for participants in the two least deprived study areas.

- The majority of the walks to and from trains were found to be within the 800m threshold that is often used in practice. Bus-related walks were however found to be relatively long, with a significant proportion being longer than the conventional 400m threshold for buses.

- The relationship between the PT-related walk distances and the distance to the closest bus stop near home did not appear to be very strong. In many cases, a stop further from home was chosen to board or alight from a bus, in which the public transport connection with the final destination was one of the major factors. Several walking strategies were identified based on the routes observed and their alternatives. For routes with multiple reasonable travel options, people rarely minimised the amount of walking, but tended to walk further to avoid a transfer, reduce the total travel time or take a train instead of a bus.
- Besides the public transport provision, the route pleasantness was found to influence the walk distances as well. More long walks occurred along street sections with a higher pleasantness index, that is where there was less traffic intensity and there were more activities on or along the road.
- When considering the public transport alternative for all recorded car trips, the differences between potential public transport-related walk distances in the two study areas reflected the big differences in public transport provision. However, the potential total travel time (including walking) of a journey using public transport did not differ significantly between the two areas. This indicated that, for the current car trip demand, the public transport alternative is relatively slow, with a lack of direct connections, particularly in Bournville.
- People who never or infrequently use public transport seemed to have a lower willingness to walk far. Though, when looking at attitudinal clusters, people with a negative attitude towards public transport were found to live in areas with lower walk accessibility of public transport as an alternative for their car trips.

Thus, overall it could be stated that the variability in public transport walk distances is mainly caused by the provision of public transport services (routes and stops). This both directly affects the distances people need to walk as well as the perceived barriers to using public transport and walking, which shape the demand for walking to or from public transport. This experience of barriers can vary between areas with different levels of neighbourhood deprivation. The directness of the public transport routes in relation to where people live and want to go is of importance, in which the length of the access and egress walks are related to each other. Therefore, to increase the share of walking, and public transport use, it is important to offer a pleasant walking environment (an environment with less motorised traffic and more activities) and adequate public transport provision offering direct connections to where most people in an area want to go. More tailored policies addressing areas with different levels of deprivation might be beneficial in enhancing a modal shift, as the citizens in these areas have different needs and aspirations.

7.4 Recommendations

The findings of this research link to current transport practice, policy directions and policy instruments, and can affect these in several ways. This section outlines some recommendations based on the findings of this study that can improve future research and practice.

Firstly, the demand for public transport related walking, studied by investigating the perceived barriers, was found to be influenced by various factors, in which the context people live in, on different levels, affects how people perceive certain transport modes. This reflects how individual behaviours are influenced by the informal aspects of governance (Rogers, 2018), such as individual or societal attitudes (which are often informed by perceptions as well as fact) that combine to shape societal norms. The research has likewise suggested that in order for a marked modal shift to occur, societal norms (and hence attitudes that inform them) are likely to need to be altered. This mechanism can, however, also be used in reversed order, since society is essentially shaped by individuals. If a group of individuals change their attitude, the societal norms can adapt over time, which can lead to more individuals embodying these attitudes.

Since the heterogeneity in culture and levels of deprivation can lead to different views on transport modes, awareness of this is important with regard to estimating the effectiveness of policy interventions. In some cases, as suggested above, policies could seek to change attitudes or the perceptions of what societal norms are or should be, i.e. change the informal systems of governance. However, this can be a difficult process. It has, for instance, been found that negative perceptions of bus use are unlikely to be significantly influenced by marketing campaigns, either because views are strongly held or there is a lack of interest in public transport (Beale and Bonsall, 2007), in which case formal forms of governance need to be invoked.

Such formal governance interventions can include regulation (to improve services in some way, such as frequency or quality) or taxation (to influence the relative costs, such as congestion charging and/or parking charges to limit car usage, or public transport subsidy to reduce fares). Policy changes might also refer to physical changes to the landscape, for example provision of cycle lanes, bus lanes, green corridors to encourage walking and cycling, the provision of shelters for walkers and cyclists to take temporary refuge, lighting to improve the perception of safety, and so on (Headicar, 2009; Rogers and Hunt, 2019).

A technique such as the free association approach used in this study can add particular richness to this planning process for policy changes. The free associations give an insight into the views and aspirations of the citizens themselves, and thus show what the citizens find important, which can point at the policy changes that are most desired. Such an approach has been used in a general sense for citizens in London and Birmingham to explore the factors that affect citizen wellbeing (Joffe and Smith, 2016), whereas the current study focusses specifically on means of travel within Birmingham. Some of the barriers are more easily modifiable than others. These modifications can either be implemented by the relevant (transport) planning authorities, as has traditionally been done in a top-down approach, or through the empowerment of citizens and communities (Rogers *et al.*, 2014).

The fact that perceived barriers to walking and public transport were found to be related to each other implies that attempts to overcome a certain barrier to, for instance, train use might not always have the desired impact, because people can have a different perception of walking too. This highlights the importance of considering the surrounding environment in public transport planning and calls for an integrated consideration and planning approach. Future research could attempt to reveal whether the relationships among barriers and between barriers and perceptions work synergistically or not. The experience of a few barriers together might lead to a much greater 'total barrier experience' to using a certain mode of transport (i.e. perceptions are reinforced). Alternatively, it is also possible that the barriers are not summative and that only the largest barrier determines behaviour.

The second part of the research, using the smartphone tracking survey, resulted in several additional findings that can have interesting implications for both research and practice. The major finding was that people in some cases walked much further to public transport than would generally be assumed and that this is highly related to the provision of public transport services, both in physical presence and service quality.

Most of the studies on walking distances to and from public transport in the literature are based on a few stations or public transport routes and do not – or only to a limited extent – consider the density of stops or the availability of alternative public transport routes. This factor can however have a very significant impact on the results, i.e. the distances people walk to or from a stop. Studies that measured public transport access by just looking at the nearest stops for people or by considering the coverage of the population by public transport service areas (400m) have similar limitations, as in many cases the closest stop is not an ideal stop for the public transport connection. The importance of the closest stop for someone will depend on the stop density and the routes available in the area. Moreover, when comparing different stops or stations across various areas it is valuable to look at the level of neighbourhood deprivation too, as this can influence the demand for public transport and walking, as was found in the first part of this research.

The research has stressed the importance of integrated planning for public transport and walking. This is, however, not evident in practice, due to different authorities that are responsible for different systems. Usually local councils take care of walking infrastructure, if walking at all is seriously considered in the transport planning process. The planning of public transport, however, depends highly on the organisational context in the country or region. In this sense, Birmingham is in a relatively good position. Transport is planned on a metropolitan level (supra-local) by Transport for West Midlands (TfWM), part of the West Midlands Combined Authority (WMCA). The WMCA is mainly a collaboration between Birmingham City Council and surrounding councils, along with some other non-constituent authorities, local enterprise partnerships and observer organisations (WMCA, 2019). TfWM works in partnership with transport operators (bus, train and tram) to establish an integrated public transport network, according to the transport strategies set by the WMCA. Because TfWM is also responsible for the development of plans for walking and cycling (Transport for West Midlands, 2019), integration between walking and public transport could be realised relatively easily from an organisational point of view. However, the current transport plans do not allude much to such integration.

Although the importance of walking to and from public transport for health is acknowledged regularly by TfWM in their Transport and Health Strategy (Transport for West Midlands, 2018), there are no clear strategies on how to enhance this specifically in their 2026 Delivery Plan (Transport for West Midlands, 2017). The Delivery Plan contains a wide variety of plans on improving public transport services, but none of them pay attention to walking. Instead, there are only a few general plans for improving some key walking routes and the public realm. It would be valuable to consider the walking conditions integrated in the public transport planning to maximise the benefits. In particular, the development of the Sprint-bus network (a new kind of bus rapid transit system to be introduced to the greater Birmingham area) could benefit from such an approach, as this system will offer faster, direct services with a larger stop spacing. More attention to walking can in this case increase the willingness to walk for public transport, and thus potentially enhance the ridership as well as public health. Additionally, it is recommended that such a new bus network is distinctive from the normal buses (e.g. through the design of vehicles and stops), to give them a higher status and avoid the mostly negative associations with the conventional bus network being applied to the new services.

Particularly the results of the tracking study can be valuable for route planning software, as it was found that in some cases people were willing to walk further than the travel advice suggested. Frequently used route planning services, such as Google Maps, could take this information on board to give a wider range of advice that includes more walking, and hence potentially contribute to an increased rate of walking and improved public health.

The method used in this research, a smartphone tracking survey, proved valuable, notwithstanding the limitations discussed in Chapter 6, as it is a cost-effective tool to gather very detailed behaviour on individual's travel patterns. For researchers who are interested in adopting this approach, it is recommended to have access to a technical expert who has a deeper understanding of smartphone apps, database systems and related technology and software. This can make it much easier for transport researchers to use the systems and can potentially omit some flaws in the apps and systems used, hence making them more robust. The MEILI system offers a unique opportunity for transport researchers, as it is an open source system that can support their research. Unfortunately, however, it has not been developed further after 2016, at least not in an open-source form, which is problematic considering the quickly developing technological context. There are various research projects that have developed apps or systems to collect travel data (e.g., Abdulazim *et al.*, 2014; Batool *et al.*, 2018; Lue and Miller, 2019), and such projects should be encouraged to make codes open-source. This can help other researchers (either to adopt the apps in research, or to develop the existing system further) and is more resource-efficient, which is especially relevant if research is publicly funded. There are however new projects, such as the EU-funded project Mobility Choices (http://www.mobility-choices.org/) at Fachhochschule Vorarlberg (Austria), which also provides their source code. Initiatives like this might help future transport researchers who are interested in adopting smartphone-based data collection methods, but who do not have the resources available to develop a tailored system themselves.

One of the major challenges in such smartphone approaches remains the sample size. It is not easy to gather a sufficient number of participants, with limited bias, who are willing to download an app that might be regarded as rather intrusive (knowing someone's exact location at all times) and inconvenient (e.g. battery drain of the phone). Perhaps there are possibilities of unlocking other big data sources, for instance data held by phone operators, although this usually has the disadvantage that there is little contextual data about the people and there might be legal issues to be covercome. Some consumer apps, like Strava, are voluntarily used by people to collect data about, for example, their cycling trips. It might have been useful to ask in the questionnaire whether people have a smartphone, and whether they already track their walks or trips in some way, which could also be related to someone's focus on health. This data is available for research as well (e.g., Sun and Mobasheri, 2017), but the sample is likely to be very biased too and the data itself can be biased towards certain activities or journeys. There is also a possibility of making the app more engaging, i.e. gamification, which might make people more willing to use an app, and hence provide data (Cavada and Rogers, 2019). In the case of travel there is, however, a risk that such approach might influence one's travel behaviour, which would make the research less valuable.

7.5 Future research

This section outlines some potential strands for future research on walk distances related to public transport.

- The issue of walk distances to and from public transport has not really been explored yet in a qualitative way, for instance using focus groups or in-depth interviews. Although there are various qualitative studies available around the use of public transport or walking, the evidence around public transport-related walking specifically is limited. Such qualitative research might provide valuable further insights to the distances people walk and the variability therein. It can explore how people choose their routes through the public transport system and to what extent walking plays a role in this route choice or the decision to use public transport at all. Furthermore, it might provide a deeper understanding of how someone's perceptions or cultural context affect this behaviour.

- It can be valuable to gain deeper insights into the differences in travel behaviour across neighbourhoods with different levels of deprivation, and how these differences might need to be taken into account in public transport planning. The current study looked at just four neighbourhoods, at both extremes of the deprivation spectrum, in one city. To be more conclusive about the deprivation effect, it is worthwhile to expand the study to other cities or include more areas. In this respect, it is also of importance to consider the cultural background of people in the neighbourhoods. Deprived areas tend to have a higher proportion of people in ethnic minorities. Since cultural differences can have important impacts on people's perceptions, these should ideally be disentangled from the deprivation effect in studies, to correctly understand the impact different factors have on travel behaviour.
- Related to this research on the influences of deprivation, it would be worthwhile developing a fuller understanding of how deprivation influences the experience of transport barriers, and hence walking to and from public transport. Perhaps there are just one or a few dimensions of deprivation that determine the effect. The Census data that is related to deprivation might be able to support such research, or otherwise a tailored questionnaire could explore these characteristics for more of the respondents. Similarly, qualitative research might reveal more about what aspects in deprived communities drive the generally larger experience of barriers towards public transport and walking.
- There are several developments of new modes in many cities globally that can influence walking, often labelled as micromobility. This mainly refers to bike sharing systems

(both docked and dockless), electric bikes and electric scooters (DuPuis, Griess and Klein, 2019). Whereas bike sharing systems have been implemented in many major cities over the last decade, electric scooters are a fairly recent development that can specifically impact walking. The shared nature of these systems can be expected to initially mostly impact the walking stage at the activity side of public transport trips, rather than the home side, unless they have a city-wide coverage including residential environments. Little is known yet about how the emergence of systems such as electric scooters affects urban walking generally or in combination with the use of public transport, and how this impacts public health. It would therefore be very valuable to conduct a longitudinal study on walking in a city in which there are plans for the introduction of an electric scooter system, to be able to measure potential changes after the implementation of the system. One of the problems is, however, that such systems are generally deployed rapidly and unexpectedly in cities by private companies, because most cities do not have regulations in place to control such deployment (DuPuis, Griess and Klein, 2019). Yet, it might also be possible to study the historical mobility patterns of current scooter users through retrospective questionnaires or interviews, etc.

- Likewise, a lot of development is taking place in the automotive industry around the realisation of autonomous vehicles. The introduction of autonomous vehicles can be disruptive to the current urban mobility patterns, although it is hard to forecast what the exact impacts of the emergence of such vehicles would be on the use of active and public transport. Autonomous vehicles might increase traffic safety for pedestrians and cyclists, which could enhance those modes, however autonomous vehicles might also offer a more appealing travel alternative which can lead to a replacement of active trips. An exploratory study of Booth et al. (2019) showed that there are particular risks in autonomous vehicles replacing public transport travel, and thus active travel related to this, when autonomous vehicles would be available.

- The emergence of new micromobility options and autonomous vehicles links into the development of Mobility as a Service (MaaS), which refers to the integration of a wide range of transport modes into one platform, where travellers can flexibly choose how to travel and conveniently book transport, typically via a smartphone app (Kling, 2019). This would imply that transport becomes more shared and there is a reduced reliance on private vehicles. A successful implementation of MaaS would mean that transport is increasingly multimodal, which has implications for the design of streets and allocation of space, in which there are opportunities for walking and cycling. There are however also threats, mainly that without the right regulatory and partnership models in place mass public transport systems might lose ridership rather than benefit from the new systems (Hirschhorn *et al.*, 2019). Ideally, MaaS enhances public transport, for instance by providing a better solution to the first or last mile problem in areas with less public transport provision, which can make using public transport as a travel option more feasible and/or attractive (Young, Allen and Farber, 2020). Just like with the emergence of autonomous cars, it is uncertain how the development of MaaS would influence public transport travel and related access and egress stages, or how MaaS could best be shaped to have a positive effect on public transport and walking, and hence public health.

APPENDIX A: QUESTIONNAIRE PACK

Cover Letter

UNIVERSITY OF BIRMINGHAM

Dear Sir/Madam,

I am inviting you to take part in a questionnaire for a research project of the University of Birmingham. This survey aims to see how people travel in Birmingham and how they think about it. The information gained through this questionnaire can give insights in how transport systems currently work and how they can be improved. This can help make the city healthier and your future travel experience better.

Before agreeing to take part, you might want to know more about what this study involves. On the back side of this sheet, you can find a lot of information. Please take your time to read this carefully. If any part is not clear or you feel that you need more information, please contact me and I will be happy to explain.

Anyone in the household between 18 and 65 years old may complete the questionnaire. After completion you can return the questionnaire in the free-post return envelope. You might prefer to complete the questionnaire online, which is possible using the following link: http://bit.ly/2xra0eh. Please complete the questionnaire before **4th February 2018**.

Your participation is highly appreciated. I would like to thank you a lot in advance.

Yours faithfully,

Dennis van Soest
PhD-student
University of Birmingham

Participant information sheet

What is the purpose of the study?
This research project aims to gain more insights to promote healthy travel behaviour, such as walking, in urban areas. More specifically, it looks at walking to or from public transport stops or stations. This questionnaire mainly explores why people do or do not walk or use public transport, and reasons for this.

Why am I invited for this study?
For this research project, several areas in Birmingham were selected. These areas have different characteristics in terms of public transport provision, socio-demographics and structure of the built environment. The area you live in is one of the selected areas. Everybody living in this area and who is between 18 and 65 years old is invited to contribute to the study.

Do I have to take part in the study?
No, participation occurs on a voluntary basis. In addition, if you decide to contribute to the research project, you can withdraw at any time within 30 days after submission of the questionnaire by contacting the researcher, without clarifying any reason. The collected data will be considered not valid and discarded. Withdrawal is only possible if you have provided your contact details, so that your data can be identified.

What happens to the results of the study?
The results will be published in a PhD thesis and can be presented in academic or professional journals or at conferences.

Is my data treated confidentially?
The data you provide through the questionnaire will be converted to a digital format. The paper questionnaires as well as the digitised data will be stored in secured data storage facilities located on the Edgbaston campus of the University of Birmingham, and can only be accessed by the researcher and the supervisors. Personally identifiable information will never be published. Contact details will only be stored if you provide them. The anonymised digital data will be stored for 10 years. Anonymous data can be shared for other research purposes.

How do I submit the questionnaire?
Fold the questionnaire and put it in the provided free-post envelope. The envelope has the address printed on it and does not need a postage stamp. Post the envelope in one of the Royal Mail mailboxes on the streets or deliver it to a postal service point.

Contact details
Dennis van Soest

If you are concerned about how this research is being conducted, you can contact the Chair of the Engineering Ethics Committee, University of Birmingham, Birmingham, B15 2TT, ethicsqueries@contacts.bham.ac.uk

UNIVERSITY OF BIRMINGHAM

Help improving travel in Birmingham!

We are interested in how you travel in Birmingham and what you think about transport in the city.
By completing this questionnaire, we will gain better insights into your transport needs and ways transport services and infrastructures could be improved.

Any household member between 18 and 65 years old can complete this questionnaire.

Prefer working online?

You can choose to complete the survey online, using the following link or QR code.
http://bit.ly/2xra0eh

About yourself

Please tick one box per question, unless stated otherwise ☑

1 Which gender do you identify yourself with?

- ☐ Male
- ☐ Female
- ☐ Other
- ☐ I'd rather not say

2 In which year were you born?

____

- ☐ I'd rather not say

3a How many people do you live with in your household (including yourself)?

- ☐ 1 ☐ 2 ☐ 3 ☐ 4
- ☐ 5 ☐ 6 ☐ 7 or more
- ☐ I'd rather not say

3b How many of the people in your household are under 12 years old?

- ☐ 0 ☐ 1 ☐ 2 ☐ 3 or more
- ☐ I'd rather not say

4 Which of the following categories represents the total income per year of your household from all sources after tax?

- ☐ Up to £15,000
- ☐ £15,000 - £25,000
- ☐ £25,000 - £50,000
- ☐ £50,000 or more
- ☐ I'd rather not say

5 Please specify your ethnic designation

- ☐ Asian/Asian British
- ☐ Black/African/Caribbean/Black British
- ☐ Mixed/multiple ethnic group
- ☐ White
- ☐ Other ethnic group
- ☐ I'd rather not say

2

Work

6 What best describes your situation last month?

- ☐ Employed full time
- ☐ Employed part time
- ☐ Student
- ☐ Retired - *Proceed to question 11*
- ☐ Unemployed - *Proceed to question 11*
- ☐ I'd rather not say - *Proceed to question 11*

7 Last month, how many days per week did you work/study (for at least 2 hours; disregarding the holiday period)?

- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6
- ☐ 7
- ☐ I'd rather not say

8 Did you sometimes work/study at home last month?

- ☐ Always, my working location is at home
- ☐ One or more full days per week
- ☐ One or more parts of a day per week
- ☐ A few hours per week
- ☐ Never, but I could choose to do so
- ☐ Never, it's impossible for my job
- ☐ I'd rather not say

9 Did you need to go to various locations for work/study, last month?

- ☐ No, mostly the same location
- ☐ Yes, my work location differs
- ☐ I'd rather not say

10 Last month, was there a specific time you needed to start working at your (non-home) work/ study location?

- ☐ Yes, I always start at a specific time
- ☐ Yes, but that time varies over the days
- ☐ Yes, but I can choose to start slightly earlier or later
- ☐ No, I am (mostly) free to choose when I work
- ☐ I'd rather not say

11 Last month, did the daily amount of time you spent at your work/study location vary over the days?

- ☐ No, I always work about the same amount of hours
- ☐ Yes, it varies
- ☐ I'd rather not say

3

How you travel

If people think about certain behaviours, images can be developed in their mind about the meaning of these behaviours. This can also be the case for different ways of travelling. In the following questions, we are interested in what several ways of travelling mean to you or how you feel about them.

Please complete the following questions at a fairly high speed, without worrying or puzzling over your answers. Your first thoughts and impressions are of interest.

12a **Think for a moment about *walking* to a destination in Birmingham (about 1 mile). Please write down the *first three* thoughts (words or phrases) that come to mind when you think about *walking*.**

1 ☐ 2 ☐

3 ☐

Now it is of importance that we can understand the meaning of these thoughts to you.

12b **Please state whether the associations you wrote down mean something positive or negative to you.**
Rate your thoughts in the order you wrote them down, and be sure to rate only the thoughts and not the travel mode itself.

	Very negative			Neutral			Very positive
Thought 1	☐	☐	☐	☐	☐	☐	☐
2	☐	☐	☐	☐	☐	☐	☐
3	☐	☐	☐	☐	☐	☐	☐

13a **Think for a moment about *driving a car* to a destination in Birmingham. Please write down the *first three* thoughts (words or phrases) that come to mind when you think about *driving a car*.**

1 ☐ 2 ☐

3 ☐

13b Please state whether the associations you wrote down mean something positive or negative to you.

		Very negative			Neutral			Very positive
Thought	1	☐	☐	☐	☐	☐	☐	☐
	2	☐	☐	☐	☐	☐	☐	☐
	3	☐	☐	☐	☐	☐	☐	☐

14a Think for a moment about *using trains* within Birmingham.
Please write down the *first three* thoughts (words or phrases) that come to mind when you think about *using trains*.

1

2

3

14b Please state whether the associations you wrote down mean something positive or negative to you.

		Very negative			Neutral			Very positive
Thought	1	☐	☐	☐	☐	☐	☐	☐
	2	☐	☐	☐	☐	☐	☐	☐
	3	☐	☐	☐	☐	☐	☐	☐

15a Think for a moment about *cycling* to a destination in Birmingham (about 3 miles).
Please write down the *first three* thoughts (words or phrases) that come to mind when you think about *cycling*.

1

2

3

15b Please state whether the associations you wrote down mean something positive or negative to you.

		Very negative			Neutral			Very positive
Thought	1	☐	☐	☐	☐	☐	☐	☐
	2	☐	☐	☐	☐	☐	☐	☐
	3	☐	☐	☐	☐	☐	☐	☐

16a Think for a moment about *using buses* within Birmingham.
Please write down the *first three* thoughts (words or phrases) that come to mind when you think about *using buses*.

1	2
3	

16b Please state whether the associations you wrote down mean something positive or negative to you.

	Very negative			Neutral			Very positive
Thought 1	☐	☐	☐	☐	☐	☐	☐
2	☐	☐	☐	☐	☐	☐	☐
3	☐	☐	☐	☐	☐	☐	☐

17 What do you think about using the following modes of transport in or around Birmingham?

	Never use	*Bad*				*Good*
Walking	☐	☐	☐	☐	☐	☐
Cycling	☐	☐	☐	☐	☐	☐
Car (driving)	☐	☐	☐	☐	☐	☐
Car (passenger)	☐	☐	☐	☐	☐	☐
Taxi/Uber	☐	☐	☐	☐	☐	☐
City bus	☐	☐	☐	☐	☐	☐
Train	☐	☐	☐	☐	☐	☐

18 How often did you use the following modes to travel last month?

	Never	*<1 day per week*	*1 or 2 days per week*	*3 to 5 days per week*	*6 or 7 days per week*
Walking	☐	☐	☐	☐	☐
Cycling	☐	☐	☐	☐	☐
Car (driving)	☐	☐	☐	☐	☐
Car (passenger)	☐	☐	☐	☐	☐
Taxi/Uber	☐	☐	☐	☐	☐
Tram/metro	☐	☐	☐	☐	☐
City bus	☐	☐	☐	☐	☐
Train	☐	☐	☐	☐	☐

19 If you have taken a city bus last month, how have you travelled to/from the bus stops?
You may tick multiple boxes

- ☐ Walking
- ☐ Cycling
- ☐ Car (driving)
- ☐ Car (passenger)
- ☐ Taxi / Uber
- ☐ Other, please specify: ____________________

If you have taken a train last month, how have you travelled to/from the train stations?
You may tick multiple boxes

- ☐ Walking
- ☐ Cycling
- ☐ Car (driving)
- ☐ Car (passenger)
- ☐ Taxi / Uber
- ☐ Bus
- ☐ Other, please specify: ____________________

20 **Have the following modes been available for your trips last month? And do you like these modes of transport?**

20a Cycling

Did you have a bicycle available?	☐ Yes, always ☐ Yes, but not always	☐ No, I don't have a bicycle available ☐ No, I can't cycle - *Proceed to 19b*
I like riding a bike	*Disagree* ☐ ☐ ☐ ☐ ☐ *Agree*	

20b Car

Did you have a car available?	☐ Yes, always ☐ Yes, but not always	☐ No, I don't have a car available ☐ No, I don't have a driving licence - *Proceed to 19c*
I like driving a car	*Disagree* ☐ ☐ ☐ ☐ ☐ *Agree*	

20c Public transport (train, bus, tram/metro)

Did you have public transport available?	☐ Yes, and I have a travel card ☐ Yes, and I have a discount card	☐ Yes, but I don't have any cards ☐ No, public transport is not feasible for most of my trips ☐ I don't know
I like using buses	*Disagree* ☐ ☐ ☐ ☐ ☐ *Agree*	
I like using trains	*Disagree* ☐ ☐ ☐ ☐ ☐ *Agree*	

7

20d Walking

Could you walk?	☐ Yes, always	☐ I have physical problems that prevent me from walking distances more than 1 km. - *Proceed to question 21* ☐ I have physical problems that prevent me from walking at all. - *Proceed to question 21*
I like walking	*Disagree* ☐ ☐ ☐ ☐ ☐ *Agree*	

There can be several reasons for not using a particular mode for your trips.

21 **Can you indicate to what extent the following barriers influence your decision not to walk to destinations in your neighbourhood?**

	Disagree			*Neutral*			*Agree*
Walking often takes too much time	☐	☐	☐	☐	☐	☐	☐
I do not feel safe in traffic when I walk	☐	☐	☐	☐	☐	☐	☐
I feel unsafe when I walk at night	☐	☐	☐	☐	☐	☐	☐
I feel unsafe when I walk during the day	☐	☐	☐	☐	☐	☐	☐
The walking routes are unpleasant	☐	☐	☐	☐	☐	☐	☐
The pavements are of bad quality	☐	☐	☐	☐	☐	☐	☐
I often feel too tired to walk	☐	☐	☐	☐	☐	☐	☐
I am too lazy to walk	☐	☐	☐	☐	☐	☐	☐
I won't walk when it is raining	☐	☐	☐	☐	☐	☐	☐
I won't walk when I need to carry some luggage	☐	☐	☐	☐	☐	☐	☐
I'd like to have more places to rest	☐	☐	☐	☐	☐	☐	☐

22 **Can you indicate to what extent the following barriers influence your decision not to take the bus?**

	Disagree			*Neutral*			*Agree*
The distance to the bus stop is too far	☐	☐	☐	☐	☐	☐	☐
Travelling by bus takes too much time for my trips	☐	☐	☐	☐	☐	☐	☐
I do not feel safe on buses	☐	☐	☐	☐	☐	☐	☐
I won't take the bus if I need to carry some luggage	☐	☐	☐	☐	☐	☐	☐
Buses are often too crowded for me	☐	☐	☐	☐	☐	☐	☐
Buses are too expensive	☐	☐	☐	☐	☐	☐	☐
The bus system is too complicated	☐	☐	☐	☐	☐	☐	☐
I don't like the other people on the bus	☐	☐	☐	☐	☐	☐	☐
I suffer from travel sickness on the bus	☐	☐	☐	☐	☐	☐	☐

23 **Can you indicate to what extent the following barriers influence your decision not to take the train?**

	Disagree			*Neutral*			*Agree*
The distance to the train station is too far	☐	☐	☐	☐	☐	☐	☐
Travelling by train takes too much time for my trips	☐	☐	☐	☐	☐	☐	☐
I do not feel safe on trains and at stations	☐	☐	☐	☐	☐	☐	☐
I won't take the train if I need to carry some luggage	☐	☐	☐	☐	☐	☐	☐
Trains are often too crowded for me	☐	☐	☐	☐	☐	☐	☐
Trains are too expensive	☐	☐	☐	☐	☐	☐	☐
The railway system is too complicated	☐	☐	☐	☐	☐	☐	☐
I don't like the other people on the train	☐	☐	☐	☐	☐	☐	☐
I suffer from travel sickness on the train	☐	☐	☐	☐	☐	☐	☐

24 **Please mark or highlight on the map which roads and paths you find unpleasant to walk in your neighbourhood, and draw an 'X' on your (approximate) home location.**

And finally…

This questionnaire is part of a wider research project. For a further study we would like to gather participants who use a smartphone.
You will have the chance to win Amazon vouchers worth £25, £50, or £75!
Your effort to participate is highly appreciated.

Are you interested to take part in this study?

☐ Yes; *please provide your contact details below*

☐ I'm not sure; *please provide your contact details below*

☐ No

Would you be interested in hearing more about the results of this research?

☐ Yes; *please provide your contact details below*

☐ No

Name: ______________________________

Email: ______________________________

Phone: ______________________________

Do you have any comments?

Thank you very much for your participation!

Please return this questionnaire in the prepaid envelope.

Consent

The information is being collected as part of a research project by the Department of Civil Engineering in the University of Birmingham, concerned with the travel behaviour of people.
The information which you supply and that which may be collected as part of the research project will be entered into a filing system or database and will only be accessed by authorised personnel involved in the project.
The information will be retained by the University of Birmingham and will only be used for the purpose of research and statistical and audit purposes. By supplying this information you are consenting to the University storing your information for the purposes stated above. Anonymous data can be shared for research purposes. The information will be processed by the University of Birmingham in accordance with the provisions of the Data Protection Act 1998.
No identifiable personal data will be published.

By completing and returning the questionnaire, you approve to contribute to the research project and agree with the following:

- I confirm that I have read and understand the participant information leaflet for this study. I have had the opportunity to ask questions if necessary and have had these answered satisfactorily.
- I understand that my participation is voluntary and that I am free to withdraw at any time within 30 days of submission without giving any reason. Withdrawal is only possible if I have provided my contact details, so that my data can be identified.

This project has been reviewed and approved by the University of Birmingham Research Ethics Board.

APPENDIX B: SMARTPHONE SURVEY PACK

Invitation email

[Attachments: Results; Participant information sheet]

[Subject: Follow-up study transport]

Dear [First name] [Last name],

In January 2018 you completed a postal questionnaire about how you travel in Birmingham and how you think about transport. I would like to thank you for your contributions and I am sending you some of the results via the file attached. You stated an interest in taking part in the follow-up study and I hope you are still keen to do so. In this study I would like to gain a better insight into actual travel behaviour, by collecting more detailed travel behaviour data.

For this study, I'll only ask you to install and run a small app on your smartphone. This app will collect location data so that I can see how, when and where you travel. In that way I can get an understanding of what trips different people in Birmingham undertake and which choices they make with regard to transport. In return, you get the chance to win one of several prizes available to participants (£50 Amazon voucher and ten £10 Amazon vouchers). For each day of transport data that I receive from you, you will get another chance at winning a prize. Of course, I can give you insights into your personal data afterwards as well, if you would like.

I would greatly appreciate it if you are willing to help me further with my research project.

Could you please confirm via a reply whether you are willing to help me and participate in this study? If so, could you also let me know if you have an Android device or an iPhone? (Other systems, such as Windows, are unfortunately not supported). Further information on the study can be found in the participant information sheet and consent form attached and in case you have any questions, you can of course always contact me.

Thank you very much for taking this request into consideration and I am looking forward to hearing from you.

Best regards,

Dennis van Soest

PhD Student

University of Birmingham - Department of Civil Engineering

Participant information sheet

You have shown your interest to take part in a study of the University of Birmingham. Before agreeing to take part, you might want to know more about what this study involves. Please take your time to read the following information carefully. If any part is not clear or you feel that you need more information, please contact the researcher.

What is the purpose of the study?
This research project aims to gain more insights to encourage healthy travel behaviour, such as walking, in urban areas. More specifically, it looks at walking to or from public transport stops or stations, or the potential of these modes in the current travel patterns. This study considers the walking routes and general walking and travel behaviour, together with characteristics of the offered public transport services and built environment.

Why am I invited for this study?
You have shown your interest to take part in a related questionnaire (end of January 2018).

Do I have to take part in the study?
No, participation occurs on a voluntary basis and you can stop at any time. Collected data can be withdrawn if you wish, up to 14 days after the final study day.

What does participation involve?
You can participate by downloading an app to your smartphone via the link provided. You can open the link on your phone. Once it is installed, you can create an account using your email and a password. The app will run in the background and tracks your location. You can start tracking by pressing the button in the app, and can stop the collection of location data in the same way at any time. We would like to ask you to keep the app running for at least a day, preferably one week (7 days).

Using your email and password with which you created your account, you can login to the website to view the trips about which data is collected, and add more information such as the purpose of your trip and the destination.

Do I get something in return when I participate?
Every participant can get information about the results of the study and have insights in their own travel behaviour. As a participant, you also automatically have the chance to win a prize. There are eleven prizes: Amazon vouchers of £50 and 10 x £10. For every day of data you collect, you receive an entry in the raffle. So if you track your travel data for a full week, you have seven chances to win a prize.

Which data will be collected?
The study is mainly interested in which trips are undertaken, at what times, by which mode and via which route. To get this information, the app collects your location data. You can switch the location tracking on and off easily in the app. Besides this travel information, the app can collect technical data about your device (phone model and operating system).

Is my data treated confidentially?
All data that is collected through the app will be stored on a secured server of Amazon Web Services for maximum one day, after which data is transferred to the secure data facilities of the University of Birmingham (Edgbaston Campus), and can only be accessed by the researchers or authorised personnel involved in the project. The data will be stored for a period of maximum 10 years.

Personally identifiable information will never be published. This includes that it will be made impossible to identify an individual from a certain travel pattern/route, by excluding contextual information such as the location of houses and no provision of street names.

What happens to the results of the study?
The results will be published in a PhD thesis and can be presented in academic or professional journals or conferences.

Contact details
Dennis van Soest

If you are concerned about how this research is being conducted, you can contact the Chair of the Engineering Ethics Committee, University of Birmingham, Birmingham, B15 2TT, ethicsqueries@contacts.bham.ac.uk

Instruction email Android users

[Attachments:]

[Subject: Transport Study Instructions]

Dear [First name],

Thank you very much for your kindness to help me with my research. As I stated in the invitation, I would like to ask you to install and run a small app on your phone, which tracks your travel behaviour. Please try to take your phone with you as much as possible, so that the collected trip data is complete.

To install the app, please follow the next steps:

1. The app can be downloaded from the Google Play Store via the following link: https://play.google.com/store/apps/details?id=meili.uobmobilitycollector
2. Once it is installed, press 'Register as a new user' and register with an email and password. Please use this current email address as your username. There won't be any emails sent by the app.
3. When you are logged in, you can press the Start button to start tracking your travel behaviour. Once you started tracking, you can leave the app running in the background.

You might experience that the battery drains faster than usually. Hopefully this doesn't cause major issues, otherwise you can stop the tracking for a while if necessary.

I'd like to ask you to track your trips for a week, although you are free to stop at any point in time. As a reward, there are several Amazon vouchers available to win by the participants in this study. For each day of collected data, you receive a chance to win a voucher. So if you complete the full week, you have 7 entries in the raffle.

Once again I'd like to thank you for your interest and time, and if you have any queries do not hesitate to contact me. I'll inform you when you can stop the participation and when you can uninstall the app.

Best regards,

Dennis van Soest

PhD Student

University of Birmingham - Department of Civil Engineering

Instruction email iPhone users

[Attachments:]

[Subject: Transport Study Instructions]

Dear [First name],

Thank you very much for your kindness to help me with my research. As I stated in the invitation, I would like to ask you to install and run a small app on your phone, which tracks your travel behaviour. Please try to take your phone with you as much as possible, so that the collected trip data is complete.

To install the app and participate, please follow the next steps:

1. The app can be downloaded from the App Store via the following link on your iPhone: https://itunes.apple.com/app/id1459790782
2. Once it is installed, press 'Register a new user' and register with an email and password. Please use this current email address as your username. There won't be any emails sent by the app.
3. When you are logged in, you can press the Start button to start tracking your travel behaviour. Once you started tracking, you can leave the app running in the background.
4. Do not fully close the app, as it will stop the data collection.
5. Stop and start tracking daily to ensure the app stays active

You might experience that the battery drains faster than usually. Hopefully this doesn't cause major issues, otherwise you can stop the tracking for a while if necessary.

I'd like to ask you to track your trips for a week, although you are free to stop at any point in time. As a reward, there are several Amazon vouchers available to win by the participants in this study. **For each day of collected data, you receive a chance to win a voucher.** So if you complete the full week, you have 7 entries in the raffle. It might be useful to stop-start tracking daily, to ensure the app is still collecting data.

Once again I'd like to thank you for your interest and time, and if you have any queries do not hesitate to contact me. I'll inform you when you can stop the participation and when you can uninstall the app.

Best regards,

Dennis van Soest

PhD Student

University of Birmingham - Department of Civil Engineering

APPENDIX C: CODE BOOK

Code	Name	Description, *Examples*
	Feelings	
101	Enjoy	Feelings of joy when using a mode; general positive evaluations *Happy; Enjoyable; Good; Ok*
102	Relaxing	Relaxing; time to think *Relaxed; Thinking; Planning time*
104	Freedom	Feelings of freedom and independence *Freedom; Independent*
106	Not like it	Not liking the use of a mode; attempt to avoid it *Don't enjoy cycling; Avoid; No desire; Urgh*
121	Unpleasant	Getting unpleasant feelings, annoyance, fear *Tedious; Unpleasant; Anxious; Crazy; Scary; Bit boring*
123	Necessity	Using a mode because it feels necessary *Necessary; Only choice to go to work*
109	Bad past experience	Statements relating to a specific experience *Knocked off recently by parking car opening door; Saw a car recently on Bristol Rd driving on the pavement/cycle lane*
110	Stressful	Feelings related to stress *Stressful; Frustration; Nerves*
111	Less stress	Feeling that it relieves stress *Stress free; less stress*
118	Lazy	Gives a lazy feeling *Lazy*
112	Control	Having everything under own control or lack of control *Control; Self-determined*
103	Preference for mode	The mode is preferred, or there are intentions to use *Better way to travel; Better than car; Obvious choice*
113	Preference for other modes	Preference for alternatives *Wish we had better public transport; Can't I drive there?*
	Practice	
124	Practice	Using a mode regularly *Do it every day; Routine; Already use bus*
107	Non-use	Statements that a mode is never used or impossible to use *Never; Rarely take a train; Can't ride a bike; Don't do it*
917	No vehicle	The person doesn't have or need a vehicle *No bike; I haven't got a car!*
	Environment	
201	Fresh air	The ability to refresh, get fresh air *Fresh me, Fresh air; Refreshing*
202	Outdoor environment	The ability to enjoy the outdoor environment; specific environments *Green space; Outside; Beautiful city; Park*
205	Pollution	Pollution and air quality issues; fumes *Pollution; Air quality; Fumes; Poor air*
206	Less pollution, green	Positive feeling that the mode is a greener alternative *Better for environment; No pollution; Green*

210	Less congestion	Notion that use of the mode does not contribute to more congestion *Less traffic; Eases congestion*
207	Hilliness	Notions about hilliness *Hills; Hills are hard work*
208	Smelly	Annoyance from smells *Smelly; Stinky; Bad smell*
209	Noisy	Annoyance from noise *Noisy; Too loud; Traffic noise*
	Money	
301	Saving money	A cheaper travel alternative *Cost effective; Inexpensive; Group discount; Save money*
302	Cost, expensive	Concerns about costs, price *Costly; Expensive; Cost*
304	Payment organisation	Need to have right amount of cash on buses; bad payment methods *Need to have right money; Change; Swift card not good enough*
	Social interactions	
401	Sociable	The ability to engage in social contacts *Sociable; Conversation*
403	Privacy	Private space, isolation *Isolation; Private; Lonely; Don't look at anyone*
613	Other people	Annoyance by bad behaviour of other passengers or road users *Bad driving by others; Atmosphere; Ghetto chariot; Drunk people*
	Opportunities	
501	Destinations	The possibility to go to shopping/eating/recreational opportunities *Local shops; Pub; High street; Tesco*
502	Journey	Possibility to visit multiple destinations *Multiple destinations; Can combine with other tasks*
505	Activities	The ability to do other activities on board *Work/read on train; Reading; Newspaper*
506	Technology	Possibility to listen to music or radio or use ICT *Radio; Strava; Music; Google Maps; Pokemon Go*
507	Pet care	Possibility to take care of pet *Dog; I walk a lot with dog*
	Concerns	
601	Time	Concerns about the time it takes; too long; time uncertainty *Time; Time saved; How long timewise*
602	Distance	Concern about distance, too far *Too far; Distance; Long distance trip*
603	Sweat	Getting sweaty by using a mode *Sweating; Can't shower at work*
604	Traffic	Concerns about the amount of traffic on the streets *Traffic; Congestion; Anxiety about traffic congestion*
605	Temperature	Feeling cold/hot *Cold; Hot; Cold wind*
606	Weather	Concerns about the weather

		Fine to walk if not raining; Weather; Staying dry
607	Crowding	Concerns that it is too crowded, lack of seats *Busy; Overcrowding; Full; Standing on train*
608	Speed limits	The presence of speed limits and enforcement *Speed limits; Speed cameras*
610	No parking	The absence of parking hassle *No problem parking; No parking worries; No need to park*
611	Parking	The presence of the need to park *Parking; Will I be able to park? Difficult to park*
612	Works	Road works *Road works; Construction*
615	Time of day	Concerns about time of day; day or night; rush hours *Slow in rush hour; Night or day; Very dark in winter*
616	Petrol	The need to get petrol *Petrol; Waste of petrol*
617	Luggage	Concerns about carrying luggage *Luggage; Carrying bags; Whether there is stuff to carry*
618	Purpose	Purpose of the journey *Work; Shopping; Travel; Purpose*
619	Route	Concerns about what route to take *Route;*
620	Items to take	Thinking about items that shouldn't be forgotten *Take my wallet; What do I need?*
	Health	
701	Healthy	Behaviour that enhances health *Healthy; Good for me*
702	Physical difficulties	Experiencing physical difficulties when using the mode *Painful; Sore feet*
703	Exercise	The ability to get exercise *Exercise; Fitness; Active*
705	Unhealthy	Related to negative effects on health *Unhealthy; Lack of exercise; Germs*
706	Effort	Effort, exhausting, not fit enough *Effort; hard work; Tiring*
707	Travel sick	Feelings of sickness while using the mode *Feeling sick; Bus makes me feel sick*
	Facilities	
802	Infrastructure	General notions of infrastructure *Roads; Pavement; Signal light*
803	Bad infrastructure	Bad state of roads, pavements *State of roads; Potholes; Cycle lanes (not enough!)*
804	Cleanliness	Concerns about cleanliness, dirty *Dirty; Filthy; Dog poop!*
805	Service quality	Service frequency, availability *Regular; Shame; Good network; Frequent*
806	Access	Notions about the need to access the mode *Location of station; Not close; Transport to station*
808	Staff quality	Related to the quality of staff *Pleasant drivers; Attitude of driver sometimes negative*
812	Good routes	Positive experiences of routes *Route; Cycle routes;*

909	Waiting	Issues related to waiting experience *Hope I don't wait too long; Waiting; Time due*
814	Station	Quality of stops and stations *Grand Central; Amazing New Street; Bus shelters not looked after*
913	Information provision	Issues related to the provision of information, uncertainty *Unsure; Bus timetable; Don't know routes; Confusing*
	Convenience	
902	Convenience	Related to the convenience and ease of a mode *Convenient; Ease; Practicality; Useful*
920	Inconvenience	Lack of convenience *Hassle; Inconvenience; Difficult; Too many things to manage*
903	Family and life-cycle constraints	Issues related to having children *Having a child at nursery; Pram on pavement; Baby crying*
904	Weather resistance	Warmth; weather resistance *Weather resistant; Warmth; Dry*
905	Comfortable	Related to the comfort offered by a mode *Comfortable; Quiet; Sitting down; Can have a drink*
906	Lack of comfort	Related to the lack of comfort offered by a mode *Uncomfortable; Small seats*
907	Reliability	Notions of reliable aspects *Mostly run on time; Reliable; Punctual*
908	Unreliability	Concerns about reliability of service *Less reliable than trains; Delays; Cancellations; Late; Never on time*
910	Transfers	Issues related to the need of transfers between services *Multiple buses to complete a journey; Will I need to change train?*
916	Special clothing	The need for clothing or gear to use a mode *Hi viz; Helmets; Clothing; Boots*
918	Slow	Slow, low speed *Slow; Not quick enough; Slow traffic*
919	Fast	Fast, high speed *Quick; Speed; Fast*
	Safety	
1001	Safety – Crime	Issues related to personal safety from crime *Theft of bike; Being mugged; Threat; Lock; Insecure*
1002	Safety – traffic	Issues related to safety from traffic *Fear of roads; Danger; Dangerous; Safety*
1004	Aggression	Concerns about aggression from other road users *Aggression; Road rage*

APPENDIX D: R-CODES FOR ANALYSES

Most of the analyses in this research were performed using R, an open-source software environment with a focus on statistical computing. Most of the codes that were written to perform the analyses presented in this thesis are available on GitHub via the link below.

https://github.com/dennesoes/PhDcodes

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