Beelining for Sustainable Transport

Analysing Accessibility Inequities and Opportunities Connecting Trams to Bicycles in Greater Manchester

Megan Richold

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A thesis submitted in partial fulfillment of the requirements of Lund University International Master's Programme in Environmental Studies and Sustainability Science (30hp/credits)

LUCSUS
Lund University Centre for Sustainability Studies

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Supervisor: Darin Wahl, LUCSUS, Lund University

Abstract

As the clock ticks on our opportunity to limit catastrophic climate change, mitigation efforts are becoming increasingly essential, especially amongst countries with high current or historic emissions. However, these mitigation attempts are not a guaranteed success, especially when the system within which they operate is not understood due to unacknowledged bias in quantitative data. As such, wicked problems arise whereby climate mitigation actions exacerbate socio-economic inequalities at a local level. This thesis uses a case study approach to explore an iteration of this wicked problem, analysing the equitability of spatial access to the sustainable tram network in Greater Manchester, and the effect of the proposed Beeline Cycling Network on this accessibility. Using feminist methodology and GIS analysis, the spatial socio-economic landscape of Greater Manchester is presented using intersectional combinations of demographics, and accessibility to the tram network is analysed for each demographic group. Accessibility is found to be disproportionately poor amongst deprived ethnic minorities and deprived people over 60 years of age. This inequity is likely a symptom of gentrification and displacement due to the commodifying of urban space. Improvements to accessibility are suggested via connectivity with the carbon-free transport mode of cycling, with infrastructure suggestions tailored to the needs of marginalised groups. Cycle parking facilities at tram stops, inner-city connected cycle paths, and longer segregated cycle paths are shown to be the best potential infrastructure measures to implement to encourage connectivity. Results presented in this study open further lines of inquiry, with suggested further research that should overcome the limitations associated with quantitative secondary data by conducting a full qualitative analysis of barriers to sustainable transport access from the perspective of the marginalised groups identified in this study.

Keywords: climate change mitigation, GIS, feminist methodology, environmental justice, urban transport, intersectionality

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Contents

Abbreviations:

GM – Greater Manchester

GMCA – Greater Manchester Combined Authority

IPCC – Intergovernmental Panel on Climate Change

LLSOA – Lower Layer Super Output Areas

NMT – Non-motorised transport

OA – Output Areas

PT – Public Transport

1 Introduction

1.1 The Social Dilemma of Climate Mitigative Action

As the clock ticks on our opportunity to limit catastrophic climate change, mitigation efforts are becoming increasingly essential. The International Panel on Climate Change (IPCC) has set the worldwide carbon budget for 1.5°C and 2°C global warming scenarios (IPCC, 2014), and countries have taken to a global stage to respond with commitments to reduce greenhouse gas (GHG) emissions. Nationally, countries have been pursuing bespoke climate change mitigative measures, in an attempt to meet ambitious carbon budgets and limit the degree of devastation caused by climate change.

In contrast to the aim of global equity, mitigation measures can create or exacerbate inequality issues at a local level. While national commitments are made in treaties such as the Paris Agreement, they do not account for significant differences between people within a nation, regardless of whether the country is higher or lower income. Climate mitigation attempts have the potential to negatively affect social justice within a country, often placing increased burden or negative externalities on the lowest income in the country, a problem which is increasingly being raised in higher-income countries in the global north (McKendry, 2016). Income is not the only socio-economic factor affecting distributional burdens of climate mitigation: household size and age of occupants, rural/urban setting, and type of dwelling was also found to affect the extent to which each group bears unjust burdens in the reduction of GHG emissions (Büchs, Bardsley, & Duwe, 2011). Justice relating to climate change mitigation is a multi-scalar problem.

Planning and implementing socially equitable climate mitigation solutions requires a good understanding of the systems they operate in, which is an easier task at smaller scales. Mitigative actions and socio-economic landscapes vary hugely, so measures must be designed for a specific context, with social justice factored into this design (McKendry, 2016). The specific context of a system is easier to grapple with at local levels, therefore suggesting that mitigation measures may be more justly implemented at a local scale (Burnham, Radel, Ma, & Laudati, 2013). Cities provide an interesting location of study that meet this local criterion, with the added interest that much climate action is focused on this level. Cities are recognised specifically in the Sustainable Development Goals and have been globally challenged to step up to achieve a more sustainable present and future (Habitat III, 2017; UNDP, 2019). Furthermore, they are the perfect epicentre of frontline climate action, as the density of people fosters innovation, spread of ideas, and quick governance reaction (Dodman, 2009; Mi et al., 2019).

However, understanding the complexities of social justice at city level is not without issue. The United Nations New Urban Agenda defines equity with reference to gender, ethnicity, age, disability, and income, amongst other identifiers (Habitat III, 2017), as social exclusion is known to occur disproportionately to some groups based of characteristics of their identity. This marginalisation extends into the way we view a system. Simone de Beauvoir documented this in the mid-20th century, explaining the hidden bias that men are seen as the natural state, the subject, and women are seen as other (de Beauvoir, 1949). This phenomenon has infiltrated modern scientific research (Hegarty & Buechel, 2006), and can be extended to include other marginalised groups – namely the experience of the privileged man is taken as the norm. This unrecognised and unaccounted for bias in the age of big data can skew the representation of the world, diminishing the experiences of the marginalised. Without looking to correct this bias, equitable outcomes to local climate mitigation actions are unrealistic.

1.2 Aims of Research & Research Questions

This thesis seeks to explore the way in which local climate mitigative action must conceptualise the social complexity of urban inequalities in order to ensure equity. I use a case study approach, exploring sustainable urban transport systems in Greater Manchester (GM), UK. GM is an urban region, containing a large city and several peripheral towns, and has an ambitious carbon emission reduction target (Manchester Climate Change Agency, 2020). Reduction of carbon emissions rely partly on more sustainable transport being adopted; the region already has a light rail tram system and intends to extend its cycle and walking infrastructure. As such, I explore the spatial accessibility of resident in GM to the tram system, and how accessibility may be increased with the implementation of inclusively designed cycle infrastructure. My research questions are as follows:

RQ 1: What socio-economic inequalities exist in the spatial access to the tram system in Greater Manchester?

RQ 2: How can connectivity with cycling infrastructure increase access to the tram system for those who have the worst accessibility?

I use urban theory and feminist urban theory to analyse and contextualise my results, which are produced using GIS methods with a feminist methodological approach. The premise of this study is that mobility in itself should be promoted for individuals, especially those groups who have experienced limited relative mobility due to oppression. This thesis can be used as a foundational level study in inequitable access to a sustainable service, which can be built on and refined with further research.

1.3 Relevance to Sustainability Science

Research in the field of sustainability science is broad, with no set theories or methods, yet there are similarities that unite studies. Kates et al. (2001) describe the problems dealt with in sustainability science as the result of complex interactions between natural and social systems. These problems are often multi-scalar and wicked, in that actions to alleviate the problem cause more complex problems to arise. Sustainability science studies are solutions-focused, inspiring action to resolve the problems explored (Kates et al., 2001).

This thesis meets these criteria. Climate change mitigation activity is the result of interlocked natural and human systems: mitigative action is necessary because of human activity causing climate change. Global climate change mitigative action exacerbates inequality at scales as small as individual cities, demonstrating the multi-scalar nature and wickedness of the problem tackled. Furthermore, this study fits into the sustainability science research platform designed by Jerneck et al. (2011) under the theme of sustainability goals, critically examined from the point of view of intersectional justice and fairness.

2 Theory

Urban theory and feminist urban theory have been selected to investigate access to trams in this study. Urban theory allows us to investigate the power structures at play in cities, and how they can be manifested in the built environment to advantage some and disadvantage others. A feminist view of urban theory allows us to broaden the scope of power structures considered and understand that these structures affect different people in different ways, and to identify where the intersection of socio-economic traits may compound the marginalisation of particular demographics. Both theories also give specific insight into urban transport development. As such, they support the research in framing the disproportional disadvantage some groups experience in urban transport infrastructure, and the causes of this inequality.

2.1 Urban Theory

Urban theory sees cities as unique environments that reflect power struggles. Developed during the modernity era, urban theory is a subset of social theory that conceptualises social phenomena within urban environments (Parker, 2004). Within the field, there is a general consensus that urban areas, or cities, are places of "integrated economies, as sites of social and political identity, as territories of conflict, and as incubators of innovation and creativity" (Parker, 2004, p. 4). Thinkers such as Max Weber and Georg Simmel laid the foundations of urban theory, seeing saw city formation as dominated by markets thus creating a place for expanding consumption (Parker, 2004). Marxists built upon these foundations, theorising the built environment as a site of struggle between classes with urban space becoming commodified and exploited, alongside labour, to benefit the powerful, therefore generating greater economic inequality (Parker, 2004).

City structure, alongside reflecting power struggles, can also act to entrench the ideals of the powerful. Pierre Bourdieu argued that people react subconsciously to signals in physical structures, which are built under certain contexts of power and therefore serve to reproduce values, norms and behaviours which benefit the powerful (Parker, 2004).

Despite this lock-in effect of creating and entrenching inequalities, marginalised groups have a significant impact on urban environments, ensuring cities are an evolving ground of struggle, rather than static snapshots of a historic context (Brenner, 2009). People form communities in cities around shared aspects of identity which can be more complex than in rural areas. More complex variations of identity can be explored in cities as we are departed from nature, and so no longer identify collectively as humans versus nature, instead categorising ourselves within human groups (Parker, 2004). Grouping can be in line with religion, ethnicity, and sexual orientation for example, and the sheer number of people within cities allows a broad range of communities to be formed. While there exists significant interweaving between communities in urban spaces, these communities struggle against the commodification of space to create sites of representation for their culture and demographic within the power structures that define the city.

2.2 Feminism, Space, and the Urban

2.2.1 Feminist Geography

Feminist geography introduces the analytical components of identity into geographical studies. Gender has always been an essential identity of analysis in feminism, but through the development of post-modern/post-colonial thinking in feminism, the concept of intersectionality is now commonplace. Intersectionality is the intersection of identities such as gender, "race, ethnicity, age, disability, nationality, religion, and sexuality" (Johnson, 2009, p. 52), and how communities at the intersection of these groups experience additional marginalisation by power (Davis, 2008). Feminist geography, therefore, aims to cater for the difference in experience depending on identities, as so provides vital additional insight to urban theory when considering the access of different groups in this study.

2.2.2 Feminist Views of The Urban

During the 70s and 80s, three paradigms emerged in feminist studies of the urban environment: the division between the public and private spheres; the relationship between an environment and behaviour within an environment; and the equity in access to certain services (Hayden, 1980; Wekerle, 1980). Within this study, the second and third of these provides the most compelling lens to illuminate obscured inequalities in urban life.

Privileged men have dominated urban theory (Roberts, 2016), and feminist studies show these designs fail to cater for the experience of diverse demographics in cities. The creation of the suburbs and the design of homes was shown to reinforce the gendered roles of reproductive work and isolate women from job opportunities (Hayden, 1980; Wekerle, 1980). Lower levels of investment, the concentration of unattractive infrastructure, or lack of social infrastructure is concentrated in spaces associated with certain ethnic groups (Roberts, 2016), creating segregation between communities. Infrastructure and access have shaped the experience of the urban in accordance with the white male gaze.

Despite dominant groups holding increased power over elements of urban design, oppressed groups have a significant hand in shaping the conflict arena of cities - their roles more complex than the label of victim. For example, while middle-class women enjoyed virtually no anonymity in cities in the 19th and 20th century, working-class women dominated the public markets and transport during the day (Parker, 2004). More recently, queer spaces in cities increased significantly after the social movement of the Stonewall Riots, creating safer spaces and more anonymity within the city for queer people.

Increasingly, gender and other marginalised group sensitive planning has been a tactic proposed as a means to change this inequality, and the redraw the structures of power that design urban space. However, this approach faces resistance and is often underrepresented in favour of lenses serving the interests of those with the greatest influence. With the rise of sustainability within urban planning, fears are that gendered planning will take a back seat (Roberts, 2016).

2.3 Urban Planning

The development of urban structure hinges to an extent on urban planning, which, throughout the 20th and 21st centuries, has drawn heavily from urban theory, and so the theoretical evolution has left tangible changes in the urban built environment (Bibri & Krogstie, 2017; Parker, 2004). In the pursuit of improving cities (based on the assumption 'good communities' are created through good infrastructure), the suburbs were created in many western cities post WWII, particularly the US and UK (Parker, 2004). This segregation of space separated communities, creating winners and losers in the use of space within urban areas (Parker, 2004).

More recently, given the context of many exceeded planetary boundaries (Steffen et al., 2015), urban development discussions hinge around sustainable urban development – this approach has four underpinnings: form, environment, economy, and equity (Bibri & Krogstie, 2017), tying in heavily with the three pillars of sustainability: environment, economy, and society. As equity is tied into the definition of sustainable urban development, it is essential this criterion is met alongside climate mitigation targets.

2.2.1 Urban Planning and Transport Systems

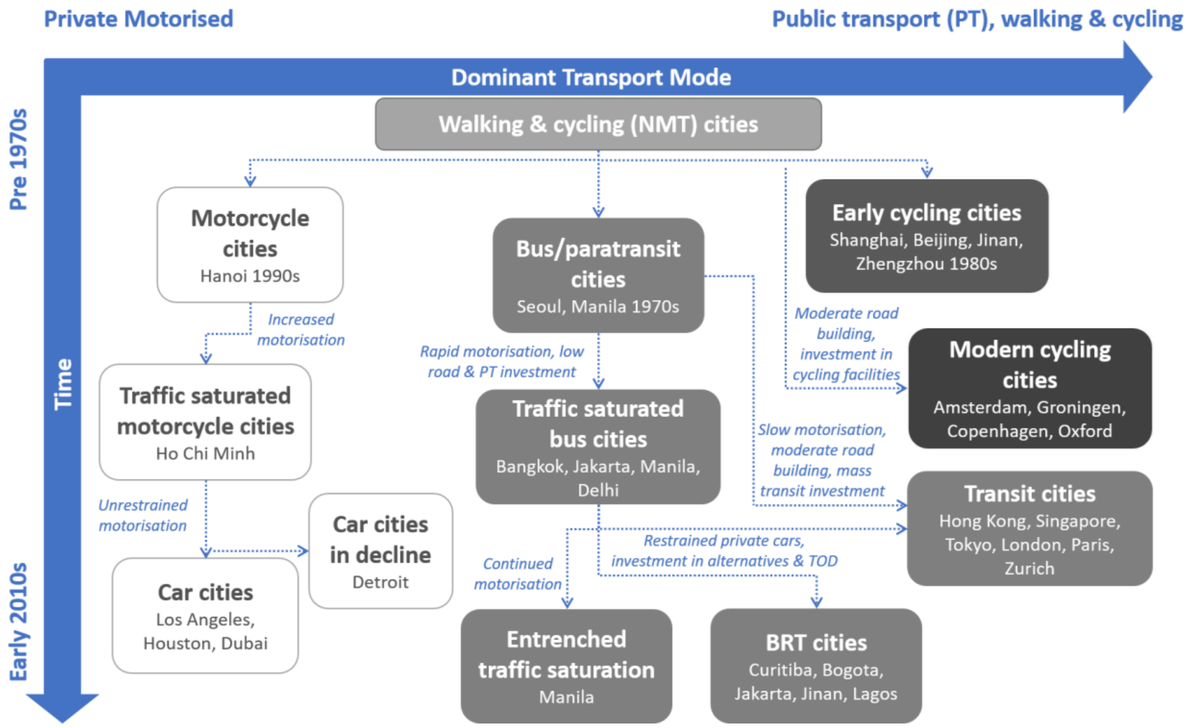


Figure 1. Urban accessibility pathways. The figure shows the development of a spectrum of city types between car, transit, and cycling cities, with examples. Figure adapted from Rode et al. (2017, p. 241).
NMT = non-motorised transport, BRT = bus rapid transit, TOD = transit-oriented development.

Urban development, and therefore sustainable urban development, is interdependent with transport systems. In a physical sense, transport infrastructure impacts the sprawl of a city. Land use can dictate transport demand, as locations of housing, employment, education and health facilities require the provision of transport to ensure they are accessible (Hickman & Banister, 2007; Karou & Hull, 2014). However, the sprawl of land is also dependent on transport mechanisms linking the centre and peripheries of urban areas. Historically city boundaries have expanded with the development of streetcars, then metros and rail systems, and to a great extent with the privately-owned car (Rode et al., 2017). Investment can significantly influence dominant transport mode and land use to reduce sprawl, Figure 1, but the global pattern is one of expanding cities (Rode et al., 2017; UNDP, 2019).

Within a sustainable development frame, it is important to recognise the ecological impact of transport and land use on a city. According to Reckien et al. (2017), "spatial planning, accessibility and transport, waste management and renewable energy" are the sectors essential in climate change mitigation within urban spaces. The volume of emissions correlates strongly with income, while the modal choice of transport (and its associated carbon intensity) and distance travelled affect the output of emissions per journey (Rode et al., 2017). Citizen modes of transport in cities (as opposed to freight transport) can be categorised into three main groups: public transport (PT), non-motorised (NMT) and private motorised. PT is less carbon-intensive than privately owned cars, as the emissions per passenger are much lower, and so it is a more sustainable mode (Sims et al., 2014).

Compact cities dominated by transport modes with low carbon intensity have significantly fewer transport-related emissions (Hickman & Banister, 2007; Rode et al., 2017). For example, the relatively compact Barcelona has much lower transport emissions than Atlanta, despite being cities with similar incomes (Rode et al., 2017). Trends show urban areas are in general becoming less dense and therefore are sprawling (Rode et al., 2017). The IPCC suggests urban development compacting urban space while encouraging NMT, as well as investment in PT, could lead to GHG emission reductions of up to 50% below 2010 baseline by the year 2050 (Sims et al., 2014). As a result, urban transport policy has taken up the general idea of "avoid, shift, improve" (Rode et al., 2017, p. 260): avoid sprawling by coordinating land use and transport, shift to PT and NMT, and improve road vehicles by replacing with less carbon-intensive vehicles. Therefore, increasing the provision of sustainable transport available in a city should increase the sustainability of that city's development path.

However, it is also essential to consider the equity of urban transport infrastructure within sustainable development. While transport mode development has increased accessibility to cities in an absolute sense, social exclusion occurs within the provision of transport. J. Preston and Rajé (2007) define accessibility as the "ease of reaching" some place, service, or activity, and recognise it as a function of the "ease of moving" – mobility (p. 154). Increases in absolute mobility do not always equate to increases in accessibility; for example, private cars becoming the dominant mode of transport increase mobility of those who own them, but likely decrease accessibility for those without the means to own a car.

Gentrification, the influx of wealthy middle-class into an area resulting in the displacement of lower-income residents (Hwang, Roberto, Rugh, & Stephens, 2019; Parker, 2004), can occur with increased PT transport service provision, deepening existing inequalities especially for lower-income households (Reckien et al., 2017). PT is also predominantly designed around a nine-to-five commuter, not catering for gendered differences in mode of transport, journey length, multi-modal use, and reason for travel (V. Preston & Ustundag, 2005; Roberts, 2016). It is therefore essential that PT is planned in such a way that it increases equity of access, as opposed to absolute mobility alone. By investing in transportation systems (a tool of accessibility), accessibility can be improved for different parts of the city, or different groups within it (Karou & Hull, 2014). PT and NMT have many positive effects on marginalised communities if investment is directed with the purpose of achieving greater equity (J. Preston & Rajé, 2007; Reckien et al., 2017).

The largest impact on modal choice of transport and transport patterns is the built structure of the transport system, followed by socioeconomic factors, such as time taken to travel, convenience, safety and price (Karou & Hull, 2014; Silva, 2013). Correspondingly, the spatial proximity of people to different transport mode infrastructures is a key component when considering urban design in the broader field of sustainable urban development. As cities produce spatial inequalities between groups that inhabit them, it is plausible that the design of urban transport systems will reproduce and deepen inequalities of access further.

The mode of transport plays a great role in how exclusionary access to cities is. Therefore, while an increase in sustainable transport will decrease ecological harm, if its planning does not account for the complex social divisions produced by cities, it is unlikely to improve the equity of a city. As such, it does not singularly achieve the goal of sustainable urban development.

3 Literature Review

The following literature review identifies how transport exclusion is manifested and measured in cities, the role of cycling in cities, and the benefit of connecting cycling with PT. By reviewing the studies in the field of transport and exclusion, best practices in measurement of exclusion can be understood and applied to this study to answer my first research question. With intersectionality in mind, I critically assess any misrepresentation in excluded groups. Cycling in the city, and any barriers to this, as well as connectivity literature, is used as a basis to answer my second research question, namely to assess the suitability of current GM infrastructure, and suggest targeted improvements to increase connectivity. Where possible, this literature has findings delineated by identity.

3.1 Transport and Exclusion

Social exclusion has a mobility aspect, meaning there is a clear equity consideration in the provision of transport. Lucas and Jones (2012) conclude that certain groups in society are particularly vulnerable to transport policy, often bearing the brunt of the negative outcomes and experiencing exclusion; namely, these groups are “children and young people, older people, lone parents, disabled people and ethnic minority populations” (p. 1). However, amongst literature in the field, there is not a single standard measurement of equity in transport systems (Carleton & Porter, 2018; Sharma, Mishra, Golias, Welch, & Cherry, 2020). Across literature, groups of people are defined in different ways (Carleton & Porter, 2018), sometimes as a conglomerated excluded or marginalised group (Halden, 2002), and sometimes with results distinct to different groups (Wang, Quddus, Enoch, Ryley, &

Davidson, 2014; Welch, 2013). Hine and Grieco (2003) raise the issue that representing spatial clusters of people, a common practice in literature in the field, misses socially excluded individuals living in areas regarded to have good levels of inclusion.

Different studies identify equity in different parts of the transport system, but this study falls in the realm of location-based accessibility (LBA), which is the "ease of reaching a station or node" (Sharma et al., 2020, p. 2). Within this subgroup, the variety of approaches is still wide. Some studies research the accessibility to the city itself. For example, Halden (2002) builds a multimodal quantitative analysis of accessibility applied to Edinburgh, Scotland, analysing in terms of transport mode as well as several socio-economic groupings, showing that accessibility is at its greatest for marginalised groups in the urban centre, because of better non-car transport availability. Others focus on access to the modes of transport. Welch (2013) quantifies the proportion of the social housing population within a certain distance of PT stops in Baltimore, US, recognising the importance of transport node (PT stops in this case) placement and the higher degree of reliance on PT by lower-income houses. Delmelle and Casas (2012) explore the spatial accessibility of residents to a newly developed bus rapid transit (BRT) system; the findings show that the BRT is most accessible by walking to middle income groups, and least accessible to those at the lowest and highest extremes of income.

Overall, transport exclusion literature is often case based, studying some kind of spatial breakdown of socio-economic indicators alongside a singular or multiple transport systems. The building of these indicators can be problematic and hold bias, with an over-simplistic view of one disadvantaged group which misses the complexities of the experience of different groups of population (Carleton & Porter, 2018). In addition, very few location-based accessibility studies make the distinction of gender.

3.2 Cycling in the City

Cycling provides an attractive NMT solution to urban transport for many reasons. Bicycles produce no pollution, thereby supporting cities to reduce their GHG output and maintain air quality for the health of residents. Their impact on the city is smaller, requiring less space for parking, producing less noise, and being safer vehicles to contend with for pedestrians (Pucher & Buehler, 2010). For bike owners, the upfront cost of a bike and any repairs are lower compared to cars, and cycling has many positive health benefits (Dodman, 2009). Pedestrianisation also comes with these benefits, however, cycling provides a broader region in which to increase access, simply because an individual can travel further in the same time. Despite this, trips made by walking/cycling have been falling in the UK since 1975, with walking being slightly preferential to cycling (Pucher & Buehler, 2010).

Research conducted by Adams, Murari, and Round (2017) identified three main reasons that people do not cycle: safety, effort and convenience. In areas with little cycle infrastructure, men tend to make up the majority of cyclists, while in areas where cycling is a popular choice and considered safe and convenient, there is a relatively even gender split (Adams et al., 2017; Pucher & Buehler, 2010). Safety of cycling positively correlates with more cyclists, but despite this, the number of older people cycling is generally very small (Pucher & Buehler, 2010).

Infrastructure can address each of the three reasons people tend not to choose to cycle and has been shown to positively influence the uptake of cycling as a mode of transport (Cervero, Caldwell, & Cuellar, 2013; Pucher & Buehler, 2010). Well connected, linear cycle paths separated from roads, and secure parking stations are key for encouraging cycling, while traffic-related measures such as traffic calming, education, regulation and reduced speed limits also help (Cervero et al., 2013; Pucher & Buehler, 2008, 2010; Saplıoğlua & Aydınb, 2018). Urban design can have an impact of the attractiveness of NMT by making walking/cycling more efficient, attractive, and interesting; qualities include condensed mixed land use cities, quality lighting, pedestrian level signposting, crossings, street art, wide and attractive pavements, and places to rest (Boulange et al., 2017; Pucher & Buehler, 2010).

3.3 Connecting Cycling and Public Transport

Connectivity between cycling and PT heavily encourages bike use, while effectively extending the catchment area of PT stations (Boulange et al., 2017; Pucher & Buehler, 2010), thereby allowing more people access to sustainable modes of transport. Linking cycling with PT is significantly more cost-effective than further PT provisions to increase accessibility (Krizek & Stonebraker, 2011; Pucher & Buehler, 2010), and so is an appealing solution for local governments. Developing connectivity has the added benefits of reducing sprawl, increasing quality of life, and appealing to non-nuclear family setups (Cervero, 2006).

Certain infrastructure is deemed to be most effective at increasing connectivity between bikes and PT. Bicycle parking at PT stations, particularly extensive secure parking, is recognised across literature to be an essential element of connectivity, trumped only by allowing bicycles on the transit system (Bachand-Marleau, Larsen, & El-Geneidy, 2011; Krizek & Stonebraker, 2011; Pucher & Buehler, 2008, 2010). Cycling facilities and infrastructure surrounding PT stations are important, particularly safe cycling path routes (Cervero, 2006; Pucher & Buehler, 2010). Pucher and Buehler (2008) suggest further measures, including good bike parking facilities at both ends of PT to allow for people to keep a bike in both locations, options for rental bikes or shared bike schemes near stations, and bike-and-ride facilities.

Literature in the field demonstrates the benefits of cycling as a mode of transport and why it is effective to link with PT. While barriers exist to the choosing of cycling as a modal choice, there are coherent infrastructural changes documented to improve the attractiveness of cycling and its connectivity with PT.

4 Greater Manchester Background

GM is a highly populated county in the North West of England, Figure 2, made up of ten different local authority districts with their own council, which combine to make the overall governance structure of the Greater Manchester Combined Authority (GMCA).

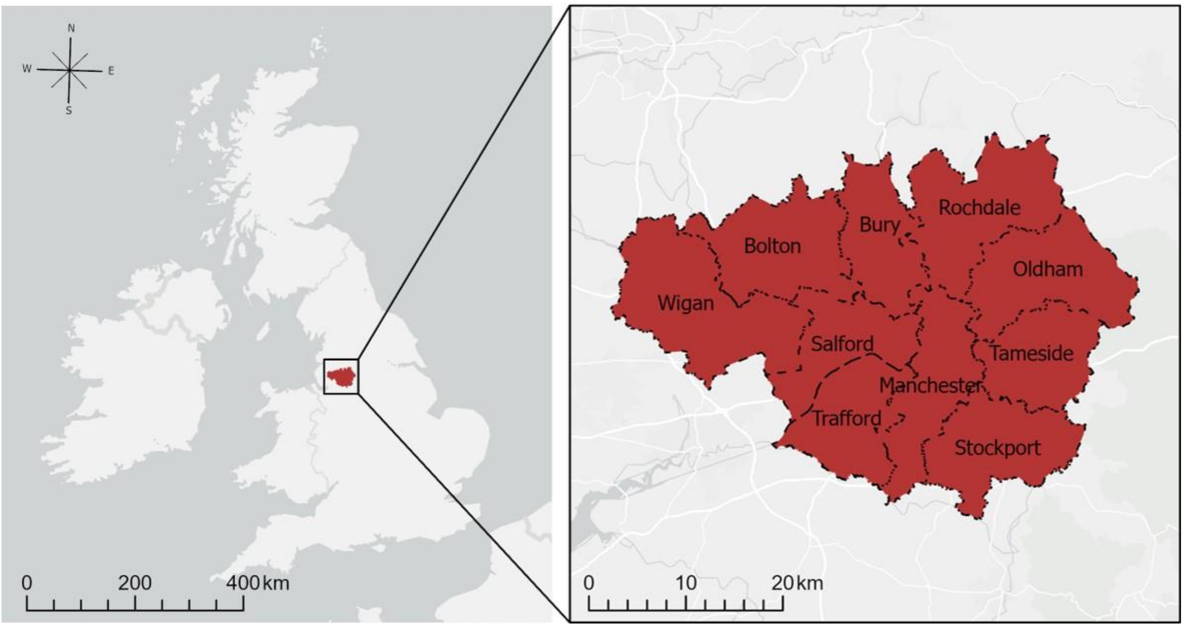


Figure 2. Location of GM in the UK. Shown with ten local authority districts (right). Image is the author's own. Local authority geography sourced from ONS (2017).

During the Industrial Revolution, GM became a global manufacturing hub, particularly in the cotton and engineering industries, helped by cutting edge transport developments: the canal and heavy rail networks (Maw, 2013; McNell & Nevell, 2000). After WWII, the UK began deindustrialising which despite almost instant environmental benefits, left urban areas needing to transition away from manufacturing (Lever, 1991); relics of the Industrial Revolution, including the canal and train systems, can still be seen in the built environment of the region.

The population of GM is approximately 2.8 million, with the densest population around the city of Manchester, followed by cites/large towns of Salford, Oldham, Rochdale, Bolton, Wigan and Tameside, Figure 2. The population of GM is approximately 50.3% female, and ethnic composition 85% white, 9% Asian, 3% Black, 2% Mixed ethnicity, and 1% other ethnicities (nomis, 2013; ONS, 2019). Manchester is the largest city and employment hotspot in the region (MIDAS, n.d.), but each local authority contains at least one major town with peripheral suburban areas.

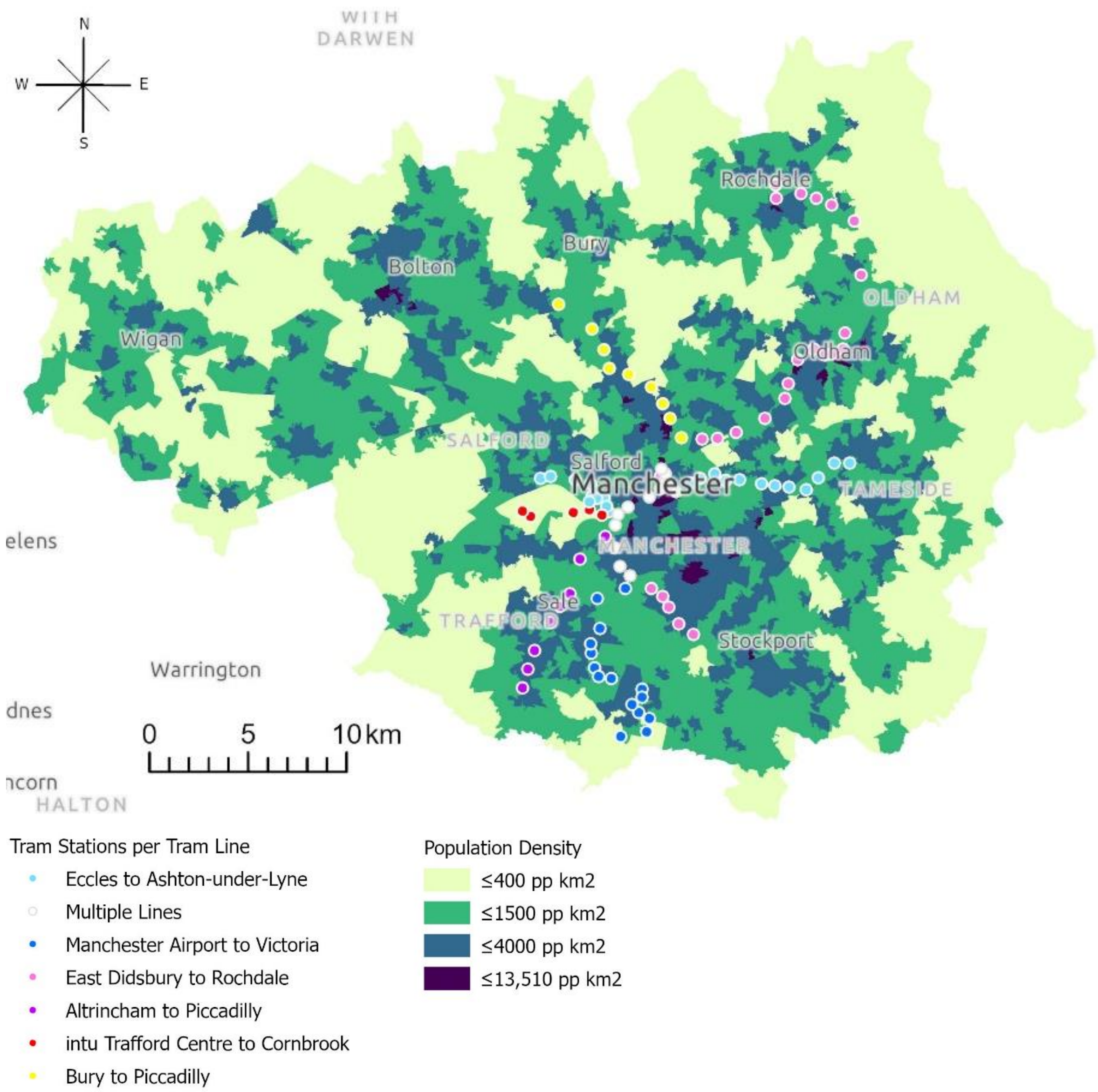


Figure 3. Population density of GM with the location of tram stops. Tram stops are shown by colour coded by tram line. Image is the author's own, data sourced from (Ministry of Housing Communities and Local Government, 2019; TfGM, 2020b).

Early in the twentieth century, GM experienced sprawling and decentralisation, with many commuting into Manchester/Salford via an early tram network, which was gradually replaced by buses in the 30s and 40s (Pooley & Turnball, 2000). In the 1950s, private motorised cars became the mode of choice which led to the rapid decrease of PT journeys made in the region (Pooley & Turnball, 2000). Later, to combat city congestion, the light rail tram system was built from an existing sub-urban heavy rail network in the early 90s, with ensuing success replacing journeys made by car with journeys made by tram (Knowles, 1996; Tyson, 2004). The tram network now has a total of 99 stations which web out from Manchester covering much of east GM, Figure 3, and provides access to larger towns such as Salford, Rochdale, Oldham, as well as the employment hot spots of MediaCityUK and SportsCityUK. In addition to the Metrolink tram system, GM has an extensive bus route, including free Manchester city buses and demand responsive (DMT) buses. Despite this provision of PT, around 70% of commuter journeys and 62% of all journeys made by residents in GM are by privately owned car (TfGM, 2018b).

GM aims to remain within its allocated carbon budget and become carbon neutral by 2038; transport plays a key role in limiting direct carbon emissions, with the first identified priority being "increasing use of [PT] and active travel modes" (GMCA, 2019, p. 32). Transport action plans rely on individuals to choose PT and NMT over private cars, which will be encouraged by improvements to the infrastructure and provision of facilities (GMCA, 2019; Manchester Climate Change Agency, 2020; TfGM, 2019f). Inclusivity is a fundamental principle in the action plans for climate change mitigation, with aims to ensure social justice and improve quality of life for residents (Manchester Climate Change Agency, 2020). Proposed infrastructure includes the Beelines Walking and Cycling Network, which will result in over 1500km of connected cycle and walking paths in GM, 120km of which will be segregated from traffic (TfGM, 2018a).

While there is good provision of PT services in the area, including a tram system granting access to Manchester and other large towns in the east of GM, but private car use still dominates. To meet GHG reduction targets, the use of more sustainable transport must be fostered by the 2.8million residents.

5 Methodology & Methods

This thesis has been conducted with a feminist methodology guiding research questions, data usage, and analysis. GIS methods are used to produce results for both research questions, with the use of optimised hotspot analysis applied to demographic data, and mapping of tram and cycle infrastructure to produce maps of GM. I then analysed these maps to identify the state of accessibility to transport for different marginalised groups, and improvements to cycle infrastructure that may increase accessibility.

5.1 Feminist Methodology

I employ a feminist methodology in this thesis to guide research questions, data usage, and analysis of results. "Methodology [has] to do with approaching research", and so to do so from a feminist perspective does not denote a certain method or theory to be used, but instead requires the researcher to consider power and identity through each step of the research (Moss, 2002, p. 2).

Feminist geography opposes the epistemology of positivism classically used in geography, critiquing it for missing key elements of lived experience (Hesse-Biber, 2012; Johnson, 2009). Quantitative methods, traditionally used in positivistic sciences, have been used to present research as neutral and perfectly objective, despite often missing complexity in the difference of experience (Kwan, 2002b).

Despite this, quantitative methods are used critically by feminists to understand the high-level context of complex systems, and are invaluable to describe measurable elements of an individual's experience (Kwan, 2002b).

Following the suggestions on approaching quantitative feminist research by Kwan (2002b), results gained from this study will not be held in a hierarchical manner over knowledge produced through different means, instead being used to contextualise and encourage broader knowledge generation. The conclusions made here will remain relevant to the context of GM, rather than claiming a "universal applicability" (Kwan, 2002b, p. 163)

5.1.1 Feminist GIS

GIS is a useful tool in feminist research, despite a history of positivistic research application. As noted above, GIS has been critiqued as a tool of the privileged scientist, leading to both a constriction in forms of knowledge generation (Pavlovskaya & Martin, 2007; Schuurman & Pratt, 2002). However, it has been recognised for its ability to create part of a "knowledge system" that can help towards social justice (Schuurman & Pratt, 2002, p. 298). The aim of feminist GIS is not to represent a universal and unobjective truth, but instead present part of a context that can be appropriately represented (Kwan, 2002a; McLafferty, 2002).

Feminist GIS research also brings identities as objects of study. By making these identities the object of study of this thesis, it is possible to begin to understand different patterns of access and requirements of transport, without diminishing these views in the statistics of the whole population. I do not intend to represent an unobjective truth or the entirety of the complex situation, instead, I create a tool for understanding the system and to inspire further exploration.

5.2 Methods

To understand the context of GM and answer both research questions, I followed a set of steps detailed in Figure 4 using secondary quantitative open-source data. By following these steps, I have produced maps demonstrating the high-level patterns of tram accessibility, and relevant statistics that establish the infrastructure connecting PT and cycling.

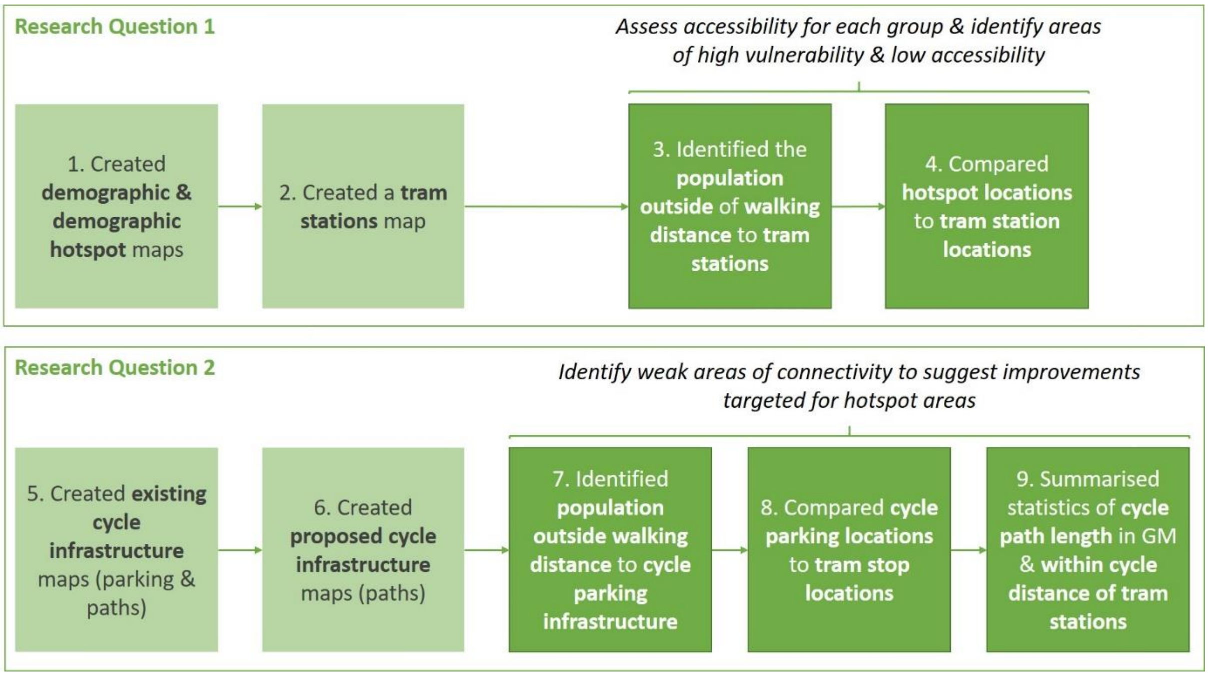


Figure 4. Method steps taken to answer research questions. Boxes in pale green represent steps to understand the context of GM, while darker green boxes show analysis steps. Above the analysis steps for each research question is an explanation of the aims of the steps.

For research question one, I use the concept of vertical equity, which means disparity in access between groups of people are recognised (Litman, 2020). Vertical equity aligns with the concept of intersectionality, allowing me to express the difference in experience between groups, and address the difference in the degree of marginalisation they experience. I use a variation on Mary Ng's vertical equity transport evaluation method to assess accessibility to tram stops for each demographic group, and identify areas of high vulnerability and low access using hotspots of overlapping demographic indicators, Table 1.

Research question two analysis is constructed from literature in the field of cycle and PT connectivity. I focus on cycle parking around tram stations and cycle path structure as these elements were repeatedly identified as priority infrastructure in the encouragement of connectivity (see Literature Review section 3.4). Improvements to connectivity of trams and cycling as modes of transport will then be made, based on the outcomes of the analysis of both research questions.

In the following sub-sections, the demographic indicator justification, data processing and map creation will be explained in detail to allow for reproducibility of results.

Table 1. Mary Ng's Vertical Equity in Transport Evaluation Method, as detailed by Litman (2020, p. 15), and how this study deals with each step.

Ng's Vertical Equity Evaluation Method	Applicability to This Thesis
1. Identify disadvantaged groups	Indicators, detailed in the following section, are used to identify groups more reliant on PT/with less access to private motorised transport
2. Identify disadvantaged geographic areas using census data	Populations, according to indicator demographics, are presented on a map of GM
3. Identify degrees of disadvantage in each geographic area	Indicators are overlapped with deprivation scores of areas in GM and analysed for spatial patterns to create hotspots, therefore building a more complex picture of disadvantage
4. Identify locations of important public services and destinations	Areas within walking distance of tram stops are shown
5. Evaluate specific transportation plans according to how they affect accessibility between disadvantaged communities and important destinations	Areas within walking distance to tram stops are compared with disadvantaged hotspots to assess the accessibility of different groups

5.2.1 Demographic Indicator Justification

A rich set of demographic categories, Table 2, are used to avoid over-simplification of experience: identity indicators were selected based on those used in modern feminist research (Johnson, 2009), those used in transport accessibility literature (Literature Review section 3.1), and from available open-source data in GM region. All ethnicities available in the data were used to avoid essentialising one 'non-white' category of people (Pavlovskaya & Martin, 2007), and sex was the only available indicator for gender. Gender indicators were also used per ethnicity to allow for intersectional analysis, but age data did not have this delineation.

Table 2. Indicators used to explore identities/demographics in this study. The demographic characteristic is listed in the left-hand column, the indicators used in this study in the middle-left column, the source of the raw data for indicator used in this study in the middle-right column, and the literature reflecting this use of indicator in the right-hand column.

Demographic to be Explored	Indicator Used in this Study	Data Source Used in this Study for Indicator	Literature Use of Indicator
Gender	Proportion of population: Female Female per ethnic indicator	(ONS, 2019) (nomis, 2013)	Wang et al. (2014) Halden (2002)
Ethnicity	Proportion of population: White Mixed/multiple ethnic groups Asian/Asian British Black/African/Caribbean/Black British Other ethnic group	(nomis, 2013)	Wang et al. (2014) Halden (2002)

Age	Proportion of population 60 and over Proportion of population aged under 16	Ministry of Housing Communities and Local Government (2019)	Wang et al. (2014) Halden (2002)
Permanent sickness or disability	Index of Deprivation Score, itself based on seven indicators: Income Employment Health/disability Education Housing and services Crime Living environment	(Ministry of Housing Communities and Local Government, 2019)	Wang et al. (2014)
Employment/Income			Wang et al. (2014) Halden (2002) Delmelle and Casas (2012)

5.2.2 Cycling and Walking Distance Justification

I use isodistance maps around the transport nodes of tram stations and cycle parking infrastructure locations to show walking and cycling distance, Table 3, and investigate the demographic landscape within these serviced areas. Buffers around transport nodes show "spatial and social clusters of those adversely affected by social exclusionary processes" (J. Preston & Rajé, 2007, p. 154) in relation to urban transportation, and are used in an abundance of literature (Delmelle & Casas, 2012; Halden, 2002; O'Sullivan, Morrison, & Shearer, 2000; Wang et al., 2014).

Table 3. Buffer distances from tram and cycle infrastructure, including justification. Buffers applied around infrastructure to study demographic in the catchment area.

Infrastructure Buffers Used in This Study	**Justification**	**Data Source of Infrastructure Locations**
500m buffer zone around all cycle parking facilities	Between 400m and 800m is considered an acceptable distance to walk to a transport node, including changing mode of transport (i.e. connecting) (Karou & Hull, 2014; Mishra, Welch, & Jha, 2012; Wang et al., 2014; Welch, 2013) This study has no decay function for that distance (Welch, 2013), combined with assumption people prefer their bicycles to be parked near their location for security, therefore the lower value of 500m buffer is used for cycling parking infrastructure	Outdoor cycle parking locations: TfGM (2019d) Cycle locker locations: TfGM (2019c) Cycle hub locations: TfGM (2019b)
800m buffer zone around all tram stops	800m chosen as upper acceptable limits (according to literature stated above), as the tram system provides significant coverage of the region, therefore assume people are more willing to walk up to 800m to reach the tram stop	Tram stop locations: TfGM (2020b) Tram stop facilities: TfGM (2015) TfGM (2020a) TfGM (n.d.)
5km buffer zone around all tram stops	5km is chosen as an acceptable "easy" distance to cycle, and is above the level of 2km for which people are shown to prefer walking to cycling (Heinen, Maat, & Wee, 2011)	

5.2.3 Data Processing & Map Creation

The processing and agglomeration of multiple datasets was carried out in several stages before map creation, Figure 5 and 6. For the processing of data, I used Microsoft Excel and ArcGIS Pro 2.5.0.

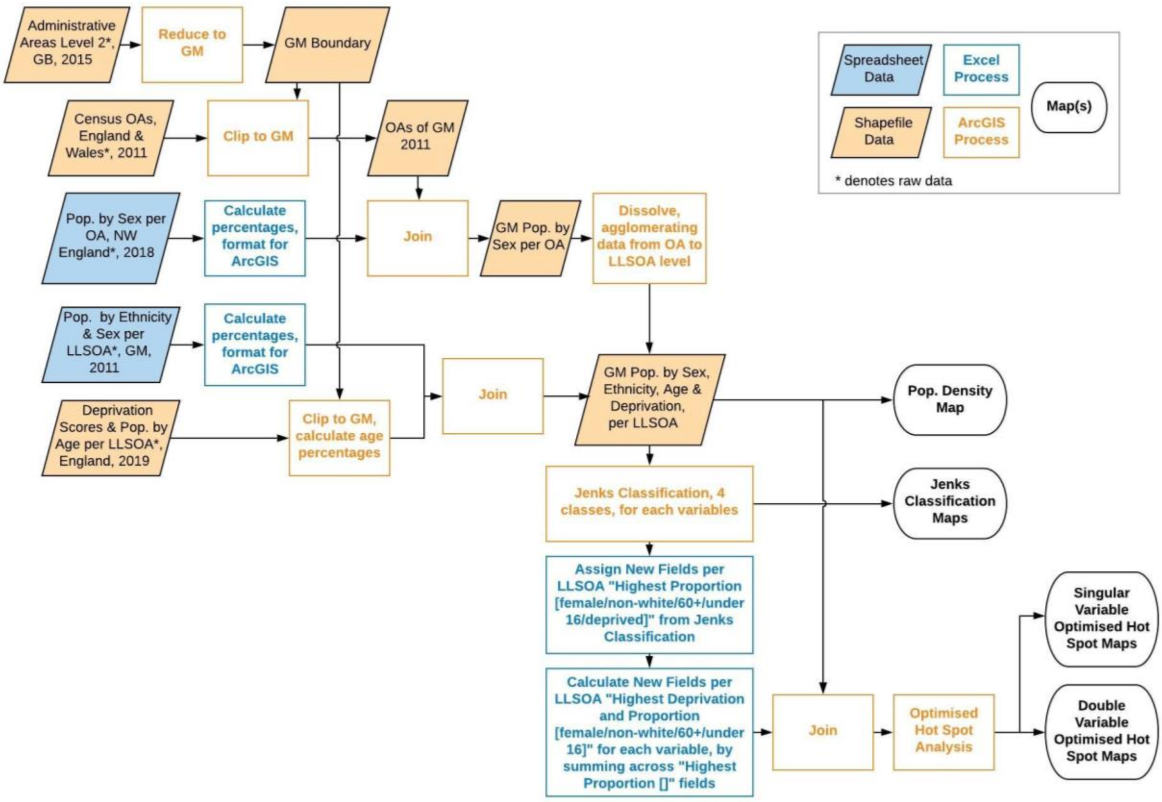


Figure 5. Data Processing Steps to produce Demographics Maps. The demographic data was scaled down to the region of GM before areas of higher proportions of different indicators were identified using Jenks classification. Optimised hot spot analysis was then used to produce hot spot maps. The legend in the top right corner indicates the type of data (and whether it is raw or not), the program used, and resulting maps. Data sources are detailed in Methodology & Methods sections 5.2.1, 5.2.2 and 5.2.3.

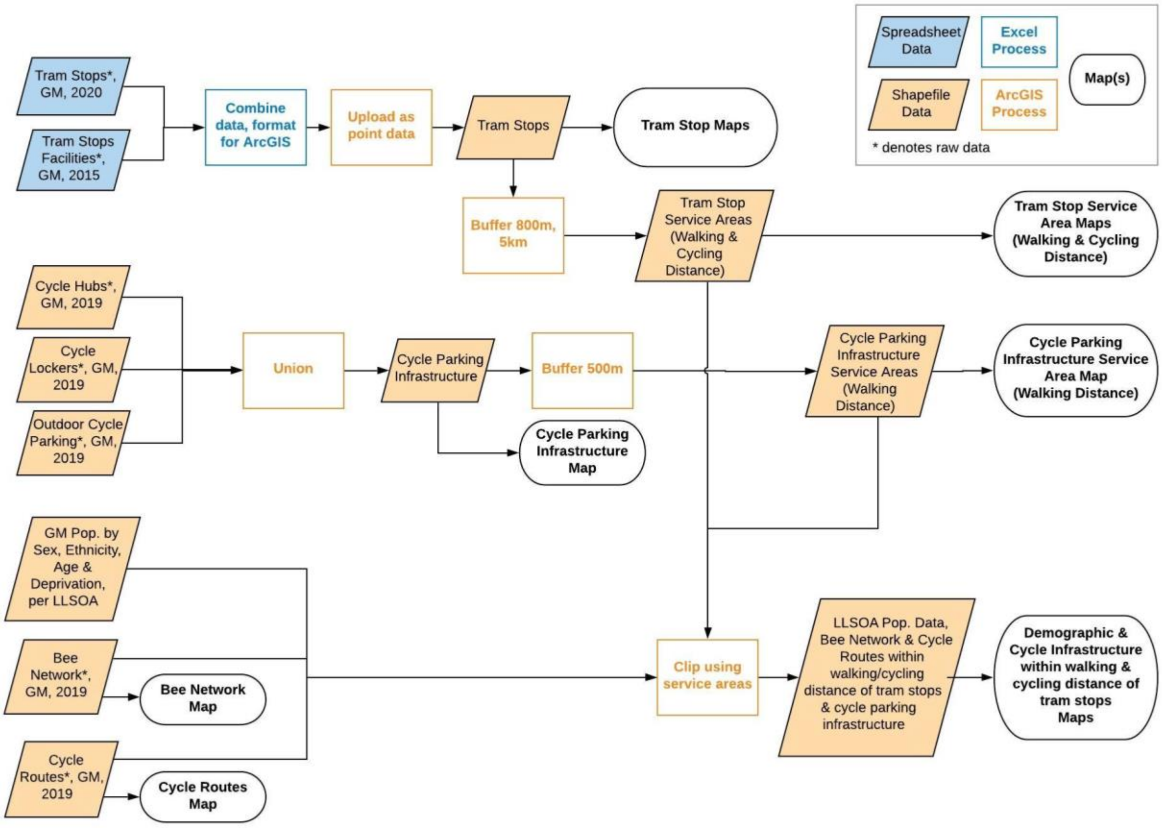


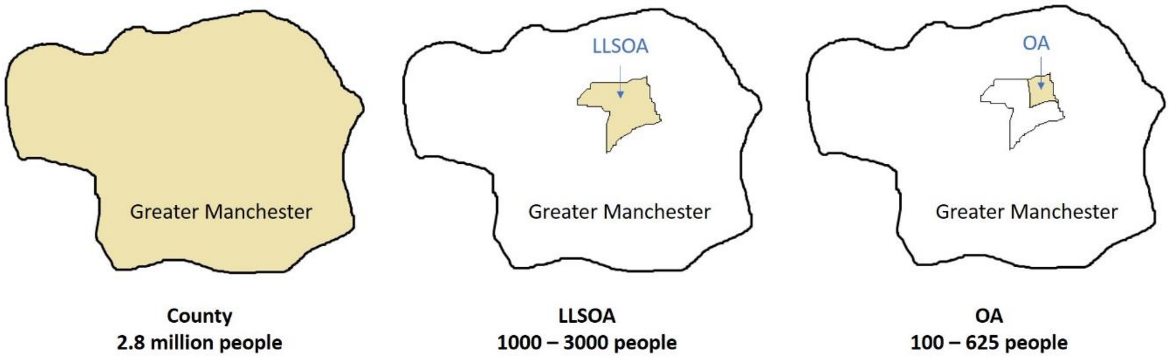
Figure 6. Data Processing Steps to produce tram and cycle infrastructure and service area maps. Tram stops and cycle parking locations were identified, and buffers were created around them. Demographic characteristics were studied within walking and cycling distance to trams. Cycle infrastructure within GM and around tram stops was analysed. The legend in the top right corner indicates the type of data (and whether it is raw or not), the program used, and resulting maps. Data sources are detailed in Methodology & Methods sections 5.2.1, 5.2.2 and 5.2.3. Bee Network sourced from (TfGM, 2019a), Cycle Routes sourced from (TfGM, 2019e).

Demographic data was presented on the scale of lower layer output area (LLSOA), a small area containing between 1000 and 3000, Figure 7. This was the highest common resolution of all data sets and is sufficient to see neighbourhood-level difference.

Demographic indicators were processed singularly, and in combination with the deprivation indicator to allow intersectional analysis of access. To combine indicators, each data set was divided into four classes using Jenks classification (Jenks, 1967), Table 4, then LLSOAs in the top class of both the demographic and deprivation indicators differentiated. This showed the areas where there was both high incidence of the demographic indicator, and high incidence of deprivation.

I used the Optimised Hot Spot Analysis tool within ArcGIS to identify spatial patterns in indicators. This analysis tool identifies statistically significant regions where an indicator is more prevalent (hotspots) and more absent (cold spots). For this study, it makes high-level patterns of accessibility easier to visualise.

From the generated maps, I analysed the spatial accessibility to tram stops of each group, identifying areas with a higher concentration of vulnerable groups who benefit from PT, and low access. I then used the maps to determine weak areas of connectivity between cycling infrastructure and the tram system, before suggesting improvements targeted at hotspot areas.



County Geography Source: GADM (2015)

LLSOA Geography Source: Ministry of Housing Communities and Local Government (2019)

OA Geography Source: ONS (2017)

Figure 7. An explanation of different statistical geographies in GM, and shapefile data sources used for each statistical geography in this study. LLSOAs and OAs are statistical geographies created to report census data; they represent small sections of the UK and are used to show high-resolution demographic data. OAs are the smallest division, and LLSOAs the second smallest. GM is a county containing 1,700 Lower Layer Super Output Areas (LLSOAs). Each LLSOA contains between 1000 and 3000 people (400 to 1200 households). Output areas (OAs) are smaller geographies used for during censuses and contain between 100 and 625 people (40 to 250 households). Descriptions based on ONS (2012); (ONS, 2016). This study displays demographic information on the scale of LLSOAs.

Table 4. Jenks Classification of each demographic indicator. All LLSOAs meeting the class criteria for the specific indicator were numerically classified with a 1 in a dedicated field. All LLSOAs not meeting the criteria were classified with a 0. The classes were specified using the Jenks Classification method (Jenks, 1967), designed for use in choropleth maps.

Demographic Indicator per LLSOA	Class Label	Class Criteria
Percentage of Population Female	Highest Proportion of Females	Percent of Population Female ≥ 51.78% (up to maximum 56.53%)
Percentage of Population Non-white	Highest Proportion of Ethnic Minorities	Percent of Population Non-white ≥ 55.2% (up to maximum 97.24%)
Percent of Population Mixed Ethnicity	Highest Proportion of Mixed Ethnicity	Percent of Population Mixed ≥ 5.28% (up to maximum 11.41%)
Percent of Population Asian Ethnicity	Highest Proportion of Asian Ethnicity	Percent of Population Asian ≥ 52.06% (up to maximum 95.21%)
Percent of Population Black Ethnicity	Highest Proportion of Black Ethnicity	Percent of Population Black ≥ 32.65% (up to maximum 56.66%)
Percent of Population Other Ethnicity	Highest Proportion of Other Ethnicity	Percent of Population Other ≥ 4.83% (up to maximum 10.94%)
Percent of Population Aged 60 & Over	Highest Proportion of 60+	Percent of Population 60+ ≥ 29.09% (up to maximum 48.72%)

Percent of Population Aged Under 16	Highest Proportion of Under 16s	Percent of Population Under 16 ≥ 25.53% (up to maximum 52.98%)
Deprivation Score	Most Deprived	IMD Score ≥ 51.259 (up to maximum 79.300)

6 Results

6.1 Tram Accessibility

Overall, 70.1(±0.5)%[1] of the population of GM live beyond walking distance of tram stops. The following results present the access of different demographic groups, focusing on those groups that tend to rely on PT (Lucas & Jones, 2012).

Deprivation is relatively high in GM compared to the rest of England, with 37% of all GM LLSOAs falling into the highest two deciles of deprivation (i.e. the most deprived 20% of all areas in England). The most deprived areas in GM are clustered widely around cities and towns, while the least deprived occur in lower-density areas around the periphery of the county. As a result, the tram stops proportionally service more deprived areas, although 67% of first and second decile LLSOAs (the most deprived areas in GM) are not within walking distance of tram stops.

Ethnic minorities living in deprived areas in GM experience poor access to tram stops, despite their proximity to urban centres serviced by the trams. Ethnic minorities show the strongest clustering tendencies around urban centres, with higher populations of Black, Mixed, and other ethnicities in Manchester, and a higher Asian population in Rochdale, Oldham, and Bolton. Ethnicity hotspots overlap heavily with deprived hotspots, forming well defined combined hotspots, Figure 8, Appendix 1 for breakdown per ethnicity. Despite the large ethnic minority population around urban centres serviced by trams, 54% of the non-white ethnic population do not live within walking distance of the trams. More precisely, 52% Asian, 53% other, 57% Black, and 60% Mixed ethnic populations live outside of walking distance to tram stops. Some deprived ethnic minority hotspots are partially serviced, however the hotspot to the south of Manchester sits of the periphery of areas within walking distance to the trams, Figure 8.

[1] This figure varies slightly because different demographic data was sourced from different locations, and the age of data varies. For gender only data, 69.70% the total population of GM is outside of walking distance to a tram stop. For ethnicity related data (including gendered split by ethnicity), 70.57% of total population of GM is outside walking distance to a tram stop. For age related data, 70.09% of total population of GM is outside walking distance to a tram stop.

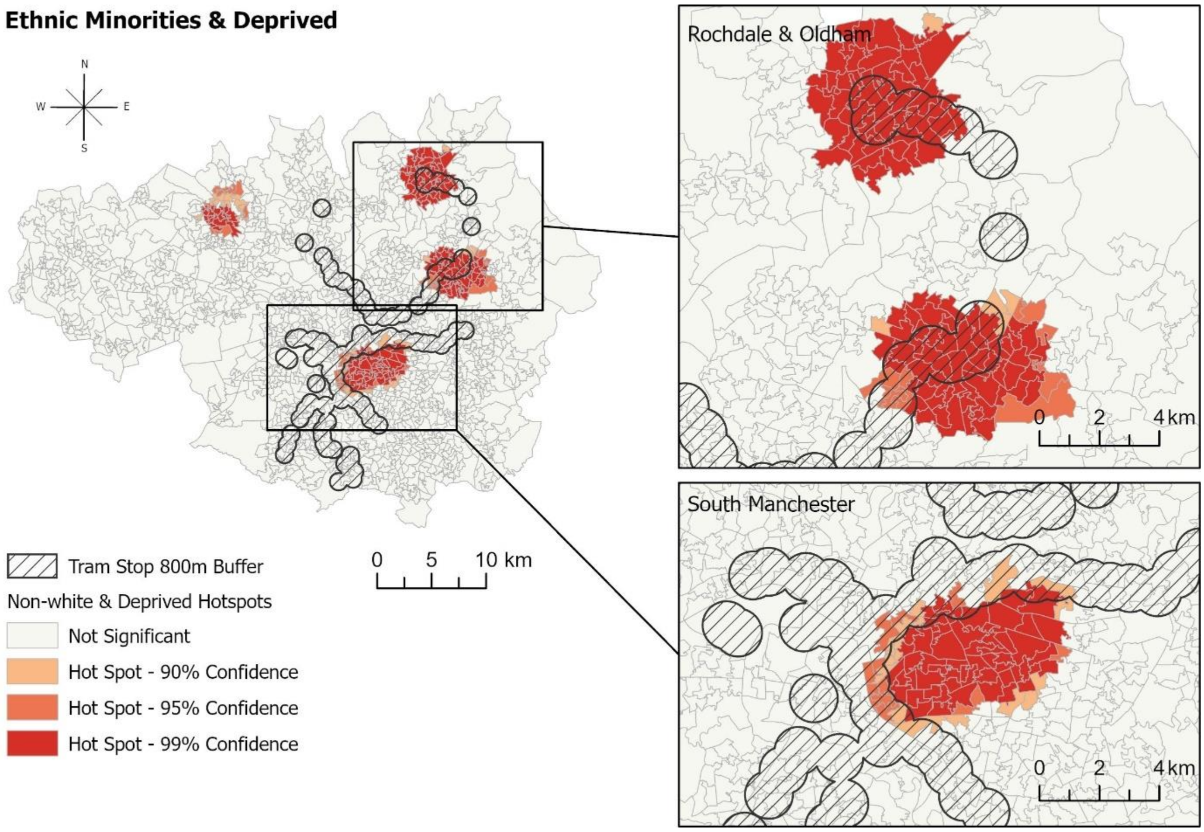


Figure 8. Ethnic minorities and deprived hotspots in GM. These are the combined hotspots of Mixed, Asian, Black, and other ethnicities. For a breakdown of each ethnicity see Appendix 1. Hotspots are focused relatively close to urban centres, in Bolton (top left), Rochdale (top right), Oldham (middle right), and south Manchester (bottom). Some areas of the Rochdale and Oldham hotspots are within walking distance of tram stops. Bolton has no tram accessibility. The south Manchester hotspot has very little walking distance accessibility, with the tram buffer sitting on the perimeter of the hotspot.

People aged sixty and over have the poorest access to tram stations of all identities studied. Older populations in general are least present in the cities and towns of the region, instead living in less densely populated suburban areas. As such, 75% of people aged 60 or over live outside of walking distance to tram stops. Combining older age with deprivation shows hotspots occur in the spaces between towns, leading to poor tram accessibility, Figure 9. In fact, these hotspots are the most consistently far from tram stations of all multi-variable hotspots explored.

Children aged under 16 have comparatively better access. While a very low proportion of the population in central Manchester is under 16, this group has a greater presence bordering the north and east of Manchester, Oldham, Rochdale, and Bolton – all areas serviced by trams. 69% of under 16s live outside of walking distance to tram stops, a proportion very similar to the average for GM. Hotspots of deprivation and under 16s are located in urban areas so are serviced to some extent, and all but two hotspots are located within 2.5km of tram accessible areas, Figure 9.

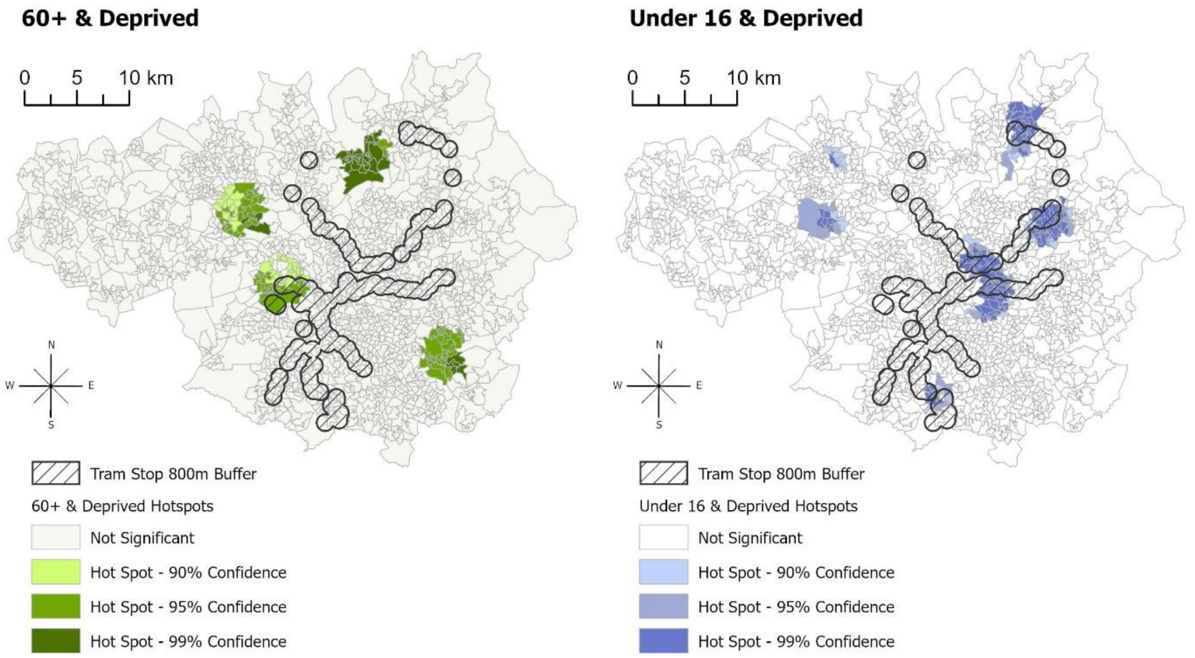


Figure 9. Age-dependent and deprived hotspots. 60+ and deprived hotspots occur outside of urban centres, with only one hotspot having limited walking distance access to tram stops. Under 16 and deprived hotspots tend to occur nearer urban centres, with all but one having some degree of their area within walking distance to a tram stop.

A slight gender disparity exists spatially in GM, causing a small difference in accessibility between females and males. A female population cold spot (population less than 48% female) engulfs Manchester, Figure 10, while female hotspots (population more than 52% female) occur in smaller peripheral towns and between urban centres, often beyond walking distance to tram stops. 70.1% of females in GM live outside of walking distance to tram stops, compared to 69.3% of males[2]. Hotspots of deprived female populations are diffuse and occur between urban centres, so are relatively poorly serviced by tram stops, and several small isolated hotspots are up to 10km away, Figure 10.

[2] 50.3% of the population in Greater Manchester is female, therefore this result reflects the slight imbalance of gendered access to tram stops.

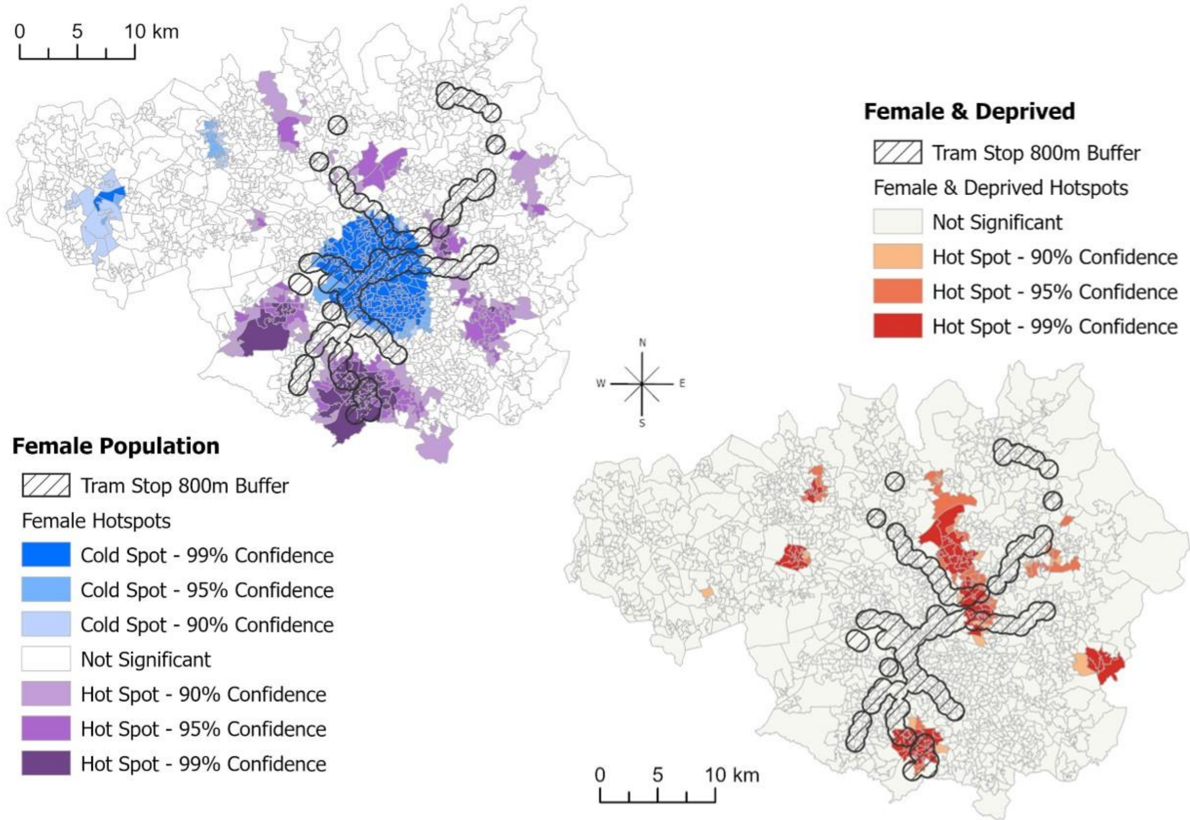


Figure 10. Hotspot analyses of areas of high proportions of female population (left), and areas of high levels female population and deprivation (right). Female population cold spots are areas where the population is less than 48% female, and hotspots are areas where the population is more than 52% female. In central Manchester exists the largest female cold spot, while areas of higher female population occur on the periphery, most predominantly in the south of GM. The areas of high female population and deprivation occur for the most part to the north of Manchester, and in smaller pockets outside of urban centres. These pockets occur at varying distances from the tram walking distance buffer.

Several more indicators were explored for accessibility to tram stations, including white population, gendered break down of each ethnicity, and per decile of deprivation, see Appendix 2 for the full breakdown. Male/female split of access within each ethnicity was very similar. Black and white females had marginally less access than males within the same ethnic groups (reflecting the gendered pattern without ethnicity breakdown, Figure 10), while Asian and other ethnic females had marginally more. Due to the similarity, the results are not factored separately to the general gender split as expressed in Figure 10.

6.2 Cycle Connectivity with Trams

Cycle paths and parking around tram stations are important to connectivity, so the analysis is focused on the area within 5km (cycle distance) from a tram stop. Most hotspots of deprivation and ethnicity/age/gender fall within 5km of a tram stop, Figure 11, which makes them key targets of increased access to trams through cycling.

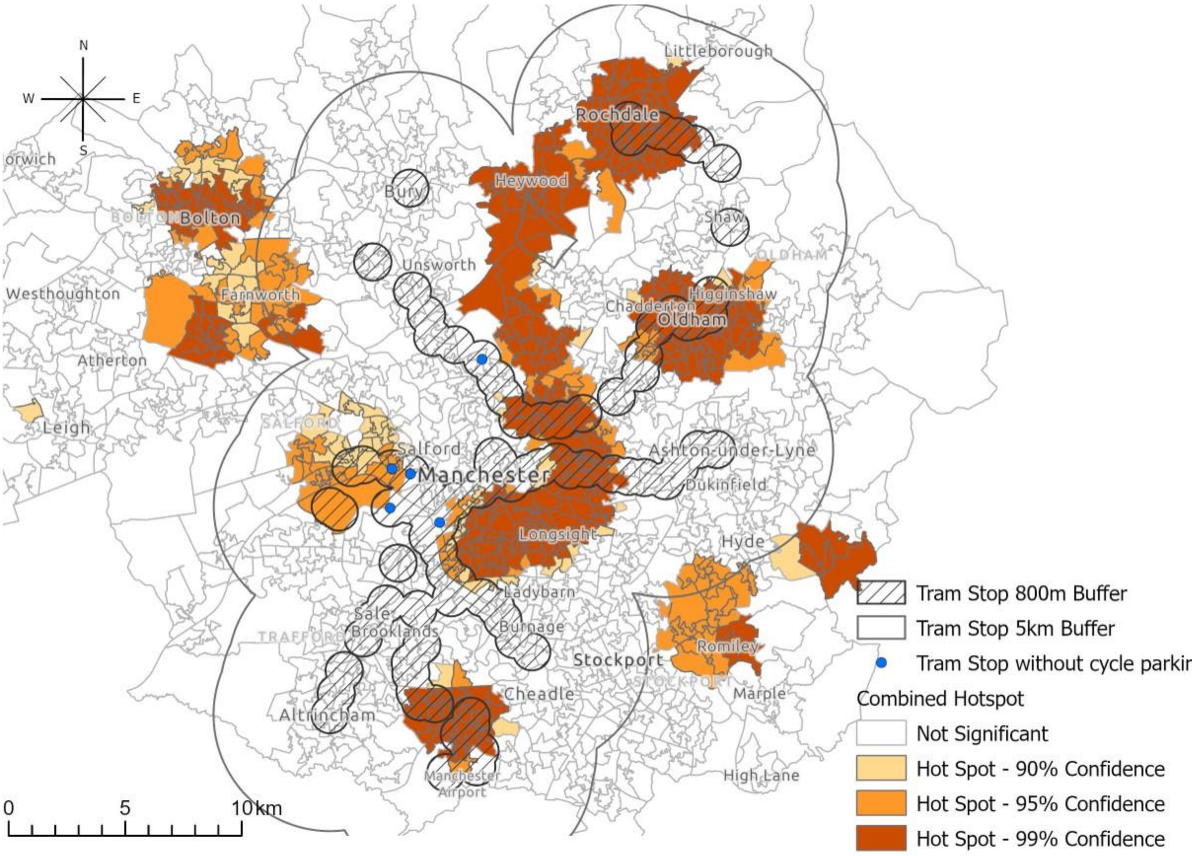


Figure 11. Combined demographic hotspots in relation to walking and cycling distance to tram stops. Hotspots used in combined hotspot above are deprived and high proportion of ethnic minorities/60+/under 16s/female. The five tram stops with no cycle parking provisions within walking distance are highlighted in blue and occur near to the edge of hotspots. Most hotspots are within 5km cycling distance to a tram stop. The hotspots around Bolton (north-west), Farnworth (north-west), and Romiley (south-east) are predominantly outside the 5km cycle distance to tram stops.

6.2.1 Cycle Parking

GM in general has a relatively good provision of low-security cycle parking locations. There are 984 outdoor cycle parking locations, 78 cycle locker locations, and 21 cycle hub locations (Appendix 3 for an explanation of types of cycle parking), spread unequally across the county. These parking sites occur more in the southern half of the county, servicing much of Manchester and its surrounding towns. Cycle parking is proportionally more accessible to locations with high deprivation, and higher proportions of ethnic minorities, and the gender split is roughly even, full breakdown in Appendix 2. Only 37% of the population of GM lives further than 500m from a cycle parking location.

95% of tram stations have some sort of cycle parking within 800m walking distance of the station, and 72% have cycle parking facilities directly at the station, however only around half have more secure cycle locker/hub directly at the station, Figure 12.

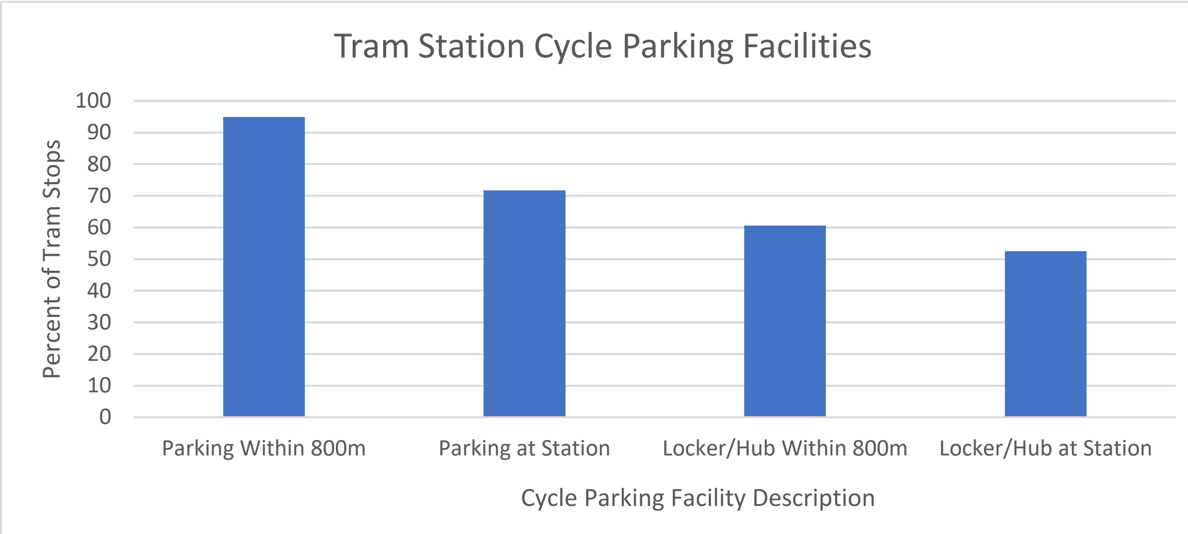


Figure 12. Incidence of cycle parking facilities at tram stations in GM. The percent of tram stops with certain cycle parking provisions are shown, with 95% of tram stops having some kind of cycle parking within 800m of the stop, 72% having some kind of cycle parking directly at the stop, 61% having a more secure locker or hub within 800m of the stop, and 53% having a locker or hub directly at the stop.

Five stations in GM do not have cycle parking within walking distance of the station[3], all of which are situated within or on the edge of hotspots, Figure 11. Three of these stations are within or adjacent to a hotspot of 60+ and deprived populations near Salford, one borders an ethnic minority and deprived hotspot to the south of Manchester, and the last borders a female and under 16 and deprived hotspot north of Manchester.

6.2.2 Cycle Paths

Cycle paths in the GM region tend to be very short and disconnected, as there are over 2500 paths and the average length of these cycle paths is 505m. Within the zone of 5km of tram stations, this average increases slightly to 509m. Most paths in GM are 500m or less, with only around 200 paths being longer than 3km, Figure 13. The shorter paths are more common around town or city centres, while the longer paths exist in places of lower population density.

The Beelines Walking and Cycling Network proposed infrastructure will increase the length of cycle paths in GM by 40%, and by 43% specifically within 5km of tram stops. It also has the express aim of connecting cycle paths, likely resulting in longer cycle paths.

[3] These stations are Bowker Vale on the Bury Line, Weaste on the Eccles Line, Langworthy on the Eccles Line, Parkways on the intu Trafford Centre Line, and Trafford Bar on the Stretford Road Line.

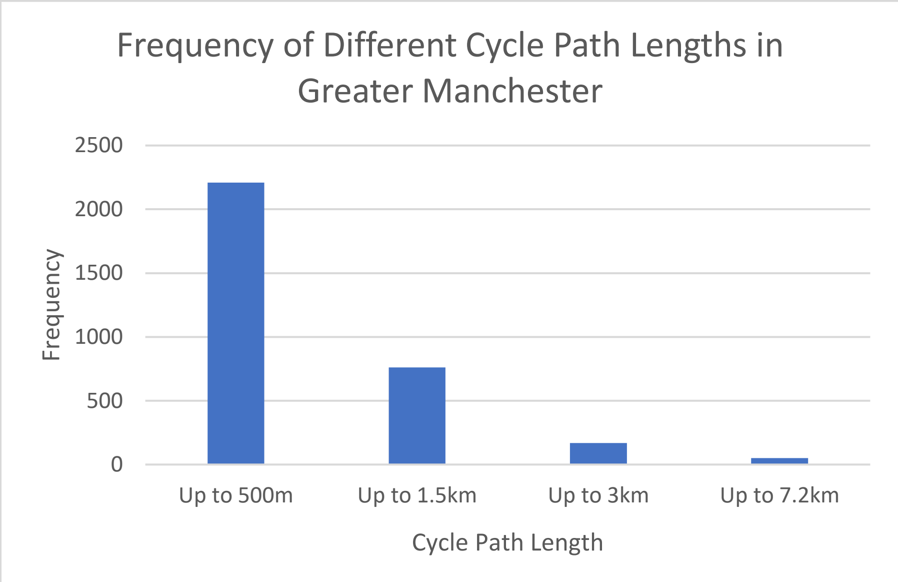


Figure 13. Frequency of different length cycle paths in GM. More than half the cycle paths are 500m or less, which is classified as comfortable walking distance. The average length of a cycle path in GM is 505m.

Cycle infrastructure is extensive in GM but in its current state unfit to promote cycling as a multi-modal choice with the tram system.

7 Discussion

This study is foundational, identifying base-level access inequity in the built environment, relating to tram access in GM. Bias cannot be completely avoided in the presentation of quantitative data, nor can it fully represent the complexity of differing experience (McLafferty, 2002). Furthermore, secondary data collected by governmental institutions can essentialise or undermine the experience of marginalised groups (Kwan, 2002b). As a result, this study can be used to initiate a dialogue with the most marginalised people (identified broadly in the following discussion), providing a platform from which to conduct deeper qualitative analyses and fully understand accessibility barriers within the principles of a feminist methodology.

7.1 Is tram access equitable?

The results presented in this study support many aspects of urban theory and feminist urban theory, providing new insights in the context of GM. Mobilising these theories allows the explanation of some elements of the spatial landscape of GM and its relation to the tram system, which reiterates the interlocking nature of urban transport and land use. Furthermore, it allows us to understand reasons behind the inequity of access to tram stops faced by some groups studied in this thesis. For the transport infrastructure to have the greatest impact on climate goals, it must be suitable for purpose – it is important this purpose is defined by all factions of society, and marginalised groups' interests are not obscured by privileged perspectives that have previously dominated urban and transport planning.

7.1.1 Deprivation

GM has a reasonably high level of deprivation, and results show deprivation is condensed around cities and towns in the region. Due to the clustering around these areas, the tram access is proportionally higher to those areas affected by the highest levels of deprivation. This finding reflects the argument that people of lower-income cluster around city centres because of the provision of PT (Glaeser, Kahn, & Rappaport, 2008; LeRoy & Sonstelie, 1983). PT is better provisioned in city centres because higher population density makes them more efficient to run allowing lower user costs, which is more affordable than car ownership and travel in from the suburbs (Glaeser et al., 2008; LeRoy & Sonstelie, 1983). This phenomenon directly links back to urban planning and urban development theories, which highlight the interlocked nature of land use and transport, as the access to transport in the region is dictating the residential makeup surrounding it. Further, the better provision of PT to suburban areas results in less clustering of lower incomes around urban centres, as PT allows access to these places (Glaeser et al., 2008). This presents an interesting question for further research into whether well-connected cycling infrastructure could have the same alleviating effect on low-income clustering.

7.1.2 Ethnicity

Ethnicity-based clustering is found to be the strongest of any indicator explored in this study, supporting the concept in urban theory of community formation around an aspect of identity (Parker, 2004). As the population of ethnic minorities in GM is very low, the results suggest clustering of communities may be tighter if the identity in question is less present in an area – there is not conclusive evidence within the scope of this study to prove or disprove this.

Clusters of ethnic minority populations, occurring around urban centres, overlap heavily with deprived areas in GM, suggesting there is more at play than community identity formation. Deprived ethnic minorities tending to live around urban centres reflects the segregation of space between the more prosperous suburbs and deprived urban centres introduced in urban planning practice after WWII (Parker, 2004). Further, these results show a racial element to this separation of suburban and urban communities, a well-documented phenomenon particularly in the US (Hwang et al., 2019), suggesting that socio-economic disadvantage is confining these groups to certain locations.

Despite deprived ethnic minority populations living so close to urban centres, they are relatively poorly serviced by trams, which demonstrates the most apparent injustice of access. The hotspot of Black, Mixed, and other ethnicities in deprived areas in south Manchester shares a perimeter with walking access to tram stops, rendering the hotspot perfectly outside of walking distance to trams. This is most likely a result of gentrification occurring after the construction of the tram system. Gentrification after the implementation of PT infrastructure is a recognised phenomenon (Reckien et al., 2017) and another example of transport affecting land use through the mechanism of house-prices. A lock-in effect is also a risk, as those in deprived areas with inequitable access to transport are disadvantaged when trying to access, for example, job markets in the city, diminishing their chances of alleviating deprivation.

7.1.3 Age

Deprived aged 60+ hotspots were shown to be, in general, the furthest from tram stations. Older populations in general have low incidence in urban centres; this provides insight into the capitalistic influence on urban form in GM, a foundational concept to urban theory (Parker, 2004). Specifically, older populations no longer in employment do not experience the economic benefit of living near city centres, Manchester particularly, where jobs are focused, and so through the commodification of space, they are outpriced from living in central locations (especially lower-income older people). This pattern is important for transport provision because older people rely more on communities and services for support than other demographics (Buffel, Phillipson, & Scharf, 2012; Scharf, Phillipson, & Smith, 2003). Mobility is of vital importance to maintain this connection, PT providing a lifeline especially for those also impacted by deprivation.

Under 16 and deprived hotspots, while serviced to a limited extent, are generally much closer to tram stations, with little spatial indication that this group receives unjustly small service from tram stations.

7.1.4 Gender

The gendered differentiation in access to trams in GM is very small, despite a pattern of lower proportions of female population in the centre of Manchester where tram access is high. This is an interesting pattern of gendered residency, however the results in this study do not provide conclusive evidence to support an explanation for why this happens; this question raised would therefore be appropriate to explore in further studies conducted in the area.

Furthermore, due to the minimal difference in male/female proximity to tram stops, inequitable access based on gender cannot be strongly confirmed by these results. This relative equity in spatial accessibility is useful to understand in the broader scheme of feminist urban planning, as it means broader access barriers are likely at play. This is supported by feminist urban theory which highlights access barriers at scales of the body (Valentine, 1989) and household (Hayden, 1980; Wekerle, 1980), which in this case, for example, could be related to safety in the use of trams, and relative deprivation within a household.

Overall, deprived ethnic minority and deprived 60+ populations experience inequitable access to tram stops in GM. Both occur due to some element of capitalistic oppression, combined with marginalisation due to identity, as the intersectional analysis displayed different patterns to that of deprivation alone.

7.2 Connecting Trams to Bicycles

GM already has a reasonably good provision of cycle parking infrastructure, but the connectivity with PT could be significantly improved to the benefit of increasing tram access equity. Currently, there is a good spread of cycle parking locations, mostly low-security outdoor parking, across the county including within walking distance of many tram stops. Additionally, there are many cycle paths, some of which provide linear connection between towns. However, the most important results for connectivity are that provision of secure cycle parking facilities occur at only around half of the tram stations, with some having no provision of any type of parking, and cycle paths are scattered and disconnected in urban areas close to tram stops. Across literature in the field of cycle and PT connectivity, including Bachand-Marleau et al. (2011), Cervero et al. (2013), Krizek and Stonebraker (2011), Pucher and Buehler (2010), and Saplıoğlua and Aydınb (2018), these results equate to barriers to choosing cycling as part of a multi-modal journey, as the security of the bike when left at a station and the safety of the rider on the road are lacking.

Current lack in infrastructure providing connection between cycling and PT can be seen as an opportunity to tailor new infrastructure to the use of those most reliant on PT for mobility (Lucas & Jones, 2012), and therefore increase accessibility of the tram system while correcting current inequalities. The area within 5km cycle distance of tram stations encompasses many hotspots identified in this study, including all hotspots for deprived Black, Mixed and other ethnicities, as well as most hotspots of deprived Asian ethnicities and deprived 60+ populations. The compact nature of Manchester and GM lends itself to connectivity improvements because of the relative proximity of locations. Connectivity can essentially improve the 'last-mile-home' issue, where the distance of an individual destination to the PT station is slightly too far to walk (Adams et al., 2017).

7.2.1 Suggested Improvements to Connectivity

Based on the analysis conducted in this thesis, cycle infrastructure to improve connectivity with tram stops should be prioritised in the following order:

1. Install cycle parking provision at tram stops with no parking facilities within walking distance.
2. Install cycle parking provision directly at all tram stops.
3. Install higher security cycle parking (lockers or hubs) at all tram stops.

4. Connect cycle paths close to urban centres and around tram stops.
5. Install where possible segregated cycle paths.

Cycle parking should be present at every tram stop, since Bachand-Marleau et al. (2011), Krizek and Stonebraker (2011), Pucher and Buehler (2008, 2010) found this infrastructure the most supportive of connectivity after allowing bikes on PT. Indeed, five of the ninety-nine tram stations lack any kind of cycle parking within walking distance, completely disconnecting these stations from multi-modal transport involving bikes. All five occur on the edge of hotspots, three on the edge of the same hotspot of deprived 60+ populations, as such limiting the convenience of this group to choose to cycle. Over one quarter of tram stations do not have parking directly at the station, and approximately half have low security outdoor parking, reducing the attractiveness of multi-modal travel involving cycling at these stations. Security must be considered with the provision of new cycle parking locations, as more secure parking encourages more usage (Pucher & Buehler, 2008). These secure parking stations should be able to cater for bikes with added modifications, such as baskets or trailers, to account for individuals making journeys for different purposes (for example larger baskets to carry food shopping or trailers for transporting children).

After improving the inadequacies of cycle parking, cycle path infrastructure can be addressed. The Beelines Walking and Cycling Network proposal for GM goes some way to improve cycle paths in the area. The ambition is for cyclists and pedestrians to be, where possible, separated from other road traffic, and paths connected with each other with decent signage for ease of use (TfGM, 2018a). The plan does not state specific easing of cycle paths to PT/tram stops, nor does it tailor infrastructure to different groups. While there is intention to involve the community in elements of planning and execution, the locations of cycle paths have already been largely decided, calling into question to what extent differences between users have been considered. Considering this, connectivity improvements to the Beelines network are suggested in the following paragraphs, considering the location of hotspots and their improvement in accessibility to tram stops.

A safe web of cycle paths in urban centres surrounding tram stops should be provisioned, protecting cyclists from heavy town traffic, especially at commuter times when traffic congestion is worse. This could be through segregated cycle paths, or alternatively (or indeed in parallel) changes to right-of-way rules giving priority to cyclists at interchanges, even allocating bike-only roads in city centres, as suggested by Pucher and Buehler (2010). These changes may be more effective and swifter to integrate into the current infrastructure compared to building segregated paths, suiting the complex network of major and minor roads which are more condensed in urban centres. Measures surrounding Manchester and other towns benefit deprived ethnic minorities and deprived under 16s, as these hotspots occur within 2.5km of tram stops – measures can further be tailored to school times to encourage bike use amongst children. Cycle path infrastructure is, to an extent, non-rivalrous and non-excludable, meaning individuals outside of targeted groups can still enjoy the benefits of infrastructure in the city. This characteristic of cycle paths helps to quell the critique that building solutions around clusters will disadvantage individuals not caught in the cluster (Hine & Grieco, 2003). Additionally, one study concludes that better integration of transport measures relieves the effect of PT related gentrification, alongside reducing demand for PT overall (Chava, Newman, & Tiwari, 2018). As such, these measures could both decrease overcrowding and reduce the impact of gentrification on accessibility.

In GM, deprived 60+ hotspots exist outside of the 5km buffer from tram stations, and wider to the context of this study, people over 60 in the UK make the smallest proportion of trips by bike (Pucher & Buehler, 2010). According to Pucher and Buehler (2010), the inclination not to cycle for this age group is less about physicality, more about the provision of safe cycle paths separated from other traffic. Segregated cycle paths in areas of higher older populations are therefore essential in areas near tram stops. Long linear paths should be provided around those hotspots which are further from tram stops to allow connection, and key connections to closer urban centres and services should be made as safe as possible in line with the urban planning target of ensuring compact mixed-use urban areas.

In conclusion, access inequities in the tram system can be addressed through connectivity with cycling, if cycling infrastructure is delivered focusing on the needs of the marginalised. While the suggestions above are derived from analysis in this study, it is essential that infrastructural changes are brought about in collaboration with the communities they affect to ensure the solutions are truly addressing accessibility and connectivity barriers. Furthermore, repairing this inequity in transport ensures that the multi-modal system of trams and cycles meets the definition of sustainable urban development as defined by Bibri and Krogstie (2017).

In a broader sense, this study has provided contextual evidence for phenomena described in urban theory and feminist urban theory, while adding complexity to the field of urban transport accessibility. Inequity in access to urban services has been shown to exist based on intersectional identity, a major paradigm in the field of feminist urban theory (Hayden, 1980; Wekerle, 1980). This marginalisation has occurred in line with the capitalistic formation of cities, as described in urban theory (Parker, 2004). Moreover, through intersectional analysis, spatial access has been explored to a level of complexity missing in transport access literature, and so this study presents an approach to integrate intersectionality into quantitative assessment of access. Finally, the feminist perspective and respect for difference in experience is demonstrated to be useful in the tailoring of sustainable urban transport, ensuring it is designed with a diverse user group in mind.

7.3 Study Limitations and Areas for Additional Research

The following sections address elements of accessibility outside the scope of this study. As a foundational study, this thesis can be used as an entry point into accessibility analysis in GM, identifying areas where further study is essential. However, it does not encompass the full complexity of accessibility issues experienced by different people in GM. Potential avenues for additional study are outlined here.

7.3.1 Priorities in Spatial Accessibility

Despite providing significant results on equity of access to sustainable modes of transportation, the research here provides some avenues to build upon as it is unable to account for the multiple forms of equity required to achieve truly sustainable urban development, according to the principles presented in Theory Section 2.3.

By increasing the access of people to the city, especially a diverse set of people and identities, city culture becomes richer, and more individuals are allowed the unique form of expression the city landscape brings. Arguably, increasing access to the cities allows for a broader opportunity of expression, especially if this access is granted to marginalised groups that have previously been excluded from cities. From a feminist perspective, access to the city can be about reclaiming space.

In a more tangible sense, linking people and services is an important application of mobility. Access to the city is only as useful as the services bought within reach, such as the facilities studied by Karou and Hull (2014): business, employment, retail, education, health, leisure/recreation. This priority of access relies heavily on the entwined nature of transport systems and land use. In the context of GM, the facilities available to each hotspot area should be analysed, and any transport measures paired with services investment to allow people to reach these services in a location near to them, rather than relying on transport into the largest city. This is especially important for those hotspots outside of the acceptable cycle distance of 5km. This further examination of services accessed by transport systems can be conducted incorporating feminist interests, access related to reproductive work in the private sector, and productive work which has been viewed as hierarchical under patriarchal and capitalist power structures.

Bikes allow a dynamic form of mobility, allowing access regardless of the service deemed as most important to access. Accessibility by bike can be applicable to each priority focus of access. PT provision is costly and rather static, but the low-cost nature of cycle infrastructure (Krizek &

Stonebraker, 2011) means it can be implemented widely and dynamically, allowing for individual freedom in travel, particularly destinations and reasons for travel. Further, NMT is effective in places of high deprivation and can be influenced by policy to generate inclusivity (Welch, 2013). Cycle infrastructure is not reliant on high densities of people for efficiency, as PT systems are, so they are also more cost-effective in less densely populated areas at increasing mobility. Cycle infrastructure provision, led by the marginalised as agents of change, may be able to reshape access, and therefore power relations in GM.

7.3.2 Barriers Beyond Spatial Accessibility

Spatial access is the foundational element in transport mode selection, so is the natural starting point for a foundational study such as this. Further research in the context of GM should attempt to display barriers to accessibility beyond spatial limitations. These include socio-economic factors such as travel time, convenience, safety and price (Karou & Hull, 2014; Silva, 2013).

Fiscal access to PT is often inequitable, particularly to those with lower incomes, and those who make multi-modal complex journeys (Delmelle & Casas, 2012; J. Preston & Rajé, 2007; Reckien et al., 2017). More provision of PT to increase accessibility is often priced too highly and remains inaccessible for lower-income groups (J. Preston & Rajé, 2007). This study has not explored the exclusionary impact the tram ticket pricing has on people, and so pricing should be explored to understand whether it presents further barriers to sustainable transport choices for individuals. The concept of fiscal access can be extended to secure cycle parking locations in GM (see Appendix 3 for details), and so exclusionary impact of pricing should also be identified here.

Safety from violence, an integral analysis point in radical feminism (Valentine, 1989), can be addressed in further studies. Extensive literature has been produced on elements of infrastructure that can aid in creating cities suitable for women and other marginalised groups, to protect them from the threat of violence (Schwittay, 2019). This should be further analysed in the context of GM.

Cycling itself is not a completely inclusive method of transport. The skill of riding a bike is not universal, and opportunities to learn in a safe environment limited. Those with disabilities or health conditions may find bike riding exclusionary due to the physicality involved. Moreover, there is still an upfront cost in the ownership and upkeep of bikes. Pedestrianisation may be more inclusive, an avenue that could be explored especially in the GM Beelines proposal (TfGM, 2018a).

Finally, the coronavirus pandemic has changed the way in which we operate our lives, presenting an opportunity for the adoption of sustainable transport. The use of public space and services, work patterns and attitudes have shifted while lockdown measures have ensued. Emergency cycling and pedestrianisation measures have been rolled out in GM to protect the public and ensure mobility in a time where PT is deemed a great risk (TfGM, 2020c). Habits are known to play a large factor in choosing private cars as modes of transport (Şimşekoğlu, Nordfjærn, & Rundmob, 2015), therefore this time of resetting habits could be used to kick start a sustainable urban transport transition. Additional research could identify the impact of COVID-19 in GM, alongside identifying paths for improved urban sustainable development.

Therefore, while this study has provided an illuminating insight into the spatial inequalities of GM's urban transport infrastructure, building a holistic picture of the relationship between transport and sustainable urban development in this city ought to be supported through a combination of alternative empirical focuses and methods.

8 Conclusion

In conclusion, this thesis has explored the wicked problem of local level equity issues resulting from global climate change mitigation commitments and action. Using the case study of Greater Manchester and analysing the population in an intersection sense, I showed that inequities in spatial access to sustainable modes of transport currently exist. Specifically, deprived ethnic minorities and deprived population over the age of 60 are under-serviced by the tram system, likely a result of gentrification in the first instance, and displacement away from city centres due to the commodification of space in the second instance.

In response to the second research question, I found that secure cycle parking at tram stops, connected cycle paths in the city centres, and longer linear cycle paths in less densely populated areas would be the best measures to increase connectivity between cycling and the tram system. Connectivity in this multi-modal system benefits those with the lowest accessibility, but due to the nature of cycle infrastructure, also benefits people outside of these groups.

By conducting this analysis, I have identified flaws in a current and proposed sustainable transport system in GM, presenting opportunities to address these flaws and create a fully realised and interconnected sustainable urban transport network.

Following the feminist methodology I employed for the thesis, I recognise this study as a foundation for further research to build on, rather than a complete presentation of the state of access to transport in GM. Some element of unavoidable bias is present within the secondary data used, and in the way data has been presented. Further research should flesh out a fuller qualitative understanding of barriers to access of sustainable transport modes in GM, working with the most marginalised groups identified in this study to correct for the bias in quantitative data. Finally, this study demonstrates the applicability of a feminist methodology to the field of sustainability science, as it encourages a more complex picture of the system to be built, and therefore a solution to the problem fit for purpose.

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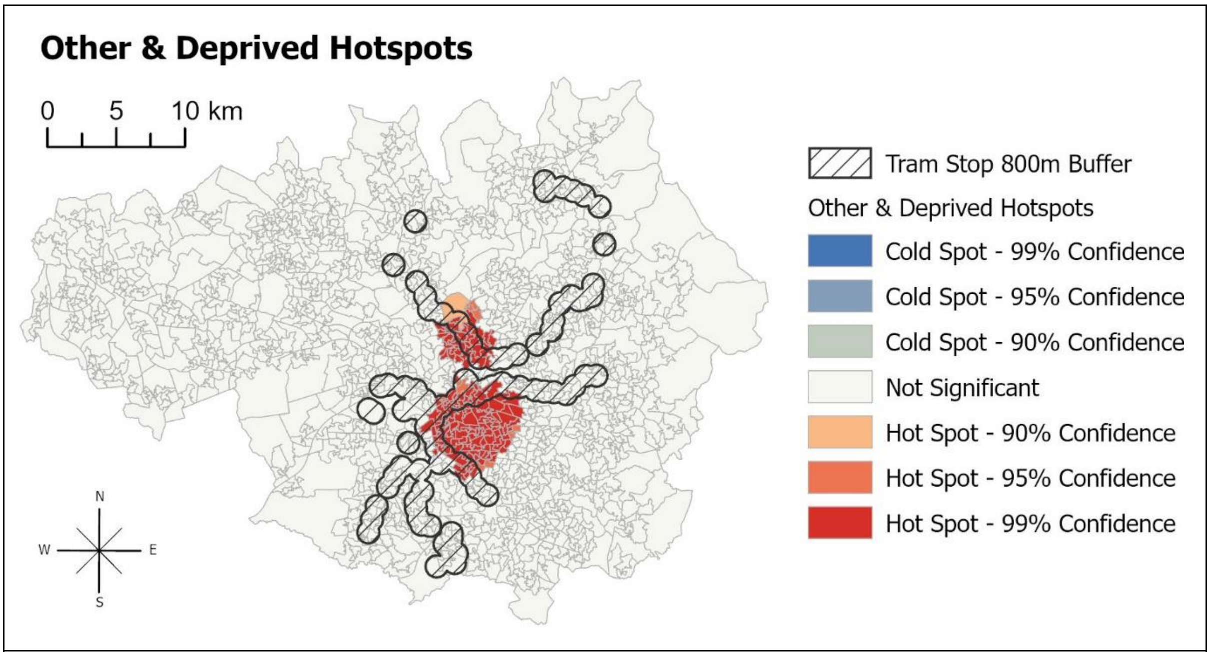
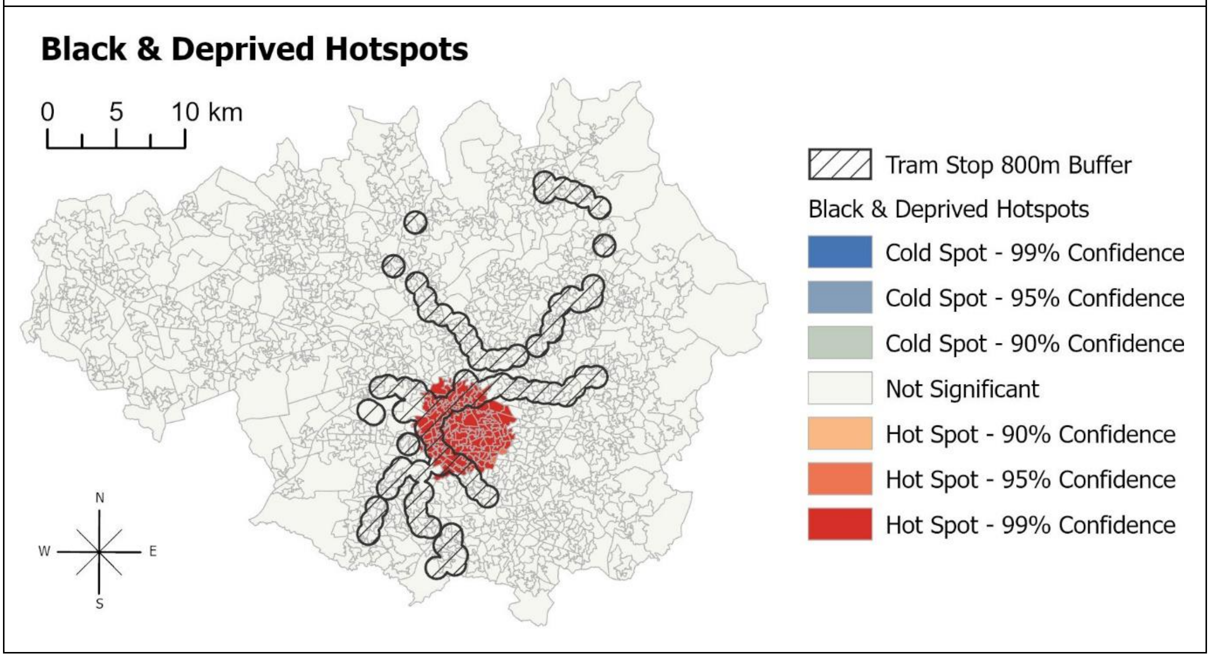
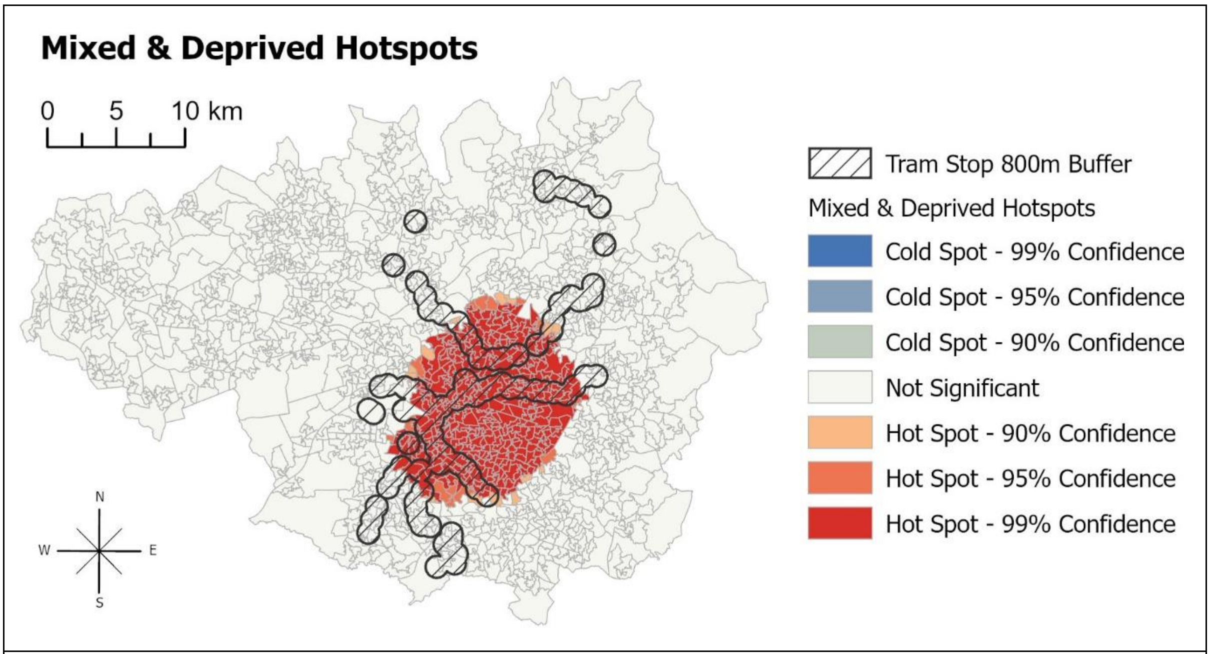
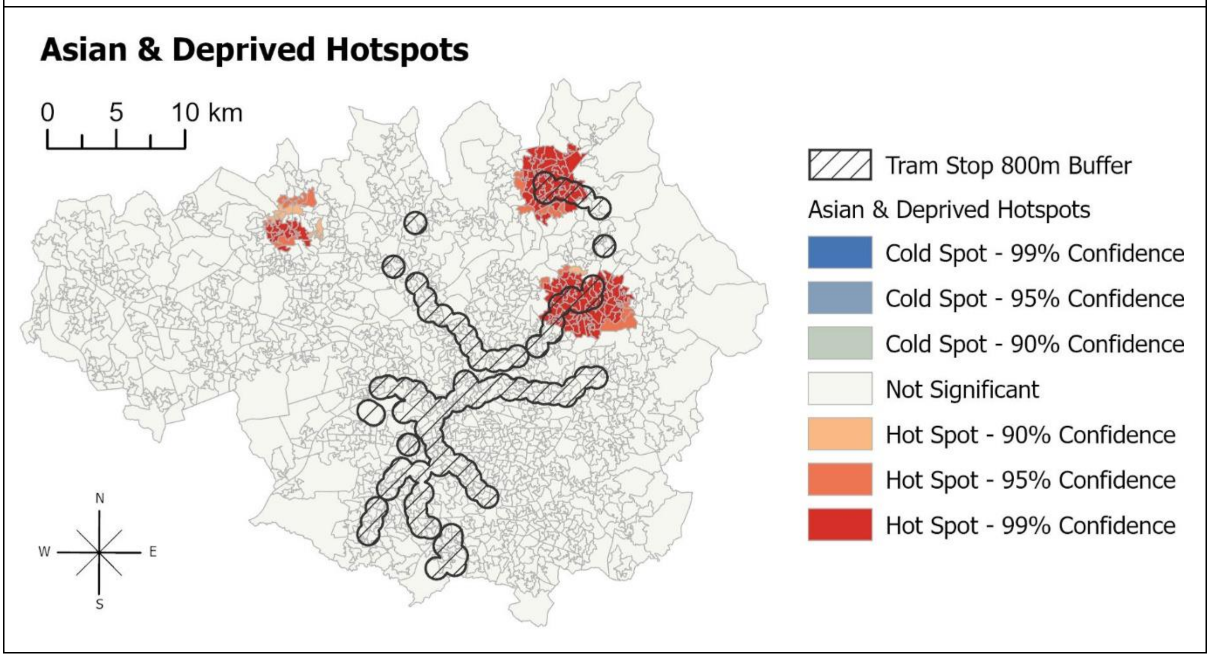
Appendix 1: Ethnic Minority and Deprived Hot Spot Maps per Ethnicity

Ethnicity and deprived hotspot maps are displayed for each ethnic minority group, with each map showing areas within walking distance of a tram station.






Mixed & Deprived Hotspots
0 5 10 km
Tram Stop 800m Buffer
Mixed & Deprived Hotspots
Cold Spot - 99% Confidence
Cold Spot - 95% Confidence
Cold Spot - 90% Confidence
Not Significant
Hot Spot - 90% Confidence
Hot Spot - 95% Confidence
Hot Spot - 99% Confidence
N
W
E
S


Asian & Deprived Hotspots
0 5 10 km
Tram Stop 800m Buffer
Asian & Deprived Hotspots
Cold Spot - 99% Confidence
Cold Spot - 95% Confidence
Cold Spot - 90% Confidence
Not Significant
Hot Spot - 90% Confidence
Hot Spot - 95% Confidence
Hot Spot - 99% Confidence
N
W
E
S

Appendix 2: Population Demographics Outside of Tram and Cycle Parking Service Areas

The following tables show the complete extent of results when addressing population outside of tram and cycle parking infrastructure service areas (walking distance). Brief discussion points have been included

<table>
<tr><th>Data Set</th><th>Percent of Entire Population Outside Tram 800m Buffer (%)</th><th>Percent of Entire Population Outside Cycle Parking Infrastructure 500m Buffer (%)</th><th>Population Demographic</th><th>Percent of Population Demographic Outside Tram 800m Buffer (%)</th><th>Percent of Population Demographic Outside Cycle Parking Infrastructure 500m Buffer (%)</th><th>Discussion Point (s)</th></tr>
<tr><td rowspan="2">Gender Data Set
(ONS, 2019)</td><td rowspan="2">69.70</td><td rowspan="2">37.09</td><td>Female</td><td>70.08</td><td>37.43</td><td rowspan="2">In both cases, a greater percentage of the female population is outside the service of trams and cycle parking. However, the difference between sexes is minimal, so the gender disparity is not particularly significant.</td></tr>
<tr><td>Male</td><td>69.31</td><td>36.76</td></tr>
<tr><td rowspan="5">Ethnicity Data Set
(nomis, 2013)</td><td rowspan="5">70.57</td><td rowspan="5">37.75</td><td>White</td><td>73.81</td><td>39.86</td><td rowspan="5">Ethnic minorities are serviced more than proportionally compared to the whole of GM because these populations are centred around Manchester,</td></tr>
<tr><td>White Female</td><td>74.06</td><td>40.05</td></tr>
<tr><td>White Male</td><td>73.55</td><td>39.66</td></tr>
<tr><td>Mixed</td><td>59.87</td><td>26.46</td></tr>
<tr><td>Mixed Female</td><td>59.85</td><td>26.43</td></tr>
</table>

			Mixed Male	59.89	26.49	the largest urban settlement in the area, as theory predicts. Despite the concentration of ethnic diversity around central Manchester, all ethnicities have over half the population in GM outside of walking distance to a tram stop. Ethnic minorities are serviced more than proportionally by bike parking infrastructure. Both Black and other ethnicities have the best access to parking facilities spatially. There are some discrepancies between gendered access within ethnicities, but to a minor extent.
			Asian	51.79	29.70	
			Asian Female	51.53	29.99	
			Asian Male	52.03	29.43	
			Black	56.60	19.89	
			Black Female	56.83	19.82	
			Black Male	56.38	19.96	
			Other	52.84	17.61	
			Other Female	52.30	17.80	
			Other Male	53.21	17.48	
Deprivation Data Set	70.09	37.20	60+ Years	75.47	41.30	In both tram and cycle parking infrastructure servicing, older people have
			0-15 Years	69.35	37.91	

(Ministry of Housing Communities and Local Government, 2019)						significantly less access proportionally, while children's access mirrors the general population. This may be because of older populations being significant around the edges of GM, further from urban centres.

Data Set	Percent of LLSOAs Outside Tram Buffer (%)	Percent of LLSOAs Outside Cycle Parking Infrastructure Buffer (%)	LLSOA Deprivation Percentile	Percent of LLSOAs In Deprivation Decile Outside Tram Buffer (%)	Percent of LLSOAs in Deprivation Decile Outside Cycle Parking Infrastructure Buffer (%)	Discussion Point(s)
Deprivation Data Set (Ministry of Housing Communities and Local Government, 2019)	72.64	40.75	1st	62.66	34.02	The most deprived decile has a relatively high proportion of service by trams, and the least deprived the least levels. However, 2nd and 3rd deciles are serviced poorly. Cycle parking infra shows more disparity – all deciles have over
			2nd	74.29	41.22	
			3rd	73.37	38.69	
			4th	62.34	29.22	
			5th	72.99	40.88	
			6th	69.49	48.31	
			7th	83.08	46.92	
			8th	79.58	53.52	

			9^{th}	89.68	53.17	half the LLSOAs serviced.
			10^{th}	80.61	36.73	

Appendix 3: Cycle Parking Types in Greater Manchester

Outdoor Cycle Parking

Outdoor parking locations, Figure 14, are available in public areas and are free to use. Different locations have different capacity, and parking is not guaranteed to be undercover. These are the most common type of cycle parking in GM.

Bike Lockers

Bike lockers, Figure 15, are a more secure cycle parking option. There is a fee of £10 for two years of unlimited access to any lockers in GM, which is provided with a unique padlock key. Bikes are locked inside the locker which provides some degree of shelter, and the user must provide their own padlock for the locker. If no lockers are available at a given location, bike racks are provided as an alternative. Different locations have different capacity.

Cycle Hubs

Cycle hubs, Figure 16, are the most secure method of cycle parking. Cycle hubs purpose-built enclosed rooms for cycle storage. A cycle stand is provided to lock the bike to, and a small locker provided for personal items (own padlock must be supplied). They are covered by CCTV surveillance and require a swipe card to enter. Belongings cannot be left in hubs overnight. Opening times apply at the hubs, often from 0600 to 2359. Different locations have different capacity. Membership costs to cycle hubs vary:

- £10 per year to park at any cycle hub except MediaCityUK and City Tower, first come first served basis
- £100 per year/£10 per month to park at City Tower or MediaCityUK, guaranteed parking space; and any other hub, first come first served
- £200 per year/£20 per for the same permissions as above, in addition to the use of shower facilities at City Tower or MediaCityUK
- £10 for 10 visits at City Tower, first come first served basis

Figure 14. Outdoor cycle parking locations at the University of Manchester campus (left) and along Oxford Road, Manchester (right). Author's own photos, 2020.

Figure 15. Cycle lockers at Old Trafford tram station. Image sourced from Google Maps (2019).

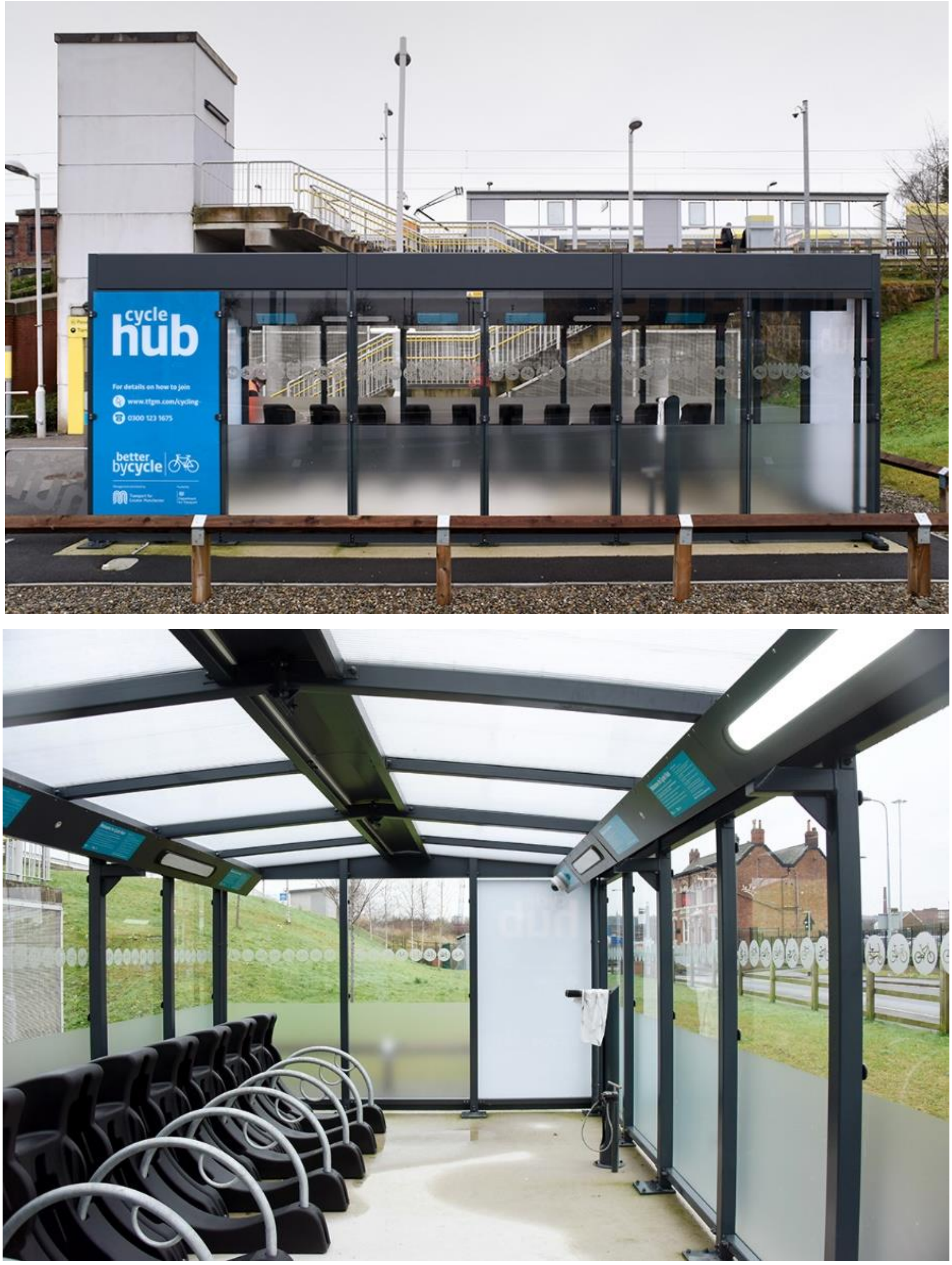


Figure 16. Cycle hub exterior (top) and interior (bottom) at Hollinwood tram station. Image sourced from Broxap (2015).