The use of mobile phone technology in the collection of user perceptions of walkability along pedestrian routes from public transport in Cape Town and New Delhi

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This work is dedicated to my Mother, LJN
for her love, strength and belief in me.

Abstract

Background

Cities in developing countries are upgrading their public transport at unprecedented rates in efforts to create transportation systems that are more sustainable and equitable. South Africa and India are seeing massive investments in features that are improving operational characteristics of public transport systems. However, more effort will need to be expended in improving public transport access/egress conditions, in order to ensure that public transport is a competitive alternative to door to door motorised transport trips. Particular attention will need to be paid to non-motorised transport, as it is the most common means of access/egress for people in the Global South, despite conditions for pedestrians being uncomfortable and a threat to their safety and security.

Traditional methods of evaluating the accessibility of public transport stations have been found to be overly mechanistic. Through improved operationalisation of built environment factors and crowd sourcing user perceptions, a better understanding of how supportive the built environment is for walking can be achieved.

Study details

This study presents the following:

1. The development and testing of an Android mobile phone application, along with its associated online dashboard. The mobile phone application allows for the collection of data on the pedestrian experience and is a shift away from the mechanistic approach to understanding pedestrian challenges. Using the application, users rate their walking environment along dimensions of safety, security, infrastructure and comfort, while geo-tagging walking routes. The dashboard is used to store and visualise the users' perception data and multimedia captured using the mobile phones.
2. A proposed spatial analysis method, using Spatial Clustering Algorithms for analysing data captured using the mobile phone application. As crowd sourced datasets are very large, filtering approaches may not be capable of distinguishing between outliers and clusters of high/low ratings. Thus, more robust analysis methods are required in order to extract meaningful insights.
3. The piloting of the application and proposed spatial analysis method in Cape Town and New Delhi

Results of pilot studies

Six public transport locations across Cape Town and New Delhi were chosen for the pilot studies. Survey facilitators, with the application preloaded on mobile phones, intercepted public transport users travelling along their egress trips. Respondents were asked to make use of the application to report on their perception of the walking environment as they were escorted to their destination.

Data from 538 egress trips were mapped and analysed. The application was able to capture nuances associated with the pedestrian experience, which may not be possible using traditional approaches. The challenges identified by respondents ranged from pedestrian infrastructure not being accessible due to road traffic violations by motorised transport, to pedestrians having to deal with filthy walking environments that made walking uncomfortable.

Future work would need to consider the incorporation of video into the mobile application. Video would allow for the capturing of dynamic challenges faced by pedestrians, such as aggressive behaviour by motorists, which cannot be captured using pictures and voice notes. An addition consideration for future work would be to make the application available to the general public so that data can be truly crowd sourced. This would require investment in marketing the application and the study. Alternatively, future studies may look to make use of systematic random sampling of egress trips and larger sample sizes, in order for results to be representative.

Acknowledgements

I would like to thank my supervisor A/Prof. Mark Zuidgeest. This research has been an incredible adventure, filled with rich opportunities for growth and learning. It has been a pleasure getting to know you, and I hope that your passion for growing young people continues. The majority of the time on the project was enjoyable, however, in the most testing times, I could not have asked for a better supervisor. Mark, your support and thoughtful advice kept me marching forward. You afforded me a positive learning environment, and I am indebted to you for incorporating me in this project and helping me overcome all the hurdles I faced in conducting this work.

To my co-supervisor, A/Prof. Marianne Vanderschuren, thank you so much for supporting me and being a sounding board for all the ideas that shaped this research. Our discussions allowed me to take a big picture view of the work that I was doing and think very intentionally about it.

An understanding of the challenges being faced in New Delhi would not have been possible without Prof. Geetam Tiwari, of the Indian Institute of Technology, New Delhi. Thank so much for engaging with me Professor, and thank you to Sneha Lakhotia who piloted the application in New Delhi; and provided the data that was analysed for the Indian public transport sites.

Not having a software programming background necessitated that an external party be brought in to assist with writing the mobile application code. Thank you to the team at KritiSolutions for helping to build and refine the application and the dashboard. It was a long journey, however, I believe the end product was worth it.

Lastly, I would like to acknowledge the help of Val Beaumont, who came in at the 11th hour and helped with editing the manuscript. Thank you so much for the time and effort you put in.

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List of abbreviations

AASHTO-American Association of State Highway and Transportation Officials

API-Application Programming Interfaces

GIS-Geographic Information System

GPS-Global Positioning System

HCM-Highway Capacity Manual

HTML-Hyper Text Mark-up Language

ICT-Information and Communications Technology

JnNURM- Jawaharlal Nehru Urban Renewal Mission

PLOS-Pedestrian Level of Service

MoUD-Ministry of Urban Development (India)

NDoT-National Department of Transport (South Africa)

NLTA-National Land Transport Act (South Africa)

NMT-Non Motorised Transport

O-D-Origin destination

OECD-Organisation for Economic Co-operation and Development

PTA-Public Transport Accessibility toolkit

QoL-Quality of Life

TCQSM-Transit Capacity and Quality of Service Manual

URSA-Urban Road Safety Audit tool

WHO-World Health Organisation

VMT-Vehicle Miles Travelled

1 Introduction

1.1 Background to Study

Sustainable urban transport is gaining traction as policy makers and planners deal with rapid urbanisation in the “Global South” and mounting congestion in the developed world (Nijkamp, 1994; Newman & Kenworthy, 1999). In the infancy of the concept of sustainability in the transportation sector, professionals in the industry looked to solutions such as improvements in fuel efficiency of vehicles and associated reductions in emissions (OECD, 1996), assuming that the role of the automobile in society’s mobility was not to be questioned. However, such an approach has been found wanting, and there has been a push towards promoting public as well as non-motorised transport, in order to achieve sustainable mobility (Banister, 2005; Banister, 2008; Hull, 2008; Santos, Behrendt & Teytelboym, 2010). This shift is being espoused in order to achieve social justice and environmental sustainability goals, among others; as auto-centric societies do a disservice to members that are not wealthy enough to own private motorised transport (Banister, 2008; Cervero, 2013).

1.1.1 The emergence of sustainable urban transport policy

In South Africa, a developing country in the southern hemisphere, the sustainable urban transport agenda has culminated in a legislative framework that makes the integration of land use and transportation a statutory requirement, under the National Land Transport Act 5 of 2009 (NDoT, 2009). This requirement serves as a formal recognition of influence that built environment settings have on travel behaviour. Further, the role that public transport has to play in addressing social justice issues within the South African context was formally espoused with the publication of the National Department of Transport’s 1996 White Paper on National Transport Policy. The White Paper set the tone for transportation planning in South Africa and explicitly stated that the transport sector had a role to play in acting to meet the basic needs of South Africans in an inclusive manner, as well as “correcting spatial distortions” that are a legacy of the apartheid government (NDoT, 1996)

In India, a developing Asian nation experiencing rapid rates of urbanisation, the Ministry of Urban Development’s (MoUD) Urban Transport Policy, which came into effect in 2006 (MoUD, 2006), has formally recognised the need to integrate land-use and transport planning so as to foster sustainable urban development. However, some would contend that cities across Asia, have historically developed in line with the integrated land use and transport planning principles such as mixing of land uses and high rates of pedestrian and non-motorised transport (Tiwari, 1999). However, to formalise integrated planning access to key urban development funding sources such as the Jawaharlal Nehru Urban Renewal Mission (JnNURM), require that planning authorities adopt sustainability principles and priorities investments in public transport (Tiwari, 2007).

In spite of policy recognition of the need for sustainable urban transport solutions and the associated legislative frameworks, sustainable transport alternatives face major challenges in South Africa and India. A legacy of under investment in public transport infrastructure has led to public transport being viewed as inferior and largely used by marginalised groups within societies of the Global South. With the idea that motorised vehicles are the primary consideration for transportation planners and following the western development agenda rooted in modernisation theory, transportation projects in the developing world have had a bias towards motorised transport (Simon, 2002; Pendakur, 2011)

Large investments in public transport are now being made, however, the majority of these are going into dedicated public transport rights-of-way, improved vehicles and boarding procedures/ticketing systems. These changes are likely to improve the operational characteristics of public transport. However, one of the hallmarks of the sustainable urban transport agenda, is that it calls for a holistic approach to planning, charging planners to also consider "conditions for non-motorised modes" (Kenworthy, 2006). This requires an acknowledgement of the multi-modal nature of every trip that makes use of public transport, by considering walking as a legitimate mode of transport. These considerations speak to the theme of truly integrated transport, and the importance of the convenience of public transport access and egress trips is starting to be advocated (Crockett & Hounsell, 2005)

Dedicated right-of-way for pedestrians is of paramount importance, however, a broad list of dimensions that contribute to the pedestrian experience, such as aesthetics and comfort are starting to be considered (Schoon, 2010). Research into Transit Oriented Design (TOD) has maintained that circuitous access/egress routes may deter pedestrians from choosing to walk (Canepa, 2007). Environments where the design of the built environment puts people's safety and security at risk may further constrain walking access/egress trips (Wallace et al., 1999; Loukaitou-Sideris & Fink, 2009). These factors fall under the gamut of what makes the environment, built or natural, easy and pleasurable to walk in; and put together have been referred to as walkability. In line with this growing literature base, calls have been made to re-design transportation systems from the perspective of pedestrians in both South Africa and India (Behrens, 2002; Behrens, 2005; Tiwari 2002).

1.2 Research Problem

Any effort to redesign transportation systems from the perspective of pedestrians requires an assessment of the challenges that exist. Historically, little attention has been paid to the presence/state of pedestrian infrastructure, the actual distances covered by pedestrians in accessing public transport, along with the safety and security characteristics of pedestrian access/egress routes (Clifton & Muhs, 2012). This has been driven largely by the use of regional travel models in transportation planning, which have been developed at resolutions that focused on trips, as opposed to tours or activities. According to Clifton and Muhs (2012), such regional, trip based models, are ill-equipped to capture the nuances of non-motorised modes.

In environments that have prioritised motorised transport over other modes, pedestrian access and egress are expected to be challenging. Rietveld (2000a) asserts that the entire trip chain "from residence to place of activity" influences the market potential of public transport; as the poor performance of trip segments may influence perceptions of the entire trip (Murray, 2003; Moniruzzaman & Páez, 2012). Assessing the degree to which the built environment supports/degrades walking, along with routes to public transport can allow for targeted transportation planning.

Tools employing GIS analysis have been developed to identify locations where public and non-motorised transport needs to be prioritised (Vajjhala & Walker, 2010; Beukes, Vanderschuren & Zuidgeest, 2011; Devkota, Dudycha & Andrey, 2012). However, improved micro-level assessments of facilities connecting pedestrians to stations need to be incorporated with such transport corridor analysis tools. Conventional approaches to assessing the micro-level quality of pedestrian trips rely on quantitative, objective measures (sidewalk widths, pedestrian green time) and fail to fully incorporate the influence of the built environment on pedestrian access/egress trips (de Cambra, 2012). Subjective factors such as user perceptions are postulated to add insight to the appreciation of the complexity of pedestrian behaviour (Livi-Smith, 2008). Such user-based approaches allows for the inclusion of nuanced understanding of the walking environment, and support the unpacking the structural and agential dimensions that may influence walking behaviour (Blacksher & Lovasi, 2012). One may find that agents have the motivation to engage in walking or abide by road traffic rules (e.g. not jaywalking); however, systematic disregard for pedestrians in an auto-normative environment may present structural deterrents.

1.3 Research Aims and Objectives

Innovative solutions are required for the collection of data on access/egress trips, as transportation authorities deal with increasing budgetary pressure. Mobile phone technology allows for the near real time collection of data on walking routes as well as geo-referencing response data (Clifton & Muhs, 2012). By making use of mobile phones processes can be automated in order to reduce respondent burden, and there are opportunities for including media that may support understanding of subjective qualities of the walking environment. As smartphone penetration rates increase exponentially in across sub-Saharan Africa and India (Watkins, Kitner & Mehta, 2012; Stork, Calandro & Gamage, 2014), deploying such solutions will become more appealing in comparison to traditional surveys.

1.3.1 Aims

The overall aim of this research is the development of a tool for the appreciation of the walkability challenges faced by pedestrians along public transport access/egress trips. The aim is to build this understanding through incorporating public transport users' perceptions of the dimensions of walkability, thereby encouraging user participation.

1.3.2 Objectives

To meet the research aim, the core objective is the operationalisation of mobile phones in the collection of public transport user assessments of walkability along access/egress routes. A further objective is the establishment of an analysis framework, which makes use of spatial statistical tools in the processing of the spatial data collected. The four sub-objectives for this research are namely:

1. Review of literature related to
    a. The pedestrian experience in urban areas and the threats faced while walking
    b. Public transport access/egress planning
    c. The development of the concept of walkability
    d. Applications of mobile phones in transportation planning
2. Development of a mobile phone application that:
    a. Utilises the location aware capabilities on mobile phones.
    b. Allows for in-app surveying of public transport users' perceived levels of "walkability".
3. Investigate spatial statistical tools
4. Pilot the mobile phone application in Cape Town and New Delhi

1.3.3 Research Questions

The following are the key research questions that have been identified in order to achieve the objectives set out in section 1.3.2

1. *What are the core issues (exposure to risk, planning, geometric design,) associated with walking in South African and Indian cities?*
2. *What is the relationship between walking and public transport when considering access/egress trips, and how has this relationship been planned for?*
3. *What is walkability and how is it assessed?*
4. *How has mobile phone technology been leveraged in transportation planning?*
5. *How can mobile phones be used in the collection of walkability data, and what is the best architecture be for such an application?*
6. *Which locations in Cape Town and New Delhi would provide for a variety of walkability challenges for the testing of the mobile application*
7. *How can spatial statistical analysis be used to analyse walkability data collected from fieldwork?*

1.4 Scope and limitations

The scope of the study includes identifying the core issues associated with walking and pedestrian public transport access/egress in South African and India cities. The development of an Android application, a web-based dashboard and piloting their use. There are multiple operating systems available for the development of the applications; however, due to time and funding limitations, the Android platform was chosen.

The research only piloted the tool at six public transport stops across Cape Town and New Delhi. The challenges that were identified are restricted to those present along the revealed routes of users that were intercepted on the egress trips. Assuming that pedestrians make trade-offs to maximise travel utility, restricting the scope to revealed egress routes might be a limitation, as the most challenging routes are avoided if the best routes are accessible. However, mapping such behaviour may allow planners to identify instances where pedestrians are systematically avoiding specific streets.

At present the mobile application is limited to an evaluation of the micro-level built environment. Walkability operates at multiple levels, however, limitations in the availability of GIS built environment data for New Delhi meant the study could not incorporate an evaluation of both the mesoscopic and microscopic built environment. Further, numerous micro built environment metrics that have been developed, however, only a subset of the measures could be incorporated in this research in order to limit respondent burden.

Crowdsourcing walkability data would have been the best field-testing of the application. However, this would require the most resources in order to recruit study participants. Further, there would be a great deal of uncertainty regarding the number of participants that could participate, given the short research period. Another approach would have been to preload the application on mobile phones and recruit people to take the phones and perform assessments. However, monetary limitations meant that there were only five test phones available for the study, thus, the process of handing phones out to participants and then redistributing them would have led to a lengthy data collection process. Due to the limitations in the two methods discussed, the research made use of intercept surveys at public transport stops, respondents were introduced to the mobile app, which was preloaded on the five phones, and requested to use it to report walkability along their egress trip while being escorted by survey facilitators. Upon reaching the destination and finishing the walkability assessment, survey facilitators would then walk back to the station and intercept further respondents.

1.5 Research Outline

This thesis opens with an introduction giving some background on the new sustainable transport planning paradigm. A description of the research problem and key research questions is given, along with a section on the scope and limitations of the study.

Chapter 2 is a literature review presenting challenges borne out of the neglect of walking in the transportation planning practice. It then shows how integral walking is for public transport and gives an exposé of the limitations of tools that have been used to evaluate pedestrian access/egress to public transport stations. Research on the influence of dimensions of the built environment on walking, and the elements within these that improve walkability are treated. This is followed by a presentation of the opportunities that mobile phones present in collecting data to improve the understanding of these dimensions. Lastly the use of Spatial Statistical Analysis in determining statistically significant spatial clusters of high/low walkability ratings is presented. Chapter 2 informed the conceptualization stage shown in Figure 1

Chapter 3 presents the methodology employed, detailing the development of the mobile application, the fieldwork conducted to collect public transport user perceptions of walkability, and the analysis framework using Spatial Statistical Analysis

Chapter 4 presents the beta mobile phone application that was used for this study, listing the associated questions, the functionality, along with the online dashboard for data display and retrieval.

Chapter 5 presents the case study sites where the beta mobile application was field-tested in Cape Town and New Delhi.

In Chapter 6, an analysis of the data collected from the mobile phone field tests is discussed. An exploration of the walkability dimension with the poorest performing element is done for each case study site using Spatial Statistical Analysis to identify cluster of low/high scores along respondent egress routes.

Chapter 7 gives the concluding remarks, providing a summary of the value of the tool and the experience from field-testing it, along with recommendations for future work.

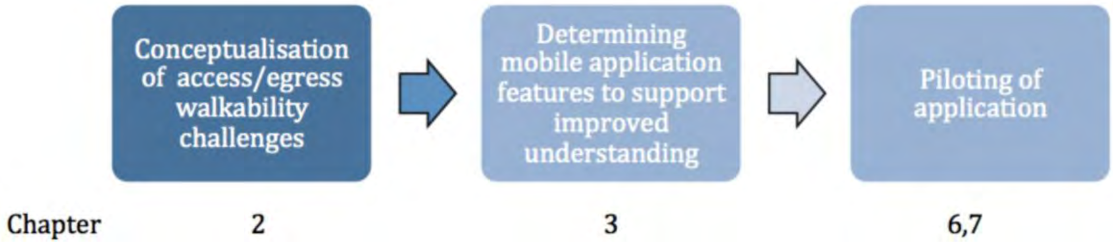


Figure 1: Research approach

2 Literature Review

Understanding the degree to which Transportation Planners have neglected walking for much of the post-war period, allows for an appreciation of the challenges associated with walking as an access/egress mode of transport. Technological advances and the desires of urban populations led to a waning of the importance of walking as a consideration by transportation planners (Newman & Kenworthy, 1996; Amato, 2004). Neglect soon became contempt as pedestrians in industrialised countries were viewed as individuals "separated from [their] vehicle, causing troubles to those who are inside theirs" (Gantvoort, 1971). However, in the last two decades, this stance has been revisited due to a disenfranchisement with what is an auto-normative paradigm. While improving the quality of public transport in order to provide citizens with a competitive alternative to private vehicles, planners are beginning to recognise how integral walking is and there is a growing literature base on how environments can be designed to serve pedestrians better.

Accordingly, this chapter presents the challenges borne out of Transportation Planning's focus on the automobile. It then moves on to describe the link that public transport has with walking as an access and egress mode, as well as presenting the tools used to evaluate access/egress trips. An exposé of the built environment-walking Nexus follows, detailing some of the considerations that are not incorporated in current access/egress evaluation tools. An examination of the literature supporting the use of Information and Communications Technology (ICT) survey methods to aid transportation planners then follows. Finally, the chapter closes with a showcasing of the promise of Spatial Statistical clustering algorithms, in assisting planners explore the large data sets produced by employing ICT solutions.

2.1 Transportation planning's abandonment of walking

Increased mobility facilitated by automobiles has come with significant economic benefits and unprecedented personal freedom for those that can afford motorised transport (Burns, Jordan & Scarborough, 2013). Such qualities are appealing and a core assumption was that private motor vehicle ownership would reach near universal levels, as such, the only requirement on Transportation Professionals would be to match this increased demand with expansions in road space (Behrens, 2005). Thus, due to this assumption, little attention was paid to other modes of transportation. However, this stance has come into question, with research into Transit Oriented Development (TOD) investigating the conditions that contribute to the willingness and ability of people to walk to transit.

This section details how these practices have precipitated what is a road traffic accident epidemic in the developing world. It presents literature that problematizes the current road design practices, which have resulted in incompatible movement networks that do not take into consideration the needs of pedestrians.

2.1.1 Human loss due to the neglect of non-motorised transport

One of the primary indicators of the challenges being faced by pedestrians is a review of the road fatality statistics. These show that developing countries have suffered disproportionally, with non-motorised users bearing the brunt of this suffering. Africa has the highest road traffic fatality rate at 24.1 per 100,000, and on the continent, 38 % of all road traffic fatalities are pedestrians (WHO, 2013). It is often vulnerable road users such as young children that are the fatalities in developing countries, with 26 child deaths/100 000 in South Africa being pedestrians involved in road traffic crashes (UNEP, 2010). Looking specifically at Cape Town, South Africa, Figure 2 shows that although there is a general downward trend in the total number of road traffic fatalities, pedestrians have accounted for the majority of casualties in the period 2007-2011.

In the case of India, it is estimated that there were 8,503 fatalities in New Delhi in the period 2006-2009, with over 50% of these being pedestrians (Rankavat & Tiwari, 2013). Compounding this reality is the fact that New Delhi public transport stops, where pedestrian volumes are high, are considered to be among some of the most dangerous areas for pedestrians. This risk is due in large part to poor planning practices, as many bus stops are at the base of flyovers and major intersections, bringing users into close contact with cars as they dis/embark (Nandi, 2014).

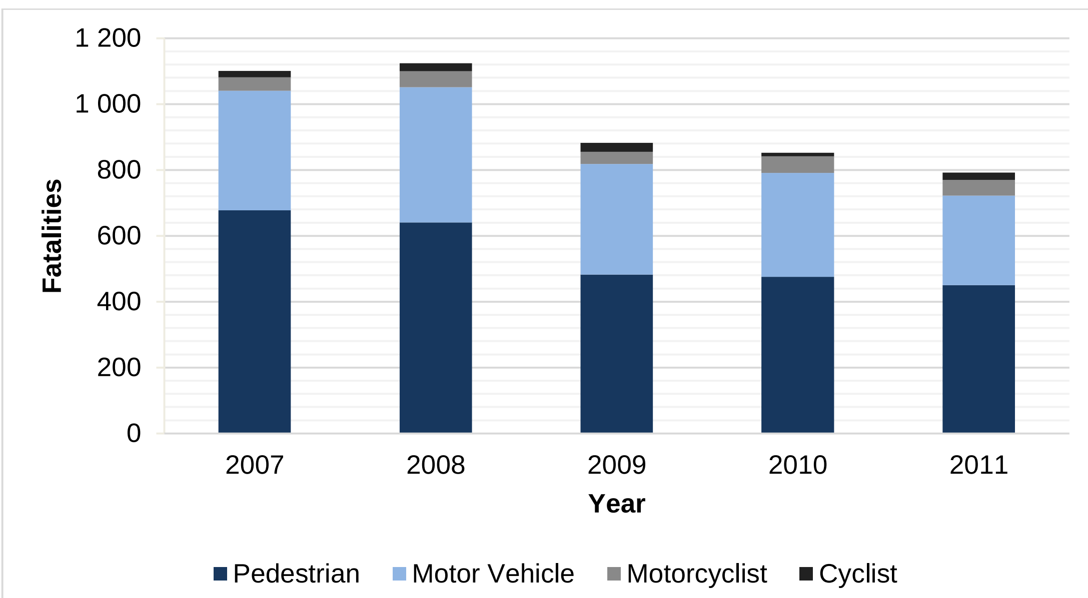


Figure 2: Cape Town road traffic fatalities by mode 2007-2011, Adapted from Jobanputra (2013) ***Source: City of Cape Town and Forensic Pathology service***

Although these statistics are striking, they may well be conservative estimates of the scale of the problem. Law enforcement officials keep road traffic accident statistics, and there is little coordination with following up once victims pass into the health services system, and possibly die as a result of their injuries (WHO, 2013). Also, looking solely at fatalities masks the plight of victims who have experienced debilitating injuries and are no longer capable of sustaining their livelihoods.

Sinclair and Zuidgeest (2015) state that in emerging global cities in the developing world, pedestrians often "lack real choices" regarding their movement networks and this may be precipitating the burden of human loss. This is to say that pedestrians may not be recklessly endangering themselves, rather, the manner in which transportation systems have been designed are doing a disservice to people on foot.

Rising vehicle ownership levels may be driving a focus on vehicular infrastructure, while investment in road space for vulnerable road users lags behind. These incompatible movement networks have their roots in a Transportation Planning paradigm that has focused almost exclusively on motorised transportation, and an exploration of the history of the design of transportation networks shows how entrenched this paradigm is in transportation planning and traffic engineering practice.

2.1.2 Incompatible transport networks in cities

Before the advent of motorised transportation, cities were largely pedestrian oriented (Newman & Kenworthy, 1996). Many commuters in South African cities walked or took public transport to work and school in the early 1900s (Wall, 2010). A majority of trips being made by walking was a trait displayed in many Asia cities too, where streets had multiple functions and a bias towards foot traffic (Mateo-Babiano & Ieda, 2007). However, there was a sharp departure from this in industrialised countries as motorised transport allowed people to satisfy their desire to move to enclaves further away from the noise and grime associated with the inner city. This was done while remaining in relative (time) proximity to economic opportunities. These cities could spread out 30 km while motorised transportation speeds allowed people to maintain their mobility (Newman, 2003). However, the sheer distances meant that walking, on its own, was no longer feasible as a primary mobility option, consequently, movement in cities began being conceptualised as being made up of door to door motorised transport trips.

In response to the growth in motorised transportation and atrocious road traffic accidents involving motorised transport and pedestrians, there was a move towards the segregation of transportation modes. This had merit, however, a functional hierarchy of roads was established, which, according to Behrens (2002) primarily focused on the stages of an automobile trip. This hierarchy was created by applying the law of inverse correlation between movement and access (Hebbert, 2005), where movement areas were to be high speed while areas where people engaged in activities, necessitated low speeds for improved access. The dendritic links of the hierarchy resulted in neighbourhoods being bound by high order roads with circuitous routes within neighbourhoods in order to prevent fast moving through traffic as shown in Figure 3. Although these detours may not be felt in automobiles, considerable effort is required of pedestrians to traverse them. As a result that non-motorised were effectively restricted to travel within neighbourhood cells, with fragmented rights of way that provided little by way of access between "activity" locations. Hebbert (2005) states that at a conceptual level, this functional hierarchy fit well with the Weberian bureaucratic model, and defined a division of labour among built environment professionals with highway engineers defining the spaces that land-use planners could then zone and the developer could then invest. This separation of functions is at odds with the integrated approach espoused in new policies that are being adopted by Transportation Planning Authorities in advancing the development of Sustainable Transportation Systems.

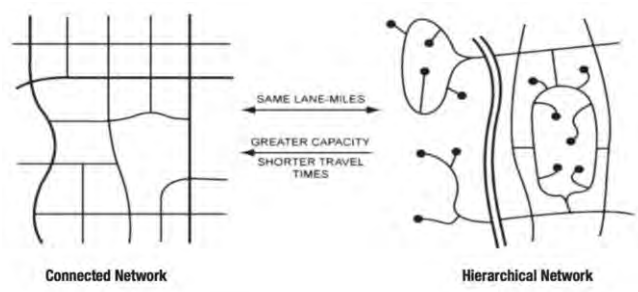


Figure 3: Connected vs. Hierarchical network

The functional hierarchy approach gained popularity with the publishing of *Traffic in Towns,* the Buchanan Report of 1963, which, according to Parkyn (2001) synthesised the core ideas of the time regarding the options available to accommodate "the pursuit of greater personal mobility and economic growth". Parkyn (2001) argues that the rise in popularity came with a misinterpretation of Buchanan's main thesis. Having "full access to front doors", which cars facilitated, would require massive infrastructure investment, as cities have a motorised transport carrying capacity *increasing of which would come at further cost due to the a loss of character of cities* [emphasis my own] (Parkyn, 2001). However, this led to engineers increasing carrying capacity along roads to improve throughput, causing quality of life problems for people in urban areas.

Behrens (2002), details how within South Africa, the guidelines for the design of movement networks were influenced by the ideas that were pervasive in the period 1920-1970. As such, the idea that motorised vehicles are the primary consideration for transportation planners became entrenched, and precipitated the neglect of all other modes in South Africa. With infrastructure funding agencies only recently starting to have debates about shared road infrastructure for all road users, pedestrians included (United Nations Environment Programme (UNEP), 2010), it is fair to assume that many of the projects that have been funded in the past have had a bias towards motorised transport.

Incompatible movement networks represent an abandonment of pedestrian at a broad planning level, however, even at the street scale, the premise that roads were to be designed primarily to service vehicles was embodied in typical road cross-sections. Lo (2009) reviewed the

2004 AASHTO Policy on Geometric Design of Highways and Streets, in which the importance of designing for pedestrians is professed. However, much of the guideline recommends the design of roads according to their vehicular function. As a result, Lo (2009) argues, professionals are not presented with a way for reconciling streets that have high non-motorised and vehicular presence; with the result being that pedestrians inadvertently get compromised if there is strict adherence to the guidelines. In the latest AASHTO guidelines, not much is different and the justification for sidewalk provisions for pedestrians is if there is potential for vehicle-pedestrian conflict (American Association of State Highway and Transportation Officials, 2012). This shows the latent vehicle bias in the treatment of road space, with infrastructure needs of pedestrians not being considered on their own merits.

Beukes (2011) states that the challenge of ensuring pedestrians have adequate provision in the case of South Africa, is the same, as the South African guidelines leave the addition of pedestrian amenities for development projects up to the judgement of design professionals. According to Beukes (2011), pedestrian provisions are often the first, and easiest, items to be struck from road designs to reduce the cost of projects. In the case of New Delhi, Parida and Parida (2011) state that much is the same with pedestrian infrastructure being an afterthought in the planning process, and whatever provision that is present, being in a state of poor maintenance.

The publishing of the 2013 Minimum Standards for Civil Engineering Services in Townships, by the City of Cape Town, which designers in the city have to use in conjunction with the 2000 CSIR Guidelines for Human Settlement Planning and Design (Red Book), provides redress to this issue. The City has presented preferred cross-sections that show pedestrian infrastructure and charges designers to think about movement networks, This may address issues of missing network links for pedestrians, while vehicles have continuous provision made available to them (CCT, 2013a). These are positive moves for new developments that are in the planning stages. However, much remains to be done to identify the areas where existing movement networks are incomplete and pedestrian provisions are poor.

With recognition of the challenges faced by pedestrians due to incompatible movement networks, investments in improvements are going to be required. These investments will need to be guided by what best serves pedestrians, but perhaps most importantly, Transportation Planning professionals will need to leverage them in supporting the investments that are being made in public transport systems.

2.2 Public transport access and egress

One of the provisos of using public transport is that it has to be combined with other modes to satisfy mobility needs. This requirement has been termed the "First/Last" Mile problem and there is a growing recognition of the gaps that exist in countries such as South Africa in rising to the challenge (Labuschagne & Ribbens, 2014). The gaps in infrastructure and integration have been the result of a tendency to conceptualise transportation in a unimodal fashion (Nijkamp, Priemus

& Shefer, 2000), with responsible custodians ensuring that their respective mode meets performance standards and not considering integration and associated synergies/dependencies (Booz Allen, 2012). This section shows how important the integration of modes is and details how some of the tools utilised by Transportation Planners in evaluating the degree of integration may not be operationalising key dimensions that may influence pedestrian access to public transport.

In most instances public transport is combined with non-motorised transport in overcoming the First/Last Mile challenge. This is due to captive public transport users not having readily available access to motorised transport, as well as the asymmetrical availability of motorised transport between origins and destinations, for more affluent choice users. However, Cervero (2001) cites a case in Santa Clara County, California, where at a station with a poor quality pedestrian environment for egress trips, patrons leave a second car at the destination stations in order complete their commute. Such behaviour shows the coping mechanisms of public transport users that have poor walking environments.

The combination of transportation modes that occurs gives rise to the concept of multi-modal travel and Figure 4 shows what is a multi-modal tour, with walking and the bus used as the two modes. However, widely used transportation planning models do not fully account for multi-modal travel, often due to challenges in determining minimum travel thresholds (time/distance) for each mode in order for them to be considered separately (Clifton & Muhs, 2012).

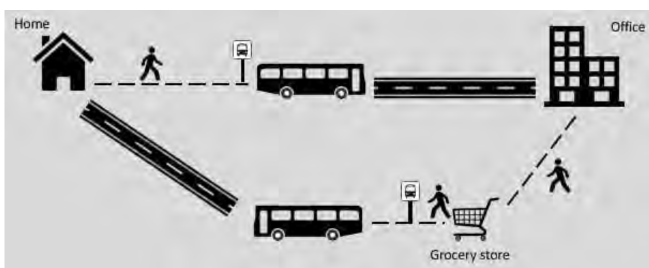


Figure 4: Multi-modal tour combining NMT with Public Transport

European cities are renowned for the inter-modality of their transit systems as well as their reverence of non-motorised transport, Rietveld (2000b) shows that by sheer volume of trips in the Netherlands, walking warrants attention and NMT is complimentary to public transport. Taking a more South African perspective, Behrens (2005) shows that walking is one of the most prominent modes of transport in South Africa, especially in Cape Town, and argues that movement networks need to be (re)-designed in order to accommodate it. The significance of walking as an access and egress mode has also been identified in New Delhi and integrated planning is required as growing public transport use leads to an increase in non-motorised transport use (Mohan & Tiwari, 1999; Tiwari, 2002).

Krygsman, Dijst and Arentze (2004) argue that the access and egress parts of public transport are the weakest and have contributed to the declining levels of public transport use in developed countries. Considering the high number of people that already walk in less mechanised countries such as South Africa and India, due course should be paid to walking in addressing access/egress issues. This is especially important as Transportation Planning Authorities are under pressure in justifying the rolling out of mechanised feeders for access and egress trips (Lewis, 2015a).

2.2.1 The use of catchment analysis in access/egress evaluation

To estimate ridership for planned public transport systems, Transportation Planners have used catchment analysis, usually in a Geographic Information System (GIS) environment, to determine the proportion of people that can access/egress a station. Outputs have been accessibility maps and tables containing the number of potential system patrons. This analysis method is used to determine the locations that are within a station's area of influence. At the most rudimentary level such analysis uses circular buffers as depicted by the typical case in Figure 5. Normally these buffers take the form of concentric circles centred on the transit station, with the associated radii developed based on the distance that patrons are "prepared" to walk when pedestrian access is being evaluated. It is then assumed that for those people that fall within each of the rings, access/egress trips are feasible and that those people form part of the core, primary and secondary catchments for the station.

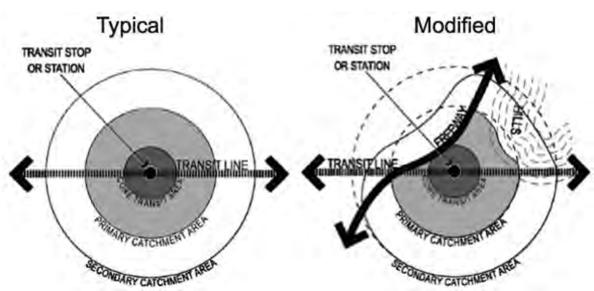


Figure 5: Station catchment areas *Source*: American Public Transportation Association, (2009)

The radii differ depending on the public transport system in use and Table 1 shows typical radii for rapid transit such as BRT and metro systems and local street transit, which operate in mixed traffic. The idea being that people are prepared to walk further to access systems that provide higher levels of accessibility to opportunities e.g. BRT and metro systems can take one further and at a faster line-haul speed, so the disutility of walking a longer distance to enter the system is offset

Table 1: Typical catchment radii by transportation mode. *Source*: American Public Transport Planning Association (2009)

	Local street transit	**Rapid transit**
Core station area	N/A	0.2 km
Primary catchment area	0.2 km	0.4 km
Secondary catchment area	0.8 km	1.6 km

However, environmental factors both built and natural can influence access and egress trips; and some of the factors that lead to the modified radii of the influence areas shown in Figure 5 by the modified case are listed:

1. Station design
   a. Stations that are well integrated into their local environment accord access modes direct access from immediate areas surrounding the station. This can make a station attractive and increase the area of influence
2. Pedestrian environment
   a. Good pedestrian environments including buffers from automobiles, well-lit streets with crossings
   b. Wayfinding signage allows public transport users to orient themselves, assisting users with their journey
3. Topography
   a. Considerable grade change influences the how far users are prepared to travel when accessing public transport
4. Safety/perception of safety
   a. Concerns about safety can limit pedestrian activity

Although the Circular Buffer method aims to make modifications based on the environment in which the transit stop is, there has been some criticism of its use of Euclidian Distances that do not take the configuration of the access/egress networks into account. As a result, it may overestimate how accessible the public transport stop is. Modifications have been made which only consider possible patrons as those within the circular buffer that have a connection to stops through the street network (see Hsiao et al., 1997). However, using such modification does not allow for the identification of streets that can be considered as being poor pedestrian environments that limit access/egress to public transport stations. Features such as dark paths and routes that are prone to flooding routes may engender feelings of insecurity and discomfort, which result in users no longer having “access” to walking routes.

2.2.2 Service Area Analysis

Andersen and Landex (2008) proposed a “Service Area” approach that can modify the area of influence around a public transport stop, using the actual pedestrians transport network used for access and egress trips, as well as through incorporating point impedances such as the time taken to climb stairways. The influence of a bridge and stairway resistance, connecting inaccessible links and requiring added effort respectively, are shown through changes in the size of the station catchment area in Figure 6.

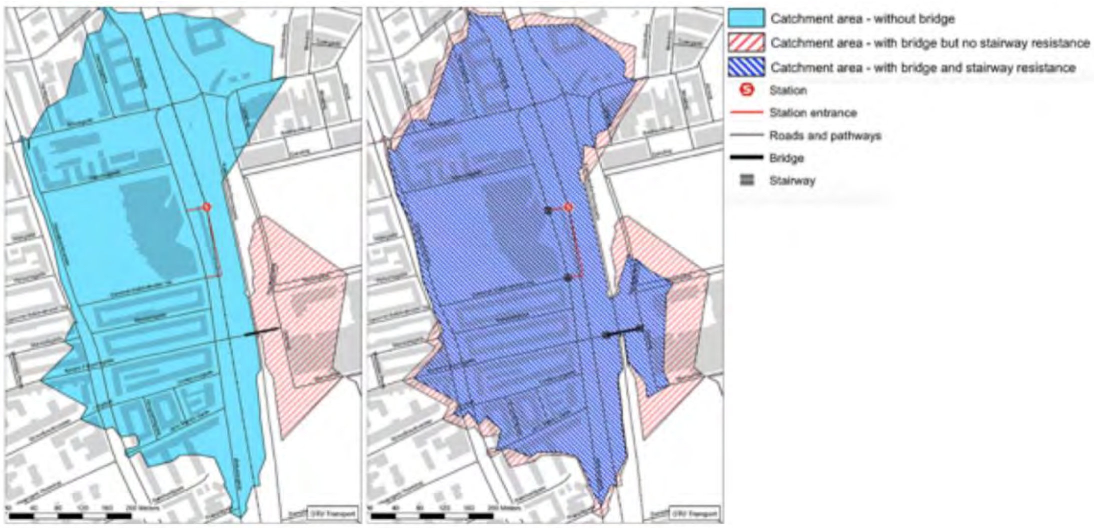


Figure 6: Station accessibility with and without consideration of point resistance, *Source: Andersen and Landex (2008)*

Notwithstanding the merits of the service area approach, through making use of network distances and the inclusion of impedance factors due to infrastructure that is hard to traverse, it has a bias toward time-based penalties. As a result, the method does not fully incorporate the influence of issues such as traffic safety and perceptions of personal security while an individual is walking. Just because a station may be in "time-based" walking distance, it does not necessarily lead to it being accessible. Schoon (2010) argues that, in spite of how well planned and executed routes and environs may be, one junction where a route is viewed as being intimidating or unsafe for pedestrians may result in the whole route being considered unacceptable.

Although mention is made of the influence that the pedestrian environment and rider perceptions may play in the service area of stations, and consequently, where access/egress trips may emanate from, there is poor operationalisation of these factors in the two approaches. The availability of sidewalks and streets that were designed to be easily crossed by pedestrian supplemented time and distances measures in encouraging people to choose to walk for their access and egress trips in a study of Montgomery County, Maryland rail patrons (Cervero, 2001). It is thus incumbent upon Transportation Planning Authorities to add on to time impedances and distances when considering peoples' choice to walk for access/egress trips.

A deeper understanding of what constitutes an inviting environment that supports walking needs to be incorporated in the planning and monitoring of pedestrian public transport access/egress. Empirical studies into how much people walk and where they choose to do this have been used to determine if there is any correlation between environmental features and the activity. Such studies can give insight into the qualities environments need to be monitored and evaluated against in order to support walking access/egress to public transport.

2.3 The built environment and walkability

That the built environment can influence travel demand and behaviour, through being more supportive of sustainable transport alternatives, has long been an attestation of proponents of Transit Oriented Development and New Urbanism (Crane, 1996; Cervero & Kockelman, 1997). The appeal of being able to influence travel demand by changing elements of the built environment has become one of the most researched subjects in urban planning (Ewing & Cervero, 2010) as researchers have looked to determine the levers that influence travel demand and the strength of their influence. This section provides some of the empirical results that show the influence that the environment has on people walking, and provides examples of the kinds of features that have been seen to facilitate this activity.

The built environment as defined by Handy et al. (2002) is a multidimensional concept made up of three elements: Urban Design, the Transportation system and Land use. The Urban Design component is related to the appeal and function of public space, as well as how physical elements within cities should be arranged. The Transportation system refers to the physical infrastructure that constitutes the rights of way e.g. Footpaths, sidewalks and roads, along with their respective level of service. Lastly, the Land use component considers how it is that activities are distributed in space. It is this description that is used for this study and through coordinated efforts; Transportation Planners can have an influence on the first two in supporting walking trips.

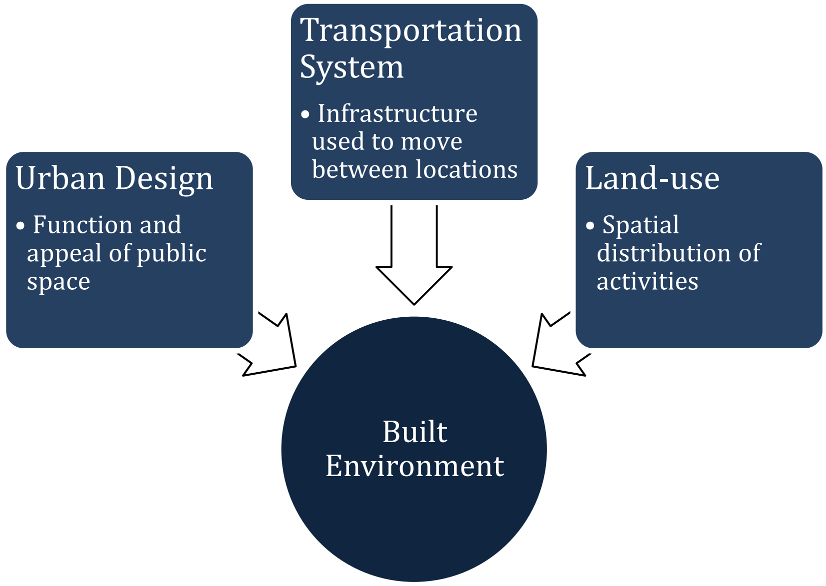


Figure 7: The built environment as defined by Handy et al, (2002)

A lot of the literature covering the relationship between the built environment and travel modes has been informed by the challenges being faced in the developed world, where there have been moves to curb vehicle use and initiate mode shifts to sustainable transport. Inquiries into this relationship were mushrooming as early as the 1970s while research focusing on possible transportation policies came to the fore in the 1980s (Handy, Cao & Mokhtarian, 2005). In line with the neglect of pedestrian travel in research, many studies in the past were concerned with changes in vehicular measures of travel behaviour and demand, with the addition of non-motorised transport in the 90s (Park, Choi & Lee, 2015). Studies employed quasi-experimental designs, examining the differences in walking trips between residents living in neighbourhoods that have built environment characteristics that are theorised to support walking, and those that have qualities that have a bias towards auto-travel and neglect pedestrian needs (Saelens, Sallis & Frank, 2003). The hypothesis tested being that neighbourhoods that are more inviting to pedestrians encourage more walking trips.

The degree to which the "environment", built or otherwise, encourages and supports walking has been termed Walkability (Leslie et al., 2007). The term has gained increasing popularity, however, it has been poorly defined (Southworth, 2005), this is in part due to it being a developing concept that is being shaped by pedestrian research. Adding to the broad definition, Southworth (2005) unpacks what can be considered as being supportive of walking by stating that it is through providing for the safety and comfort needs of pedestrians as well as with connecting them to varied destinations without requiring excessive amounts of effort and time that we may begin to have "Walkable Cities".

This section presents empirical studies that have sought to identify the qualities of the built environment that are correlated with increased walking. Walkability has traditionally been a focus area for transportation planning researchers as well as urban planners. However, in recent decades, Public Health researchers have been building an empirical base so as to inform Public Health policy on active living and its promotion (Bauman et al., 2012).

2.3.1 Conventional transportation literature and the choice to walk

One of the seminal works on the effects of the built environment on travel demand is by Cervero and Kockelman (1997). The study tested the effects of Density, Diversity and Design on trip rates and mode choice in the San Francisco Bay Area, at the census tract geographical scale. The models that were developed in the study, using reported trips from travel surveys, showed that for non-work trips, linear combinations of factors that make up Density and Design (factors shown in Table 2) encourage more non-private automobile trips in a modest, but statistically significant way. Non-private automobile trips is a lumping together of transit, bicycling and walking trips. However, the Design dimension used in the models is made up of elements that related to the quality of the pedestrian environment. Further, each of the non-private automobile modes requires that one either be a pedestrian at some point along their journey (transit and walking) or usually use infrastructure shared with pedestrians (bicycle).

Table 2: Density and Design factors used by Cervero and Kockelman (1997)

Density factors	Design factors
Retail store density	Sidewalk provisions
Activity centre density	Street light provisions
Retail intensity	Block length
Park intensity	Planted strips
Population density	Lighting distance
Walking accessibility	Flat terrain

Saelens, Sallis and Frank (2003), reviewed Transportation, Urban Design and Planning literature, estimating and comparing average walking or walking and cycling trips per week between residents living in neighbourhoods with high/low walkability qualities. Neighbourhoods that were dense, diverse environments and had pedestrian infrastructure i.e. continuous sidewalks, were considered highly walkable. While low walkability was ascribed to environments that had poor street connectivity, low densities and uniform land use. By comparison, the average non-motorised trips rates in the studies reviewed were higher in the neighbourhoods having high walkability qualities than those having low walkability qualities

A meta-analysis of travel demand literature by Ewing and Cervero (2010) found a strong association between the built environment dimensions of land use Diversity and Design with walking. The meta-analysis included seven studies that used intersection/street density and five studies that used the percentage of 4-way intersections to represent the Design variable. The computed weighted average elasticity for each was 0.39 and -0.06 respectively. Land use mix, job-housing balance and distance to a store represented the diversity variable. The computed weighted average elasticity for each was 0.15, 0.19 and 0.25 respectively. The computed weighted elasticity values are modest, further, few of the reviewed studies entered into the meta-analysis due to reporting or methodological discrepancies.

These studies represent the core thesis and approach in the conventional transportation literature. Trips reported in travel surveys, as well as zonal measures of built environment characteristics, have been used to test the relationship between walking and the built environment. The association between walking and land use diversity and density is intuitive as one would posit that the likelihood of being able to satisfy one's needs in a compact, land use diverse geographical area increases with higher land use mixing and thus the short distances would suit walking (Pickrell, 1999). However, Cervero (1988) extends the benefits of mixed-use environments to quality of life (QoL) considerations, stating that the increased pedestrian traffic creates a “far more active and socially interesting milieu”. Further, environments with a mixing of uses and higher density tend to have a better temporal balance of human activity which can engender a sense of security in pedestrians, supporting walking, as there are more eyes on the street (Efroymson & Rahman, 2005). These extended considerations of the value of mixed land use take into account the experience of being a pedestrian and not merely the utility of engaging in walking. The design dimension has generally been operationalised as street architecture i.e. intersection density, block length, using road centrelines. This speaks to the route options that pedestrians have available to them, with people who choose to walk being “penalised” if they have to use circuitous routes due to the excessive amount of effort and time this would require. Although micro level design qualities of the built environment (e.g. sidewalk availability and maintenance, streetlight provision) have been advanced in the urban design literature as having an influence on travel behaviour (see Ewing & Clemente, 2013), poor inventories of these measures have presented challenges in them being operationalised in research.

The direction of causality of the relationship between the built environment and travel behaviour has been the cause of heated debate, and often the methodological limitation of transportation studies has meant that there are still some unanswered questions (Heinen, Steiner & Geurs, 2015). Issues such as residential self-selection have brought into questions whether the built environment results in the choice to walk or if people that have a proclivity for such activity move to neighbourhoods that support walking. Results from studies employing structural equation models have shown that residential self-selection plays a role in walking behaviour. However, enhancements such as appearance, and maintenance, as well as low traffic volumes, may lead to increases in walking when people's current attitudes are controlled for (Cao, Mokhtarian & Handy, 2007). This points to the complexity in addressing issues associated with the choice to walk, these issues are not accounted for in time and distance based evaluations used to review public transport access/egress.

2.3.2 Public Health literature and the choice to walk

In support of a holistic approach to research on sedentary lifestyles, researchers in the Public Health have borrowed from the conventional Transportation and Urban Design literature in developing ecological models to study the characteristics of places that support or hamper physical activity (Sallis et al., 2006). Researchers have recognised the value of activities like walking in helping people to meet activity requirements for healthy lifestyles, as opposed to solely focusing on vigorous activity (Pikora et al., 2003). These ecological models expand the realm of inquiry into active living beyond interventions that focus on just the individual, to ones that include the physical environment that people interact with, as well as sociocultural factors and policies that are hypothesised to influence behaviour. Sallis et al. (2006) present an ecological model that considers the domains of Active Transport, Active Recreation, Household Activities and Occupational Activities. The multiple levels along the Active Transport (walking and cycling vs. motorised transport) domain are presented in Figure 8

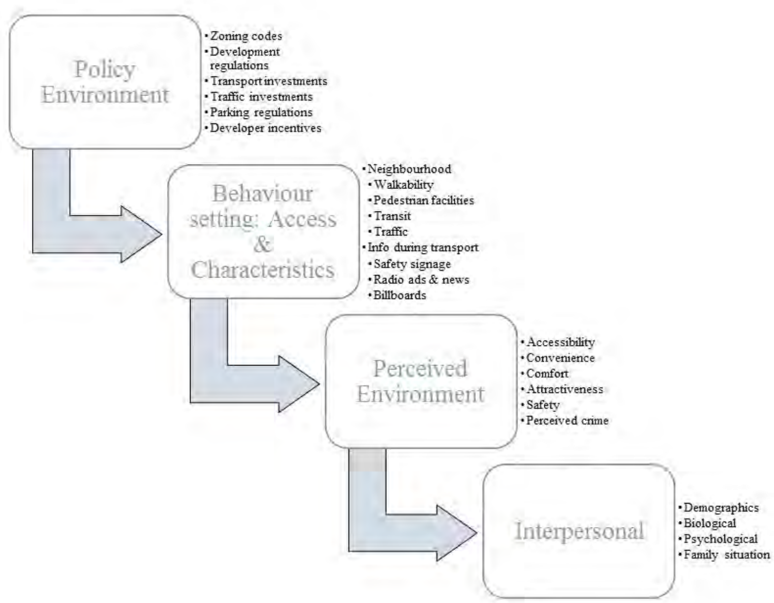


Figure 8: Ecological Model of active Living, adapted from Sallis et al. (2006)

At a broad level, the Ecological Model encompasses the ideas presented in the transportation literature: zoning codes, development regulations and developer incentives at the policy level speak to facilitating high-density, mixed use environments. Under the behaviour setting, considering issues of access and the characteristics of the environment are presented. The inclusion of traffic speaks to the recognition of pedestrian traffic safety being an important consideration in supporting active living.

Sallis et al. (2006) include perceptions of the environment in their model, positing that perceived qualities of attractiveness, safety, crime, comfort, convenience and accessibility are influencers of active living. Moudon and Lee (2003) term these spatio-psychosocial attributes and also theorise that they may illicit innate responses from people, which has potential to influence behaviour. Traditionally these considerations are not operationalised in the conventional transportation literature. However, they are related to Urban Design concerns in that more pleasing, attractive and comfortable environments result in people making active lifestyle choice like opting to walk.

Sallis et al. (2009) developed logit regression models using self-reported, neighbourhood environmental factors as well as self-reported levels of physical activity data from 11 countries. The self-reported neighbourhood factors were obtained by asking study participants to respond to statements of how they perceive their neighbourhood environment on a scale of: strongly agree, strongly disagree, does not apply and don't know/not sure. The statements used in the surveys were as follows, the dimension of the built environment that they represent is provided in square brackets:

- Most streets having sidewalks [Design]
- The main type of housing (listed different housing types) [Density]
- Presence of shops, stores, markets that are within close proximity to place of residence [Diversity]
- Transit stop being within 10-15 minutes walk [Distance to transit]
- Presence of bicycle facilities
- Presence of free or low-cost recreational facilities
- Crime rate in the neighbourhood making it unsafe to walk at night*

Through the modelling exercise, it was found that the presence of sidewalks in neighbourhoods had the highest odds ratio with the physical activity. The use of sidewalk presence as opposed to measuring area-wide network architecture is an important distinction, as streets may have high road connectivity, but without pedestrian right-of-way these environments may not be accessible to pedestrians. Further, being an international study, the research provided useful insights on how the influence of the built environment can be applied across a broad range of countries

A meta-analysis of the perceived environment and physical activity literature, aiming to determine the strength and direction of the relationship, reviewed 16 studies (majority of which

* The security environmental factor reduced the internal consistency and was dropped from further analysis

were in the USA) that employed logistic regression analysis (Duncan, Spence & Mummery, 2005). The perceived environment included reporting of the presence of, sidewalks, nearby shops and services, heavy traffic, the prevalence of crime as well as the presence of street lighting, among others. The findings from Duncan, Spence and Mummery (2005) point to peoples' perceptions of sidewalk availability, low levels of heavy traffic as well as the availability of close shops and services as being associated with higher levels of physical activity.

As part of a larger study investigating the built environment's influence on active living and vehicle emissions, Frank et al. (2006) studied the effects of neighbourhood walkability on the use of active transport i.e. walking and cycling, using a sample of 1228 adults in King County, Washington. A composite index of walkability, calculated in a GIS environment by summing z-scores of measures of land use mixing and retail floor area, residential density as well as intersection density, was used to characterise a 1 km buffer of the respondents' places of residence. Respondents then self-reported the number of days in the past week that they walked or cycled for at least 10 minutes at a time and the number of minutes per day usually spent engaged in these activities. The findings showed that socioeconomic and demographics covariates explained 1.4% of the variance in the linear regression models while the inclusion of the walkability index produced an addition 8.3% of explanatory power. However, the study brought into question the validity of self-reported physical activity, one of the issues being that such an approach may result in a lot of underreporting. When using accelerometer data to measure moderate to vigorous physical activity, Frank et al. (2006) found that demographic covariates (gender, age, education, ethnicity, and income) provided higher explanatory power than the walkability index they developed. However, by choosing only to consider moderate to vigorous physical activity data from the accelerometers they may have missed out light intensity activities such as walking that may not register as a brisk walk or jog would in the moderate to vigorous physical activity classification band. Possible reasons for omitting light intensity activity might be the signal to noise issues associated with such monitoring, where it would be difficult to determine whether light activity took place or if it was just noise in the signal.

Despite the shortcomings of the measurement of the outcomes of active transport and physical activity, the development of Ecological Models has advanced work done in the transportation literature through the inclusion of user perceptions. Albeit, limitations in the use of perceptions were raised by Brownson et al. (2009), who found in their review of the literature that "tangible" environmental attributes such as the presence of sidewalks closely match objective measures. Whereas, perceptions of attributes like crime level yield lower validity when compared to objective measures such as the counts of criminal incidents in neighbourhoods. However, such a comparison between respondent perceptions and "objective" measures assumes that the zonally aggregated enumerations are exempt from the challenges of criterion-related validity, which Brownson et al. (2009) describe as the measure being closely related to a gold standard measure of the attribute being investigated. Yet, zonal aggregations are prone to the modifiable areal unit problem, in that the choice of boundaries and scale of the areal units may influence whether there is a correspondence between perceptions and objective measures. This problem arises due to environmental features being continuous geographical phenomena while the administrative boundaries imposed are artificial. Further, Schneider, Ryznar and Khattak (2004) argue that for cases such as perceived risk, perception information, which may differ from reported incidents may point to locations where accidents are waiting to happen. Thus, treatment of both perceptions and objectively measured attributes may go a long way towards making environments increasingly welcoming to pedestrians (Livi-Smith, 2009).

Community Improvement Districts are deploying mobile units, such as the one in Figure 9, in order to improve perceived security (Berg, 2004) and initiatives such as “Violence Prevention Through Urban Upgrades” are looking at proactive ways to enforce social control of public space (Bauer, 2010). Thus, there are ways in which Transportation Planning Authorities can address less “tangible” environmental challenges that may be affecting access/egress by collecting such data and coordinating efforts with other parties that are addressing them.

Figure 9: Groote Schuur Community Improvement District mobile security unit on Main Road, Cape Town

Another challenge in properly incorporating respondents’ perceptions of environmental qualities has been that they are collected through interviews and self-administered questionnaires, without the respondent necessarily being “in the environment” that is being evaluated. As a result respondents’ definitions of the boundaries of their perceptions cannot be ascertained (Saelens &

Handy, 2008). As Saelens and Handy (2008) point out it could be that the perception of their neighbourhood quality extends radially from their homes ending at some unspecified distance or specific streets in the neighbourhood exert a larger influence on certain perceived qualities of neighbourhood environment. Having reports of neighbourhood qualities while people are interacting with their environment may yield responses that closely match actual conditions. However, this requires a change in the geographical scale used in studies, from the neighbourhood and administrative boundaries, to the streetscape. Such a shift in attention to the streetscape is becoming increasing important as research into "Liveable Streets" highlights the negative impact, such as increased stress, that traffic volumes along streets can have on peoples' lives, (Sanders, Zuidgeest & Geurs, 2015).

2.4 Microscopic measures of the built environment

The Transportation and Public Health Research reviewed employed neighbourhoods, administrative boundaries (e.g. census tracts) or Transport Analysis Zones (TAZ) among others, as the geographical unit to measure built environment qualities. This geographical scale is similar to the Mesoscopic geographical analysis scale used in transportation modelling that lies between highly aggregated macroscopic models and very detail oriented Microscopic models. Consequently, this has restricted the types of built environment characteristics that can enter into models as economic constraints make it difficult to catalogue built environment features at a fine-grained resolution. However, Appleyard (2012) contests that the measures employed are out of step with the pedestrian experience, rather they are better suited to measuring effects on vehicular trips.

Accordingly, this section presents one of the main microscopic evaluation tools applied by Traffic Engineers and Transportation Planners, along with the observational community audit tools developed to capture features omitted by the purely functional measures of the streetscape.

2.4.1 Pedestrian level of service

The Pedestrian Level of Service (PLOS) method was developed as a micro level street traffic standard to determine operational conditions. Early inquiries into pedestrian trips, and their associated quality were very mechanistic, based on the work in Fruin (1971). The approach borrowed from investigations of vehicular flows and defined relationships between pedestrian walking speeds, average personal space on sidewalks, and control delays at crossing points. The latent performance metric being speed, the faster one can traverse the walking environment the better, which is similar to the mobility driven paradigm prevalent in transportation planning. Under this assessment regime, the duty of the analyst would be to identify links where flows are impeded and recommend these for upgrade, which would entail capacity increases by widening sidewalks. However, even in the 1985 Highway Capacity Manual assessment of environmental factors was encouraged, yet no methods were given for their consideration (Khisty, 1994).

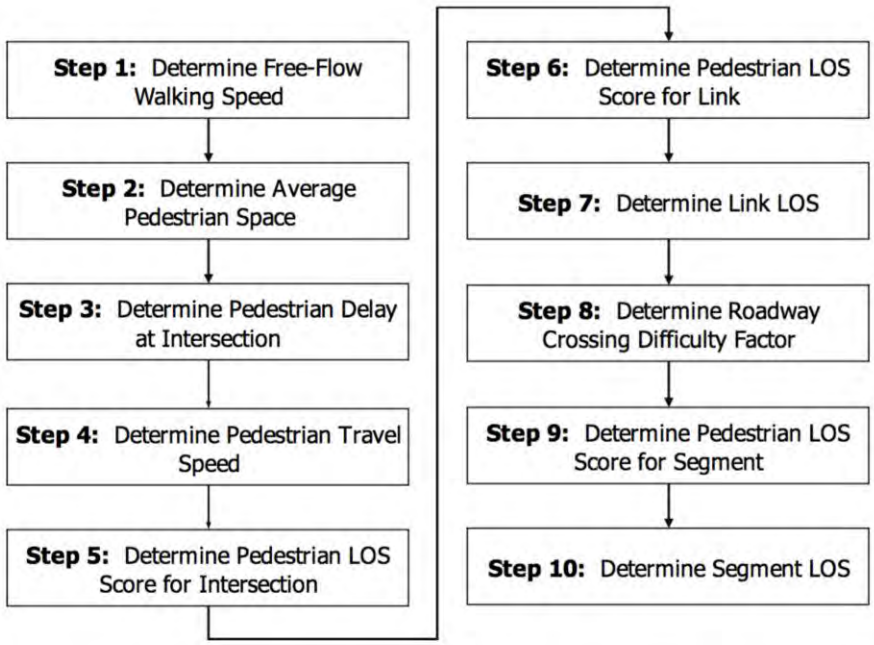


Figure 10: Pedestrian Level of Service calculation methodology, *Source*: TRB, 2010 (Transportation Research Board, 2010)

The latest iteration in the 2010 HCM, purports to come from a user perspective. However, this is through evaluating how closely the model matches with the ratings by 145 people of video clips of 10 locations (Dowling et al., 2008). The dimensions evaluated do not include issues of security and comfort. Rather they were the same ones of: sidewalk width, separation from traffic†, traffic speed† and traffic volume†.

In spite of the HCM not including environmental factors, the publication of the 2010 edition served as a watershed moment. The committee responsible for preparing the manual formally recognised the need for developing quality of service measures that are correlated with travellers' assessment of the operating conditions (Transportation Research Board, 2010).

2.4.2 Observational audit tools

Observational audits of streets have developed in parallel with tools used to collect respondent perceptions and GIS indices of the built environment. These audit tools are usually standardised forms that researchers code while walking through the study area, some being very comprehensive requiring the coding of up to 144 items per street segment (Brownson et al., 2009).

† Introduced with the 2010 edition of the HCM

Twenty such audit tools are contained in a review of built environment measures by Brownson et al. (2009). The development of many of these tools was funded by the Robert Wood Johnson Foundation as part of its Active Living research programme in the United States, and Public Health researchers have played a crucial role in advancing the measurement of the micro-level built environment. The most commonly known examples being: the Irvine–Minnesota Inventory (Day et al., 2006) developed at UC Irvine in conjunction with the University of Minnesota, the Pedestrian Environment Data Scan (PEDS) Tool which also included an electronic version that could be used on handheld Palm PDAs (Clifton, Smith & Rodriguez, 2007), and the Systematic Pedestrian and Cycling Environmental Scan (SPACES) Instrument developed in Australia (Pikora et al., 2002).

The PEDS and SPACES tools assess factors associated with: the walking surface, traffic safety, personal safety (e.g. street lighting) and the quality of the streetscape e.g. presence of trees and street cleanliness/maintenance. Auditors report on 36 variables along with including subjective assessments of the attractiveness of street segments (Schlossberg et al., 2015). The Irvine-Minnesota Inventory, is one of the most comprehensive tools assessing 160 factors, cutting across: perceived safety from crime (security), perceived traffic safety, pleasurability and accessibility (Day et al., 2006).

An audit tool was developed for the South African context in response to the country's road traffic accident epidemic (Albers, Wright & Olwoch, 2010). It was tested at five locations across Tshwane, Gauteng that registered the highest number of pedestrian accidents and hit and runs between January 2007 and May 2009. In the development of the Pedestrian Environment Assessment Tool (PEAT), the SPACES tool was reviewed among others. The tool does not differ significantly from the other audit tools; save for a consideration of how vehicle right of way condition may make walking on the side of the road dangerous if automobiles take evasive action due to infrastructure challenges such as potholes.

In order to support public transport patronage, the Indian Ministry of Urban Development created the Public Transport Accessibility (PTA) Toolkit that can be used to audit streets in the vicinity of public transport and identify the challenges that may be present along those streets. The PTA Toolkit is similar to the many of the international audit tools, requiring auditors to rate the quality of footpaths in terms of design and maintenance, provision of pedestrian comfort amenities such as street lighting and cover from the elements, along with measures that support pedestrian traffic safety such as the provision of crossing facilities.

2.4.3 Microscopic built environment measures for access/egress evaluation

Rodríguez, Brisson and Estupiñán (2009) audited street segments within a 250 m buffer of BRT stations in Bogotá, Colombia using the PEDS audit tool developed by Clifton, Smith and Rodriguez (2007). At the segments, auditors also took a 10 min pedestrian count, which served as the dependent variable for the negative binomial models that were developed. Their study found that there was a positive relationship between pedestrian activity and improved pedestrian oriented amenities (e.g. bins and benches), street crossing aids and area wide connectivity (3-way and 4-way streets). However, one of the shortcomings of this study is that it presents associations, and just as with the studies at a mesoscopic scale, one cannot establish causality. Moderating this concern is that all of the audited segments underwent upgrading with the development of the Bogotá BRT (Rodríguez, Brisson & Estupiñán, 2009), but it cannot be established whether at stations where higher pedestrian volumes were anticipated, designs were supplemented to provide added amenities for pedestrians.

Park, Choi and Lee (2015) tested the influence of micro-level walkability on respondents' mode choice for travel to a rail station in Mountain View, California. Walking routes to the station for 150 habitual drivers with walking experience to the station and 99 patrons who predominantly used walking as their primary access mode, were collected by respondents drawing on maps. In addition to the walking routes, respondents provided demographic and socioeconomic information. Using the street segment as the analysis unit, auditors measured 38 walkability indicators capturing architectural, physical and environmental characteristics along the 228 street segments (~33 km) that made up the 249 access routes. Factor Analysis combined the indicator variables into 4 groups, inferred to represent the qualities of: sidewalk amenities, traffic impact, street scale/enclosure and landscaping elements (Park, Choi & Lee, 2015).

Hypothesising that respondents' appraisal of walkability while walking influenced their predominant mode choice for accessing the stations, Park, Choi and Lee (2015) specified a pair of binomial logit models. The basic model had the variables: trips distance (network), trip purpose, car availability and race; while the expanded model‡ added the micro-level factors of Sidewalk Amenities, Traffic Impact, Scale & Enclosure and Landscaping Elements

Comparing the two models, Park, Choi and Lee (2015) found that Sidewalk Amenities and Landscaping Elements had a positive relationship with the choice to walk to the station, while Scale & Enclosure and Traffic Impact had a negative relationship with the choice to walk. Traffic Impact having a negative relationship aligns with the idea that pedestrian opt for streets that offer high levels of traffic safety. Environments not being at the pedestrian scale by having large building masses and wide streets is in line with Urban Design theories (Park, Choi & Lee, 2015). The model incorporating micro-level features also had improved predictive power, showing the merits of analysis of the built environment at a scale that pedestrians experience first-hand.

A similar study also collected pedestrian routes to public transport stops by getting respondents to draw them out on maps. However, the study sought to investigate pedestrian preferences for particular routes. Weinstein Agrawal, Schlossberg and Irvin (2008) surveyed a total of five rail stations in California and Portland, asking respondents to draw their common routes to the transit stations. Respondents also provided reasons for why they chose the route with shortest distance and traffic safety consistently cited as the main reasons. The traffic safety considerations were presence of traffic control devices and low vehicle speeds. Coding the drawn routes into a

‡ Race had a significance greater than 0.05, however, included in the expanded for comparison

GIS environment and calculating shortest paths validating that pedestrians consistently selected the shortest path. However, one caveat of these results is that the areas that were surveyed had performed well in terms of traffic safety, security and they were relatively attractive (Weinstein Agrawal, Schlossberg & Irvin, 2008). The value of such studies is that they present a case for upgrades to neighbourhoods on the grounds of needs expressed by respondents. This allows for targeted upgrades along revealed access routes. Further, if it is found that patrons are making use of circuitous routes, yet stating that they prefer to use the shortest paths, this can easily be identified in a GIS environment.

Considering the influence that satisfaction with the built environment can have on habitual behaviour, Kim, Park and Lee (2014) utilized a pedestrian survey of 83,291 people at 1,170 locations in in Seoul, Korea. Respondents gave a rating of their satisfaction on a 5-point Likert Scale from Very Dissatisfied to Very Satisfied. Surveyors also coded the presence of the following micro-level built environment features within 50 m of the survey location:

1. Presence of bus-dedicated lanes (0. no; 1. yes)
2. Presence of crossings (0. no; 1. yes)
3. Sidewalk width (m)
4. Presence of sidewalk fences (0. no; 1. yes)
5. Presence of signal control device (0. no; 1. yes)
6. Presence of street lamps (0. no; 1. yes)
7. Presence of ramps (0. no; 1. yes)
8. Presence of trees (0. no; 1. yes)
9. Presence of trashcans (0. no; 1. yes)

A multilevel model was produced that included mesoscopic variables extracted using a 400 m buffer around the survey location, and respondent characteristics. Wider sidewalks and the presence of crossings and trees were significant for both utilitarian and recreational walking. Although this study was performed at a large scale, the respondents did not give an account of the relative importance of different qualities of the built environment, thus, it would not be possible to determine if a particular one may have made up for a shortcoming in the rest.

Two approaches have been highlighted for the way in which micro level built environment measures are used for evaluating public transport access/egress. The first has been to model the built environment to see which features are related to increased walking (Rodríguez, Brisson & Estupiñán, 2009; Park, Choi & Lee, 2015). This first approach allows Transportation Planning Authorities to appreciate the kinds of designs they should be implementing if they want to support increased walking. While the second approach, has been to see if the built environment meets the expectations of pedestrians at locations (Weinstein Agrawal, Schlossberg & Irvin, 2008; Kim, Park & Lee, 2014). Both add value, however, the data collection requirements make it difficult to implement these approaches at scale. Either studies are limited to piecemeal investigations of a handful of stations or the alternative is the approach of Kim, Park and Lee (2014), which goes to scale (Number of respondents) but the built environment investigation is restricted (50 m around survey location for Kim, Park and Lee (2014)) and the questions asked of respondents are very basic. However, allowing respondents to independently offer up data on their built environment while on their access/egress trips may be a more cost effective way of identifying where there are gaps in provision. Mail back questionnaires provide a means of doing this, but they result in double handling of data and respondent burden may not make them user friendly. The automation of certain tasks and handling of data can be done using mobile phone devices that are becoming ubiquitous in urban society.

2.5 Mobile phone technology and transportation planning

Historically, transportation surveys have relied on subjects to provide evidence of their spatial behaviour, utilising three main methods, namely: recall of a normal time period, game playing and time space diaries (Isaacson & Shoval, 2006). However, there has been a growing interest in the use of Information and Communication Technology in the collection of transportation survey data; with mobile technology being viewed as a means of reducing respondent burden and tackling the challenges of declining survey response rates (Chorus & Timmermans, 2010).

Early inquiries into the use of mobile phones in travel surveys looked to leverage tracking technology developed in the early 1990s, utilising the network of land based cell phone towers to triangulate the location of the mobile phone user (Isaacson & Shoval, 2006). The use of location services has been expanded with the introduction of automatic transport mode detection, which leverages positioning data as well as mobile phone accelerometer data. Applying pattern recognition algorithms to the data allows for the detection of whether users are using non-motorised transport or in vehicular transport (Widhalm, Nitsche, & Brandie, 2012). The application of this technology has benefits for trip analysis, and greatly reduces the respondent burden, through limiting manual input. Examples of such applications include Protogeo's "Moves" application (acquired by Facebook), and Google Now's tracking extension (Metz, 2013). All these applications, have been made possible through the development of enhanced mobile phone operating systems with Application Programming Interfaces (APIs). APIs have allowed for the creation of mobile applications that take advantage of web based services, allowing users to access a plethora of information while on the move, but also share information about their activities and the cities within which they live (Bayir, Demirbas & Cosar, 2011). The Google Android operating system, which is open source, has resulted in a sharp drop in the price of smartphones that can perform such tasks, as such, opportunities for a larger number of people to partake in this "knowledge sharing" abound.

Presenting the benefits of mobile technologies, Gould (2013), states that they allow for engagement at a community wide level and afford survey respondents with an anonymous means of submitting survey responses. Tasks such as recalling routes, departure and arrival times may no longer be the purview of survey respondents, rather, location aware mobile phones can produce such records, and early assisted GPS technologies were capable of providing accuracy to within 5m, showing superior accuracy and precision to traditional methods which relied on recall by respondents (Asakura & Hato, 2004). Further smartphones are now equipped with cameras and can record voice clips. The use of multimedia allows for the incorporation of affective and experiential expression, which Davies et al. (2012) argue makes for improved citizen engagement.

Gould (2013) posits that location aware mobile phones can allow for an assessment of the built environment factors that facilitate or impede walking, further, the "real" time capability of surveys that leverage mobile phones allows respondents to rate and provide their impressions of factors as they are experiencing them. Leveraging such technology for use in collecting data on how the built environment is perceived can reign in the costs of collecting data for transportation survey, especially since these cost are known to constrain the actions of transportation agencies (Eboli & Mazzulla, 2011). In addition, such tools allows for an emic approach to understanding pedestrians challenges, leveraging the knowledge of people to identify issues which may not be obvious to outside parties.

The proliferation of smartphones within developing countries such as South Africa and India has meant that many individuals can run sophisticated applications without the need for expensive computers or cumbersome mobile GIS units. These technological advances have created opportunities for public transport users to provide real time feedback on perceived challenges associated with public transport systems. Researchers have looked to find means of creating a sense of community between transportation service providers and end users (Steinfeld et al., 2011) and as members of society increasingly identify with causes using online platforms, having a mobile application which allows for the sharing of information on perceived problems can enhance community engagement and support inclusive design.

2.5.1 User centric mobile phone applications for assessing the micro level built environment

There are examples of studies that have operationalised mobile phone technology to collect data on the micro level built environment. Shumi et al. (2013) made use of IPAQs, mobile PDA devices, to collect data that was used to understand the impact of walkability on the Quality of Life of women working in the Bangladeshi garment industry. The respondents were escorted along their commute to the garment factories while being interviewed on walkability challenges, with responses to questions being recorded on paper. Surveyors would then walk back along the route and geo-tag walkability challenges using the IPAQ. The study by Shumi et al. (2013) adds tremendous value, however, by not using the mobile device to store "questionnaire" information, the benefits of mobile phone technology are not fully exploited.

The Clean Air Asia initiative, a network funded by the World Bank and Asian Development Bank, developed a mobile phone application to capture user ratings of walkability factors (CAI Asia, 2012). The application allows users to give point ratings of issues related to traffic safety, security, sidewalk maintenance, universal accessibility, and motorist behaviour. In addition, in the latest iterations users can submit a single image to provide contextual evidence for their ratings at the point. The ratings are scored on a 1-5 Likert scale, and a total score is calculated based on a tallying of individual ratings, this index is then uploaded online and the GPS point where each index was calculated is given. The application has been used in over 130 cities (Aparajita, 2015). However the application's major shortcoming is that it is designed to evaluate points. This lack of continuity in the tool does not allow for an understanding of routes that are used by pedestrians. In addition, only allowing the uploading of one image per assessment limits how much contextual evidence that can be provided especially in really challenging environments.

Schlossberg et al. (2012) developed an iPhone application that allowed for the submission of unstructured: subjective feelings of the environment, along with descriptions of the location where data was recorded and uploading of images to supplement assessments. This information is geo-tagged using the iPhones internal GPS, alternatively, the test subjects could make use of a Google Map integrated with the application, in order to provide information for areas which they may have prior experience with, but may not be in at the time of assessment. The use of unstructured submissions may be the best way to allow respondents to present challenges as they are truly perceived, however, translating those challenges to insights that Planning Authorities have the capabilities to address is probably the biggest challenge to employing this approach.

The studies that have made use of mobile phones for understanding pedestrian walkability challenges show promise, however, there are some limitations in that they do not incorporate a means of discovering routes that people use, rather, they rely on point assessments. Leveraging the capacity for recording walkability ratings along walked routes using mobile phone GPS chips can support a segment-by-segment evaluation of the walking environment. In addition, unstructured questions may allow respondents to provide information that closely matches their perceived challenges, transforming this data to actionable insights presents a major challenge to Transportation Planning Authorities.

As the value of using mobile phones for such assessments is that the data is spatial in nature, the analysis methods need to fully leverage this quality. Filtering the data and then mapping subsets of ratings may not take into account the complexity of multiple ratings in a particular area. Rather tools are required that consider the interplay of ratings in space.

2.6 Spatial Statistical Cluster Analysis

Having numerous respondents supply geographical data requires that planners have tools to process the information efficiently, in order to identify trends and pinpoint problems. Cluster Analysis allows for the grouping of statistically significant clusters of both high and low values within a dataset. The value of such an approach becomes evident as the number of respondent and the extent of study areas increases, and visually analysing trends in spatial data becomes increasingly challenging.

Geographical information systems have developed over the years from being used exclusively for the storage of spatial data, to having the ability to run complex graphical algorithms in the analysis of patterns (Fischer & Nijkamp, 1992) and the development of spatial statistical analysis tools has benefited from these advancements in GIS technology.

There are two main approaches to spatial statistical data analysis, these are the exploratory and confirmatory approaches respectively (Anselin & Getis, 2010). The former allows for new insights to be gained through the identification of spatial patterns and allows for data to be explored within a GIS or exported to standard statistical analysis packages, while the latter is “model driven” and allows researchers to see what the underlying drivers are in trends that have been observed.

The field of spatial autocorrelation, which forms part of spatial statistical analysis is distinguished from regular statistical analysis in that it considers variable values at locations and determines if there are spatial patterns in values across other locations (Wulder & Boots, 1998). One of the more common ways of measuring autocorrelation is Moran’s *I* statistic, a global indicator, which tests the null hypothesis that there is no spatial autocorrelation within a dataset. If the null hypothesis can be disregarded then the dataset can be said to contain some autocorrelation (Ord & Getis, 1995). The calculation for Moran’s *I* is given by:

$$\mathbf{I} = \frac{n}{S_0} \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} v_{ij} z_i z_j}{\sum_{i=1}^{n} z_i^2} \tag{2-1}$$

Where *n* is the number of features considered in the test, the spatial weight between features *i* and *j* is v_{ij} and z_i is the difference between the mean and an attribute for feature *i*. The aggregate of the spatial weights S_0, is given by:

$$S_0 = \sum_{i=1}^{n} \sum_{j=1}^{n} v_{ij} \tag{2-2}$$

A separate class of autocorrelation indicators, termed Local Indicators of Spatial Association (LISA) operate at the local level. LISA statistics assess the degree of association between a spatial variable at a location and all other variables within an analysis window (Getis, 2001) allowing for the identification of pockets of non-stationarity in a geo-referenced dataset (Anselin, 1995), these being either clusters of cold or hot spots.

The Anselin Local Moran’s *I*, I_i is calculated as follows:

$$I_i = \frac{x_i - \bar{X}}{S_i^2} \sum_{j=1, j \neq i}^{n} v_{ij} \left(x_j - \bar{X} \right) \tag{2-3}$$

The attribute under consideration in the analysis for feature i is x_i, n is the total number of features while the mean of the attribute is $\bar{X}$ and v_{ij} is the spatial weight between features i and j .

$$\boldsymbol{S_i}^2 = \frac{\sum_{j=1, j \neq i}^{n} \left(v_{ij}\right)^2}{n-1} - \bar{X}^2 \qquad \textbf{(2-4)}$$

These statistical analysis tools can be applied to user ratings of the built environment in order to identify clusters of low/high ratings of walkability. Clusters are found by comparing z-scores of the calculated index. Global tests that show autocorrelation within a dataset can be followed by tests using LISA statistics that identify the location of spatial clusters.

By reviewing an analysis window around a rating, LISA statistics can account for outliers which filtering methods would not be capable of doing. Clusters can be mapped and any geo-referenced media can be used to gain insight into the underlying drivers of spatial clustering.

2.7 Résumé

This chapter presents the challenges that pedestrians have to deal with in an auto-normative society. Walking has been neglected as a transportation mode with poor pedestrian networks and down at the streetscape there is still a vehicle bias and inadequate infrastructure. However, considering the multimodal nature of all public transport trips, with walking being so integral to this multimodality, Transportation Planning Authorities are doing a disservice to their patrons by not acting on the needs of pedestrians. The existing analysis methods do not fully incorporate the complex issues that are experienced by pedestrians and any modifications to these tools have still remained mechanistic, by being focused on time penalties.

Travel Demand and Active Living research have advanced the state of the practice with regard to understanding how walking can be supported by the built environment. The Ecological Models developed by Public Health researchers call for an understanding of factors that have been neglected, such as the perceptions of users. This challenges Transportation Planners to start looking towards a more emic approach by incorporating spatiopsychosocial attributes of the built environment that may mediate walking decisions. If transportation planners want to remain true to getting user perceptions, then the analysis units in use may need to be at the scale that pedestrians interact with the built environment. Zonal measures of built environment qualities are better suited to vehicles.

Although there are micro-level tools that have been used by transportation planners, these have their roots in vehicle standards and implicitly equate the needs of pedestrians to those of motorists. Audit tools developed for use in Public Health research have promise, however, they require large resources. Further, one time evaluation of streets may not be able to capture time-sensitive challenges. This approach may also be limited by the observer effect, as auditors in official uniform may make people in the area alter their behaviour.

Allowing public transport users to participate in data gather efforts at the microscopic level by using mobile phones presents an opportunity for a user-centric reporting of walkability challenges. Mobile phones have been used for Transportation Planning; however, there have been shortcomings in their designs. Walking is a linear activity and it is important to understand the links that make up a walking trip, and the evaluation of points may not allow for the identification of circuitous routes.

The use of Spatial Statistical Analysis adds further rigour that is missing from the other tools that have been developed to assess walkability. The clustering algorithms allows for planners to quickly identify trends in the geo-referenced data, which can become complex as the amount of data and the spatial extent of evaluations increase.

From the literature, some of the walkability considerations and key performance indicators are presented in Table 3, along with a rational for including them. From these a walkability mobile app that can be used to evaluate access/egress trips can be developed.

Table 3: Walkability Dimensions and rationale for their inclusion

Walkability consideration	Rationale
Safety	The burden of loss of life and injury due to road traffic accidents in South Africa and India is borne heavily by pedestrians. Thus a walkable environment, has to be one where pedestrians face minimal risk to injury
Security	Temporal and spatial accessibility may be restricted by a sense of insecurity. The risk of harassment or mugging places undue stress on pedestrians
Infrastructure	Pedestrian right-of-way infrastructure facilitates safe access to activities
Comfort	Pedestrian oriented amenities make the walking experience more pleasurable and can help entice people to use public transport
Geographical scale of analysis	One of the challenges to previous studies of pedestrian travel has been the use of aggregate mesoscopic zonal measures that do not adequately capture the pedestrian experience at the streetscape. Microscopic assessments of the built environment is better suited to evaluating walkability
Linear nature of walking trips	An understanding of the all the segments that make up a walking trip can provide insight into shortcomings pedestrian networks

3 Research methodology

The primary aim of this study is the understanding of pedestrian perceived walkability challenges along public transport access/egress, through the development of a mobile phone application. This chapter gives details of the methodological approach to meet the research objectives outlined in section 1.3. Figure 11 shows the research stages:

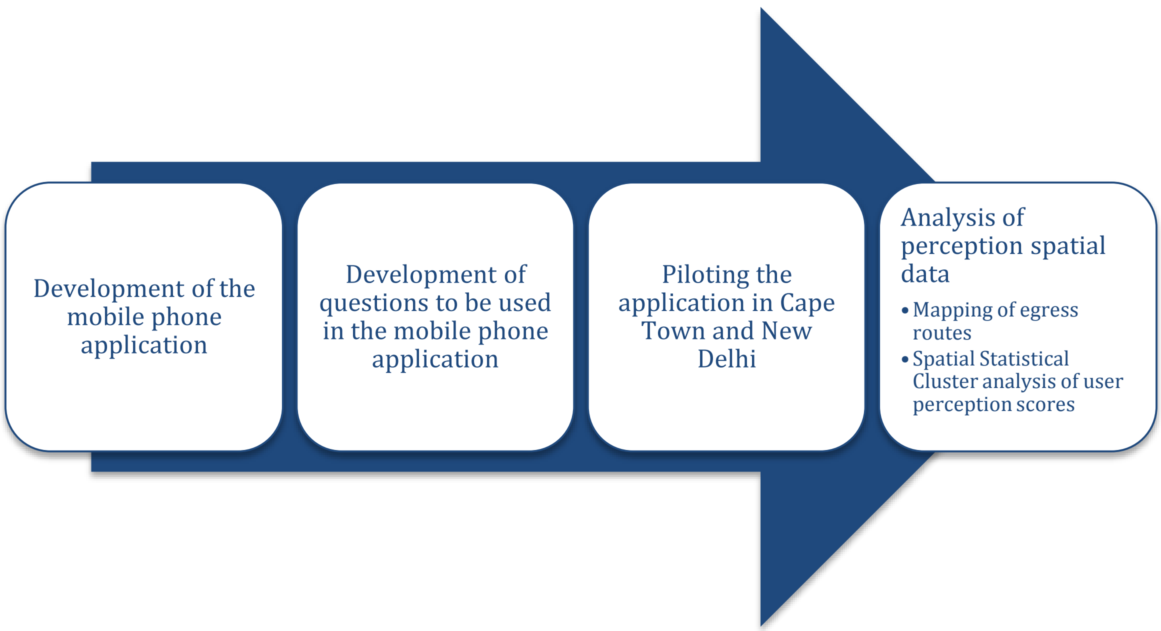


Figure 11: Stages in research process

3.1 Development of mobile phone application

From the literature review, a list of requirements was established for features that the application should have in order to support improved understanding of walkability challenges. These included that the application be able to:

1. Track the walking routes of respondents and monitor distances walked
2. Allow for submission of multimedia to support incorporation of affective and experiential expression of access/egress challenges
3. Input user ratings of street segments at a predefined segment distances and prompt users to submit data
4. Input responses to a list of structured questions regarding user perceptions of parameters associated with walkability

Using these requirements, a web browser based HTML prototype of the application was developed. The prototype was used to test the operation of the application with respect to the data entry scheme. Consideration was given to the use of text based user ratings scales versus pictograms rating scales.

Using the prototypes software programmers were engaged to implement the vision we had for the application. The programmers were called upon to collaborate on the development of the interface between the mobile application and online server. Location data (routes and points where media was saved) and all responses to questions had to be sent to a server as a series of text strings, while media could be sent in its native format of either jpeg and mp3 files. A schematic of the interaction between the mobile phone and the online server is show in Figure 12. The location data would then need to be converted on the fly to Comma Separated Value (CSV) files of latitude and longitude, when the files are downloaded from the server and used for analysis.

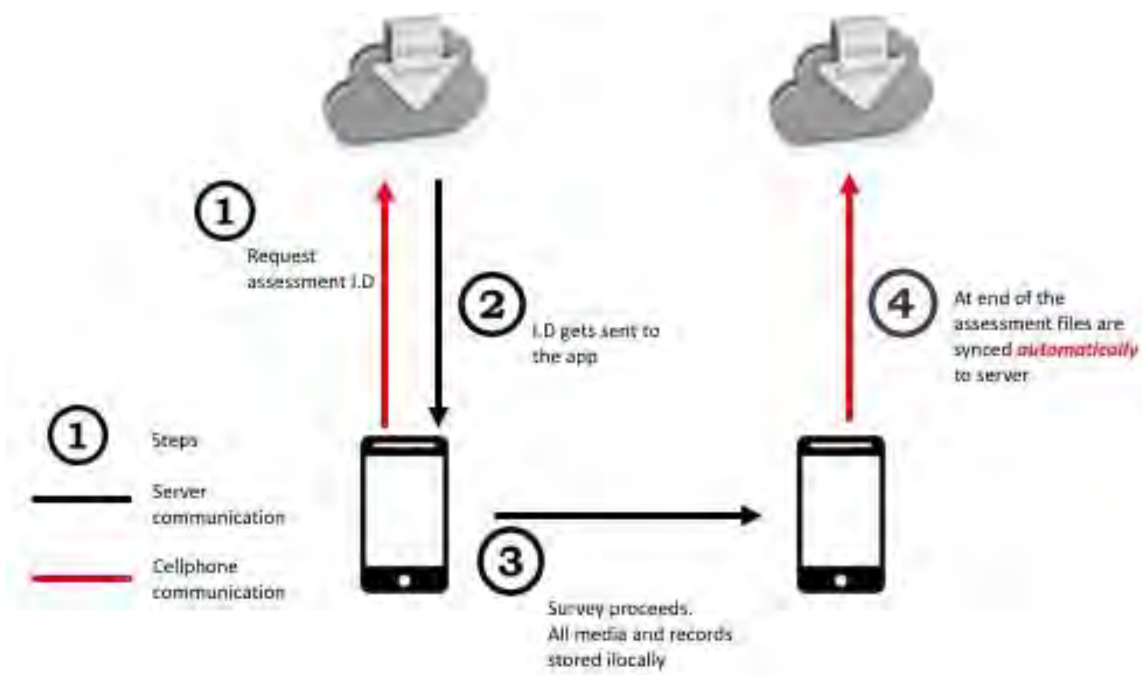


Figure 12: Mobile application - Database/Dashboard interfacing

3.2 Development of route level walkability questions

The prototype was populated with a list of questions, Table 4, understood to cover walkability challenges from the literature reviewed in chapter 2. These questions were later refined in a workshop with project leaders. The prototype was then sent to programmers that were responsible for writing the Android code.

Table 4: Themes for structured questions used in app

Infrastructure	Personal safety	Comfort	Security	Demographic
Sidewalk provision	Vehicular traffic volumes	Pedestrian amenities	Presence of pedestrian oriented lighting	Age
Maintenance	Signalised intersection availability	Walking space	Sense of security along route	Gender

3.3 Design of pilot surveys

A real world implementation of the mobile application would have required that the tool be made public, crowd sourcing walkability assessments. However, in order to get this off the ground, a recruitment campaign publicising the application would have been required. The challenge would have been recruiting a sizeable cohort to make use of the same public transport stop, in order to pass the validity requirements for employing spatial statistical analysis.

Considering the budgetary and time constraints, an on the move intercept survey was chosen as it would be the quickest method to gather user ratings at public transport stops. In this survey public transport users are intercepted and recruited for the study by survey facilitators while exiting the public transport station. The facilitators have mobile phones with the application preloaded on them, and escort the pedestrian along their egress trip to their destination while allowing the user to submit their assessments via the mobile phone. For the fieldwork in Cape Town, survey facilitators were recruited from students at the University of Cape Town. In New Delhi, a partner institution, The Indian Institute of Technology New Delhi, piloted the application and provided data that is reported on in this dissertation.

The decision to survey egress trips was made due to it being difficult to determine where access trips start. The main assumption is that access/egress trips are symmetrical for most people; however, differences in environmental conditions between morning and evening may make users choose different routes. This is one of the trade-offs associated with this approach.

In order to intercept the greatest number of people, the surveys took place during weekdays either in the morning or evening peak period. The time of day depended on when it was expected that people would be making egress trips from the station. In Cape Town, fieldwork took place in spring 2016, while in New Delhi the fieldwork took place just before the beginning of the 2016 monsoon season. The timing of the survey was due to the availability of survey facilitators. Surveys were only paused when it rained, in order to prevent damage to the mobile phones.

At a workshop, survey facilitators were given training on how to approach potential respondents and the requirements for ensuring that they explained all the study details so that respondents gave informed consent. At the stations, facilitators randomly intercepted system users and only asked them to participate if they were above the age of 18 and had not already participated in the study at the same station (avoiding double assessments of the same route). Survey facilitators introduced potential respondents to the application and explained the nature of the data that would be collected. Upon agreeing to participate and having signed consent forms, the assessments would commence.

3.4 Spatial Statistical Analysis

ArcGIS 10.3 was used for the preparation of maps of walking routes and the calculation of walking distances. The CSV files of location data produced by the online database were imported into ArcGIS; routes were reproduced using the longitude and latitude points collected by the GPS unit. An ArcGIS add-on ET GeoWizards was used to split routes into the predefined segments and a join was done with records of user ratings.

In order to identify locations along egress routes where respondents systematically gave low or high ratings, Spatial Statistical Analysis was employed. Using the Spatial Statistical Analysis Extension in ArcGIS 10.3, an incremental Global Moran's *I* test was first run to identify if there was statistically significant clustering within the dataset. If the global test yielded results showing clustering, a further analysis was run, using the Anselin's Local Morans I to identify segments of streets that respondents walked along that had high/low ratings of walkability.

4 Mobile application design outcomes

This chapter presents the outcomes of the mobile application design process. Screen dumps from the mobile application are provided, showing the graphical user interface. The structured questions that were developed for each of the themes listed in Table 4 are then presented. Finally, the chapter closes with an exposé of the dashboard that was developed to store and visualise data collected with the mobile application.

4.1 Mobile application user interface

Screen dumps from the application are presented in Figure 13. Having entered credentials[§] on the first screen, the application loads screen two, which requires the user give consent to take part in the study. Checking the consent tick box, and engaging the GPS chipset is how consent is given. Without having followed the process, the application will not allow the respondent to begin an assessment.

Screen three is the holding screen that presents the distance walked and the amount of time spent on the assessment. As discussed in section 3.1, the application had to allow for inputting of ratings at a predefined distance. A distance interval of 100m was chosen for the purposes of this research. Street condition can change drastically along segments. The distance of 100 m was judged to provide good resolution for capturing changes, however, the application can be recompiled using different distance settings. As it is likely that users will be engaged with their surrounds while walking, the phone sends a notification to the respondent by vibrating, and flashing screen number four every 100 m walked. On screen 4 the user submits ratings between 1 and 5, where 1 is very poor and 5 is very good, of the perceived quality of Safety, Security, Infrastructure, and Comfort for the last 100 m they walked. The tool also allows respondents to report whether or not there was a sidewalk available over their last 100 m.

The questions that were developed to assess route level walkability are presented in Table 5. Of the questions, 13 are related to walkability challenges, while a further six are demographic and general questions.

[§] For the intercept surveys, respondents didn’t create a new account

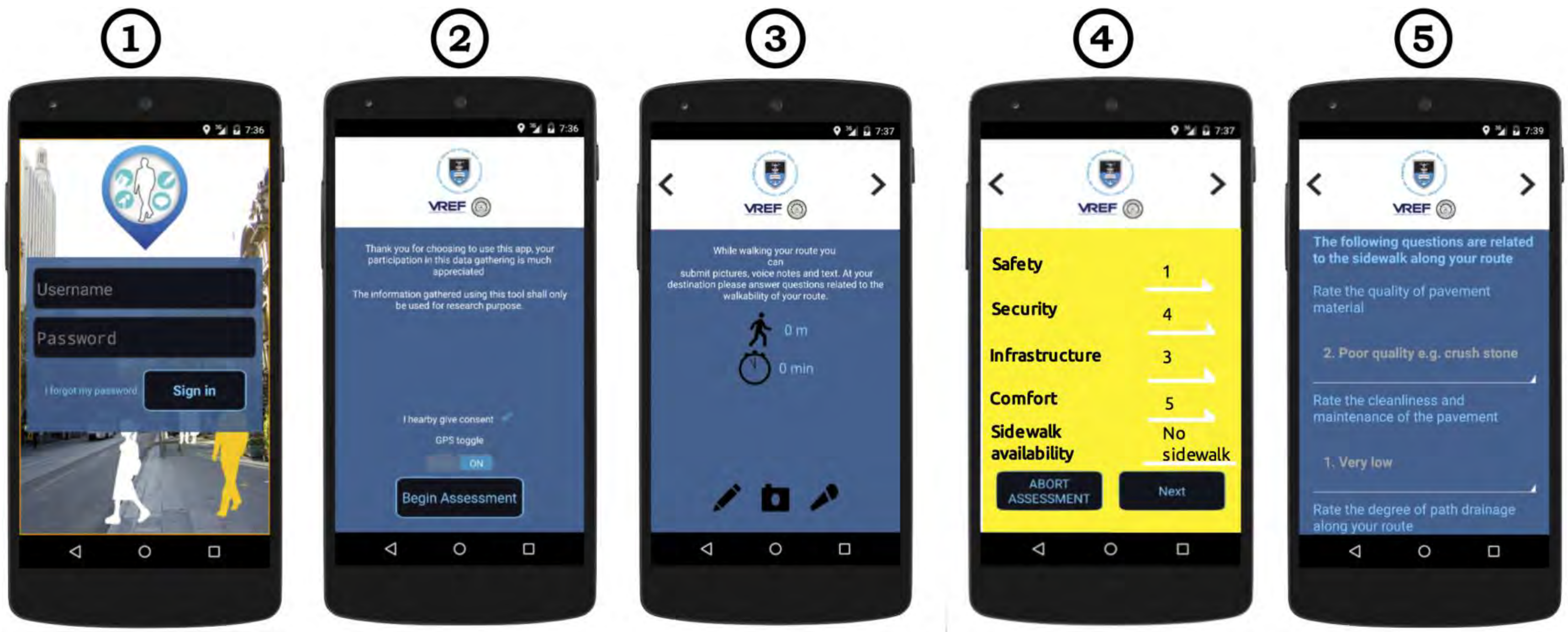


Figure 13: Mobile application screen dumps

4.2 Route level walkability assessment questions

The questions that were developed to assess route level walkability are presented in Table 5. For the general questions, information on whether an individual walked in doors was used to check for distortion of the GPS data. The questions are answered on a Likert scale: 1-Very Low, 2-Low, 3-Moderate, 4-High and 5-Very High. The scale is reversed for questions 3 and 6 to 8 where Very low is scored as 5, Very high is scored as 1.

Table 5: Mobile application route questions

Comfort	**Safety**	**Infrastructure**	**Security**
1. Rate the cleanliness and maintenance of your walking environment	5. Rate the provision of safe crossings along your route e.g. zebra crossings/ pedestrian malls/signalized intersections**	9. Rate the quality of pavement material	11. How much pedestrian oriented lighting is available along your route**
2. Rate the degree of path drainage along your route	6. Rate your sense of safety from injury caused by motorised transport	10. Rate the provision of walking space along the route**	12. Rate the level of human activity along the streets that make up your route
3. Rate the degree of obstruction along the route	7. Give a rating for the amount of moving motorised transport along your walking route		13. Rate your sense of personal security while walking along your route
4. Rate the provision of pedestrian oriented amenities such as dustbins and public seating along the route**	8. Give a rating of how you perceive the speeds of motorised transport along your route		
Demographic and general questions			
What is the most important factor associated with choosing your route?	How often do you walk to public transport in this area?	Did you walk indoors	Do you have access to motorised transport for this trip?
Gender	Age		

** Rating scale for questions runs from 0-5 to allow for the identification of routes where there is no provision made

In addition to the structured ratings of the user setting every 100 m and the route level questions submitted at the end of the assessment, respondents can also submit unsolicited media to provide evidence of walkability challenges. The value of doing this on mobile phones is that these visual and audio accounts are geo-referenced, giving authorities information that can be easily acted upon as they can see the extent of challenges and their exact location. As shown in Figure 14, the application leverages Google Maps within the application, allowing the user to confirm the location of their challenge before submitting media as part of the assessment.

Users are allowed to submit multiple images, voice notes and text notes as part of an assessment. The only limitation is the network credit the user has to upload information to the servers.

Figure 14: Media submission user interface

4.3 Dashboard

An online dashboard was developed to accompany the mobile application. The dashboard provides an environment for sorting assessments and viewing them overlaid on Google Maps within the dashboard, as shown in Figure 15. The route taken by the user is shown along with an indication of the locations where media was submitted during the assessment. The media can be reviewed within the dashboard by clicking the representative icon.

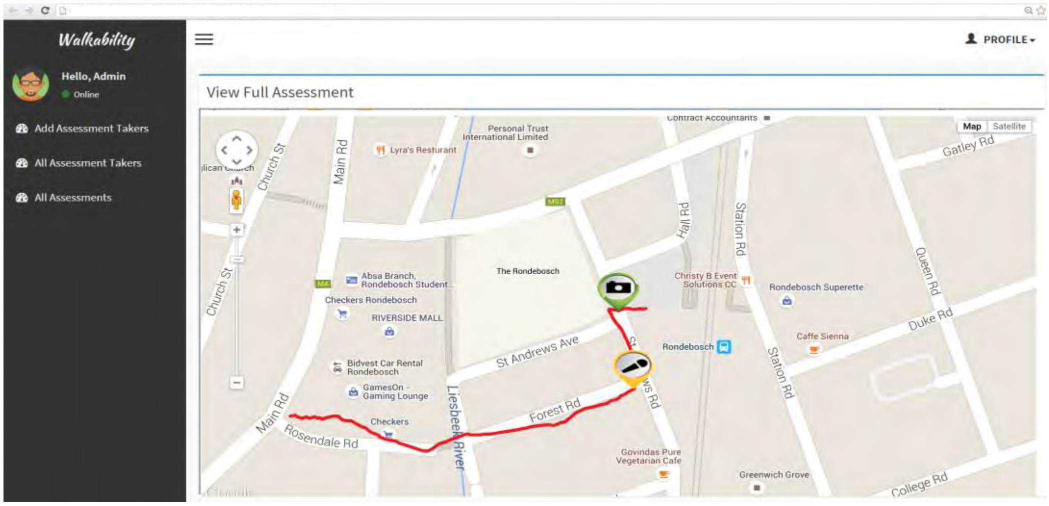


Figure 15: Google Maps Assessment overlay in the Dashboard

The most powerful features that the dashboard has, leverages the work that Google has done in mapping streets across the world. Google Street view can be accessed through the Dashboard and the media saved along the route can be reviewed while looking at the site features as shown in Figure 16. The voice note saved along the route shown in Figure 16 is presented at the GPS coordinates where the user uploaded it. By clicking on the icon the clip can be played within the browser.

Figure 16: Dashboard Google Street View integration

5 Mobile application pilot sites

The main public transport modes in Cape Town are: Mini-bus taxis, the Golden Arrow Local bus service, Metrorail (a division of the Passenger Rail Agency of South Africa, PRASA) and MyCiTi BRT. Massive investments have gone into the development of MyCiTi, the first phase of the system has NMT infrastructure running parallel with the bus route as well as streets within a 500 m buffer around stops seeing improvements. The next phases that are under construction are going to continue with their provision for pedestrians (Lewis, 2015b). Due to this focus on implementing BRT, it seemed appropriate that this be the system that was reviewed for pedestrian perceptions of walkability. However, it must be said that Metrorail accounts for the majority of passenger trips entering the Cape Town CBD (CCT, 2013b).

Following the South African choice of case study sites, the now defunct New Delhi BRT was chosen for testing the application. The development of the BRT saw the construction of pedestrian and cycle paths parallel to the bus lanes, along with parking for bicycles and auto-rickshaws[††] (Tiwari & Jain, 2012). In comparison to South Africa, Bus based public transport in New Delhi meets nearly half of the travel demand (Jain et al., 2014).

In an effort to get as much variability in the challenges faced by pedestrians, and consequently what the application could pick up, BRT stations were chosen on the basis of the surrounding land use. Three stops were chosen in each country, each being either: Residential, Mixed use or Industrial. A secondary requirement was that the station needed to have a high number of passengers alighting in order to meet the minimum requirements for employing the Spatial Statistical Analysis.

5.1 Cape Town

Summarised in the are the three BRT stations that were chosen for Cape Town

Table 6: Summary of Cape Town pilot sites

Station	Land use	Ridership
Gardens	Mixed use	Low
Woodstock	Industrial	Medium
Table View	Residential	High

[††] Three-wheel paratransit taxi running on compressed natural gas

5.1.1 Gardens

The Gardens MyCiTi station is located in the inner-city suburb of Gardens, the station forms part of the City Bowl feeder system and is situated underneath the M3 expressway bridge as shown in Figure 17 in close proximity to the M3 on and off-ramps as shown in Figure 18

Figure 17: Google street view of Gardens MyCiTi station under M3 Expressway

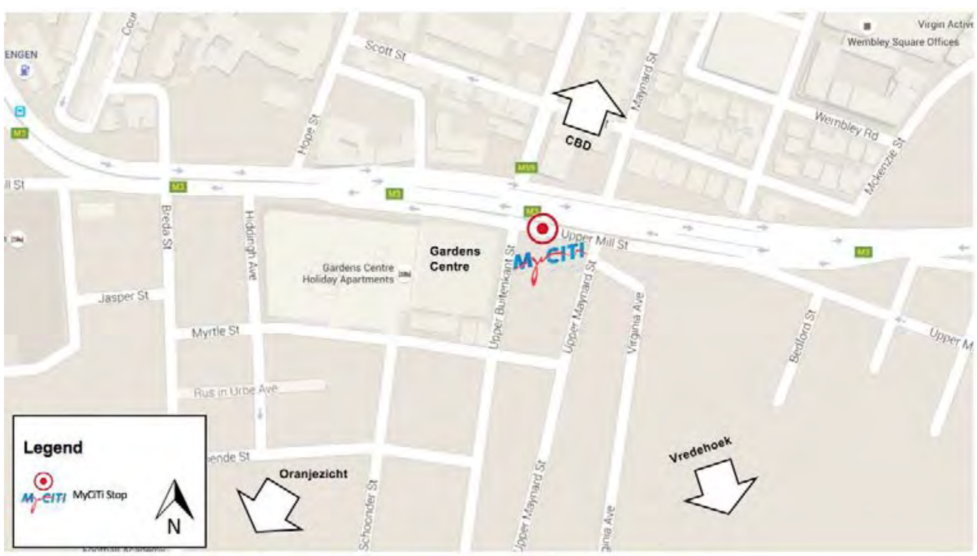


Figure 18: Gardens MyCiTi station environment

The Gardens stop was taken as the mixed use environment for the study, due it being an inner-city suburb with a number of offices, restaurants, shops and schools in close proximity to the MyCiTi Station. Figure 19 is a Google Earth 3D representation of the site with the Wembley Square mixed use development in the foreground, and the Gardens Centre and Apartments in close proximity to the station.

Figure 19: 3D Google Earth imagery of Gardens Station

5.1.2 Woodstock

The Woodstock station situated between the Cape Town docks and the Woodstock/Esplanade Metrorail stations as shown in Figure 20. The station lies on a portion of the MyCiTi Phase 1 trunk route that was not constructed on a pre-existing road; rather, a purpose built right-of-way was constructed along a servitude.

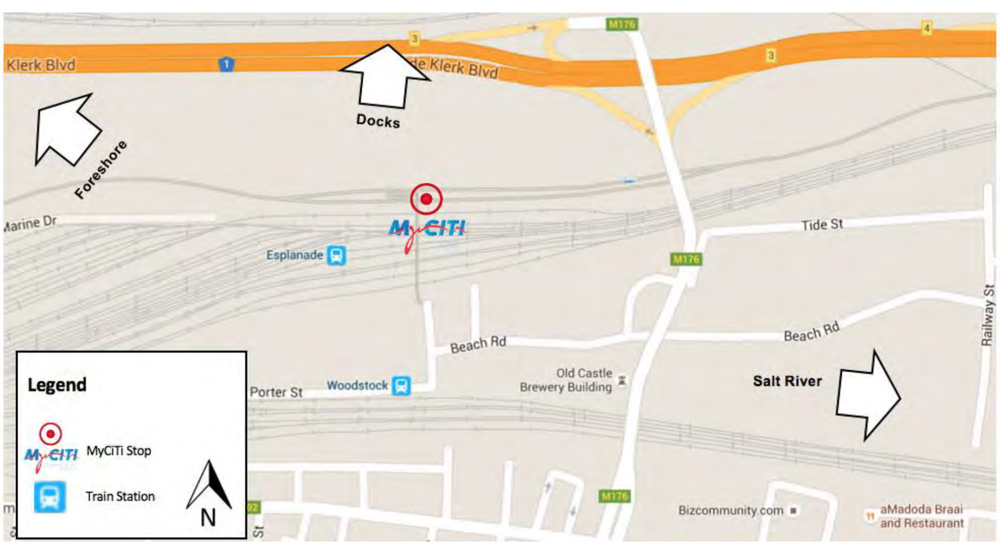


Figure 20: Woodstock MyCiTi station

The station was chosen as the industrial environment as it is close to the docks and there are a number of processing plants and warehouses. Figure 21 is a Google Earth 3D representation of the site; however, the imagery was taken halfway through the construction of the bus corridor, which is the mauve/pink strip by the station. The grading work done in preparation for the laying of the busway towards the M179 can be seen in the image, a pedestrian access path has subsequently been constructed, running parallel to the bus corridor and rising up to meet with the M179. Pedestrian also have access to an overhead walkway that passes over the Esplanade station platforms connecting to the Woodstock Metrorail station and beyond into Woodstock.

Figure 21: Google Earth imagery of Woodstock Station

5.1.3 Table View

The Table View station has the highest passenger volumes outside of stations in the City Bowl area. It is located along the West Coast of Cape Town on the Phase 1 trunk route, in the median of the M14 (Blaauwberg Road), just after the intersection with the R 27 (West Coast Road) expressway as shown in Figure 22. The Blaauwberg road cross-section is very wide with the westbound direction having six lanes vehicle lanes, including turning, at the intersection with the R 27 as shown in Figure 23

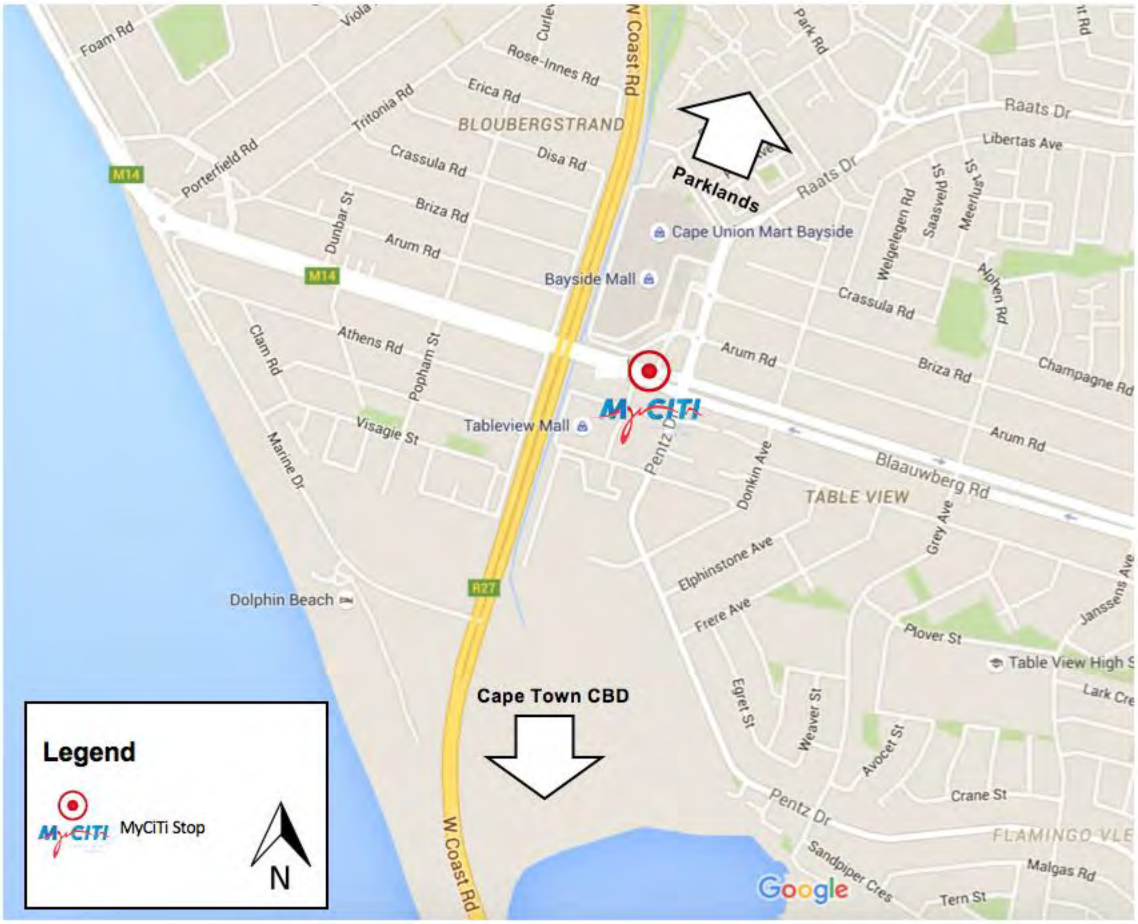


Figure 22: Table View MyCiTi station

Figure 23: Google Street View of Table View MyCiTi station

5.2 New Delhi

Summarised in Table 7 are the three stations that were chosen for New Delhi, ridership levels were not available for the different pilot sites.

Table 7: Summary of New Delhi pilot sites

Station	Land use
Modi Mills	Industrial
Sheikh Sarai	Residential
Pushpha Bhawan	Residential

5.2.1 Modi Mills

Modi Mills bus stop is located in Okhla Phase III an industrial area in Southern New Delhi. The stop is not located along the open BRT corridor, however, it was chosen due to there being no industrial areas along the 5.8 Km BRT corridor. The stop is located on the high volume Bhakti Vedant Swami road.

Figure 24: Modi Mills bus stop area

5.2.2 Sheikh Sarai

Sheikh Sarai is located in Southern New Delhi along the now defunct 5.8 km open BRT bus route. The bus station is located in the median of Lal Bahadur Shastri Road, as shown in Figure 25 just before an intersection with the Press Enclave Road. This site is largely residential area, however, there are two colleges in the neighbourhood.

5.2.3 Pushpa Bhawan

Pushpa Bhawan is located along the BRT corridor roughly 500 m from Sheikh Sarai along Lal bahadur Shastri Road. The station has formal commercial land uses along with housing in the area, and was taken as the mixed use environment in the study.

Figure 25: Google Earth image of Sheikh Sarai and Pushpa Bhawan Stations

6 Analysis of data from pilot studies

The case study stations for the piloting of the application were introduced in Chapter 5. This chapter presents the summary statistics for the walking surveys in Cape Town and New Delhi. Respondent egress routes were mapped, showing the areas people walk to from the respective stations. Ratings provided by respondents to route level questions, which were presented in Chapter 4, guide the identification of challenges for further investigation using Cluster Analysis. Candidate dimensions for the Cluster Analysis are chosen on the basis of the dimension containing the lowest scoring element. The Anselin Local Moran's I is then used to identify 100 m segments along egress routes where there are statistically significant clusters of low/high ratings for the dimension under investigation. Supplementary media, related to the dimension under investigation is shown in order to better understand the challenges faced by pedestrians.

6.1 Cape Town analysis

A total of 309 respondents formed part of the Cape Town pilot; across the stations the lowest gender split was in Woodstock where just over a third of the respondents were female. In Gardens the majority of the respondents were female, while in Table View the gender split was ~57%/43%. The age breakdown is provided for the survey is provided in Table 8. Very few people over the age of 50 were captured in the surveys.

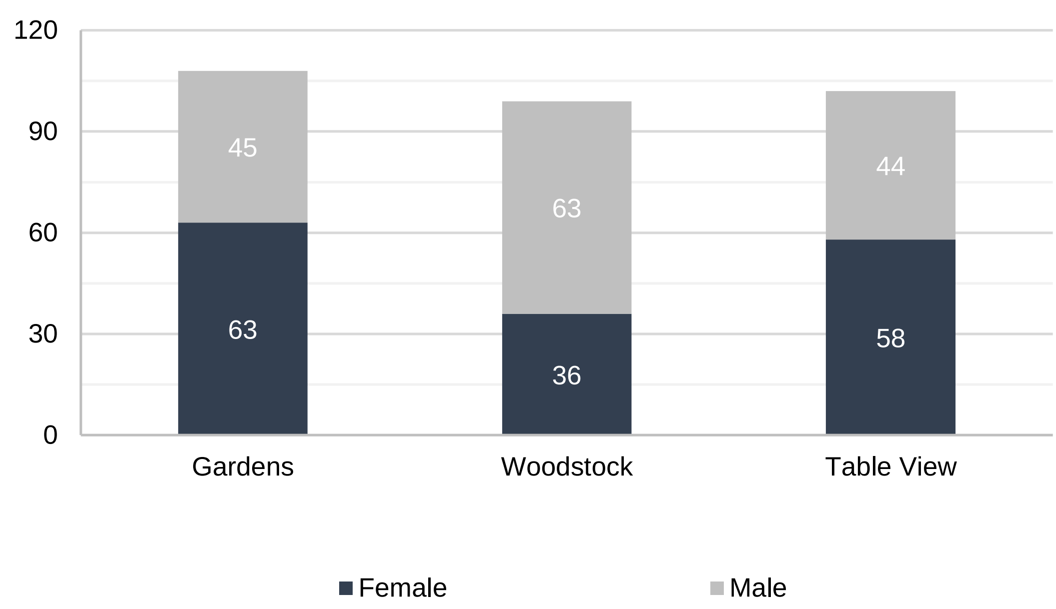


Figure 26: Cape Town gender breakdown at each station

Table 8: Cape Town pilot respondent age breakdown

Age bracket	Gardens	Table View	Woodstock
18-29	48	49	47
30-49	51	49	48
50+	9	4	4

As shown in Figure 27, the majority of people in Gardens and Woodstock rely on walking for their egress trip. However, a caveat to this is that some trips may be in close proximity to the station and using a vehicle would be impractical. In Table View, just over half of the respondents have access to private motorised transport for their walking trip; this is expected in what is largely a residential area.

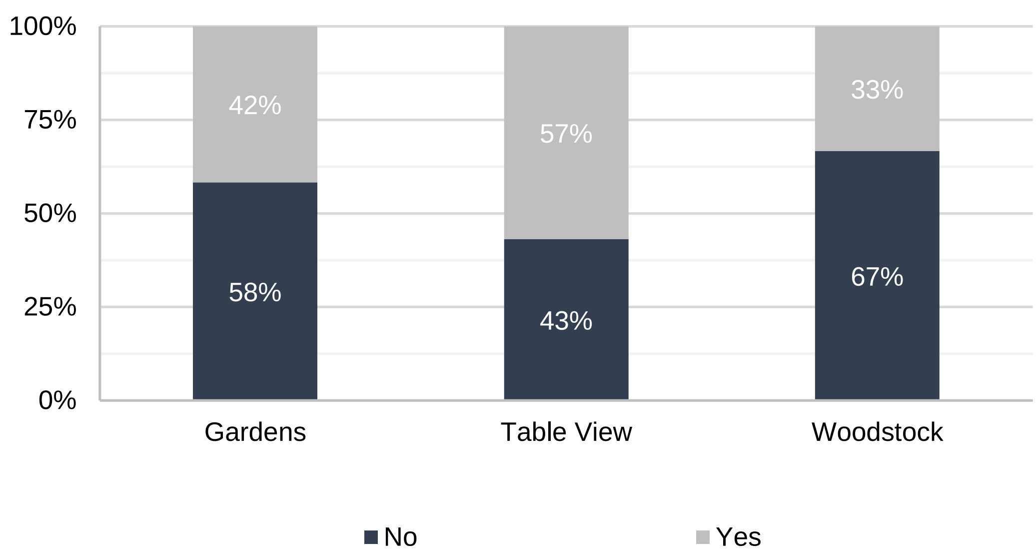


Figure 27: Cape Town respondents' access to motorised transport for egress trips

The majority of people on their egress trips across the three stations frequently walk to public transport in the area[‡‡], thus it is likely that they have a rich set of experiences and exposure in the environment, which can help in appreciating walkability challenges.

[‡‡] Frequent walkers were calculated by summing the number of people that walked to public transport daily and weekly, while infrequent is a summing of people that walk in the area at least once a month

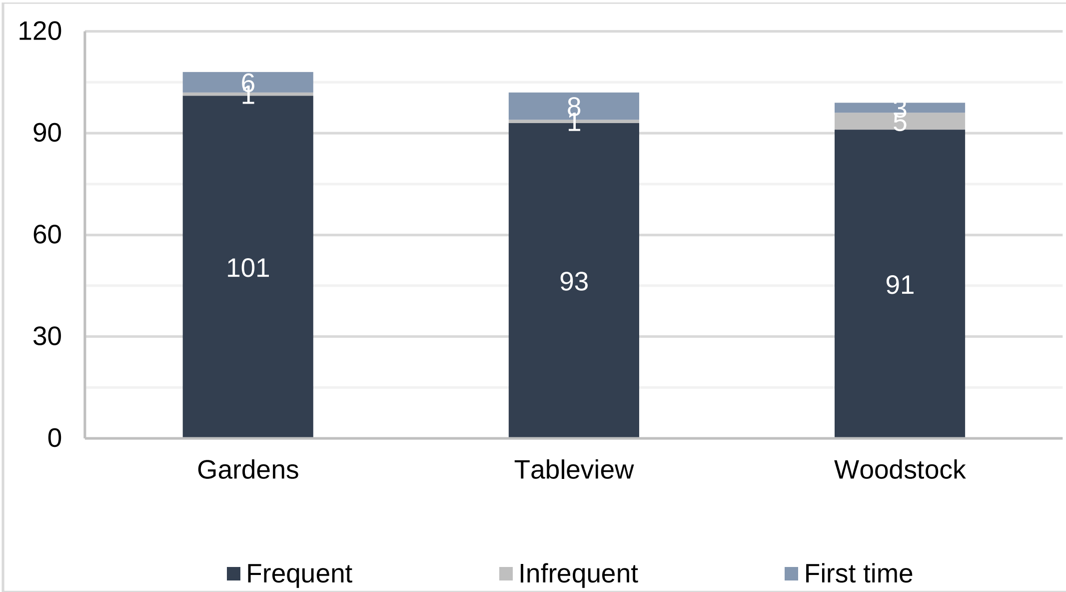


Figure 28: Breakdown of how frequently respondents walk to public transport in the different areas

6.1.1 Gardens

The mapped GPS traces for Gardens are presented in Figure 29. The majority of trips were from the MyCiTi stop to the Gardens Centre, which is just over 100 m from the MyCiTi stop. Although the majority of respondents were moving onwards to their final destination after their stop at the Gardens Centre, the design of the pilot only allowed for the capturing of this initial segment in the trip chain. Summary statistics from the routes are provided in Table 9, ,the longest walking trip is 1.4 km while the shortest is 22 m, with a mean walking distance of 214 m. Although MyCiTi buses run up to the neighbourhoods of Oranjezicht and Vredehoek, where some of the longer walking trips ended, respondents chose to make the walking trip.

Table 9: Gardens walking distance summary statistics

Statistic	**Distance (m)**
Mean	214
Max	1446
Min	22
75 Percentile	233

Figure 29: Gardens respondent egress routes

The majority of the respondents cited time saving as the primary reason for them choosing their route as shown in Figure 30, however 16 % of respondents chose their route due to the provision of a pedestrian path.

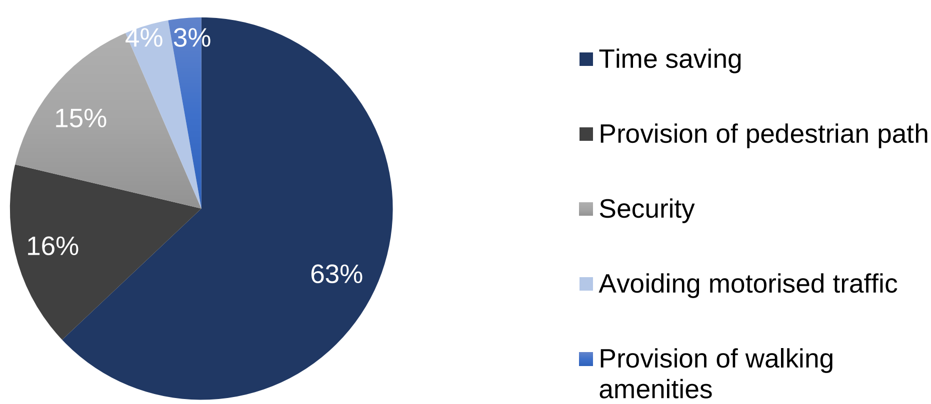


Figure 30: Gardens: Respondents' reasons for choosing egress route

Radar plots of the average score from the Likert Scale responses to the route level walkability questions are plotted in Figure 31, the red dotted line indicates questions that had a 1-5 scale, while questions 4, 5, 10, 11 allowed for respondents to indicate where no provision was made, which was assigned a value of 0.

Looking at the radar plot, one sees that all the dimensions (Comfort, Safety, Infrastructure, and Security) have elements that are scoring below 3. The lowest scoring question was the availability of safe crossings, with an average score of 1.4, followed by the provision of pedestrian oriented lighting with an average score of 1.6. High average scores for questions 2, 3 and 9 indicate that the sampled routes are have few obstructions for pedestrians and the degree of path drainage as well quality of pavement material, are perceived to be very good.

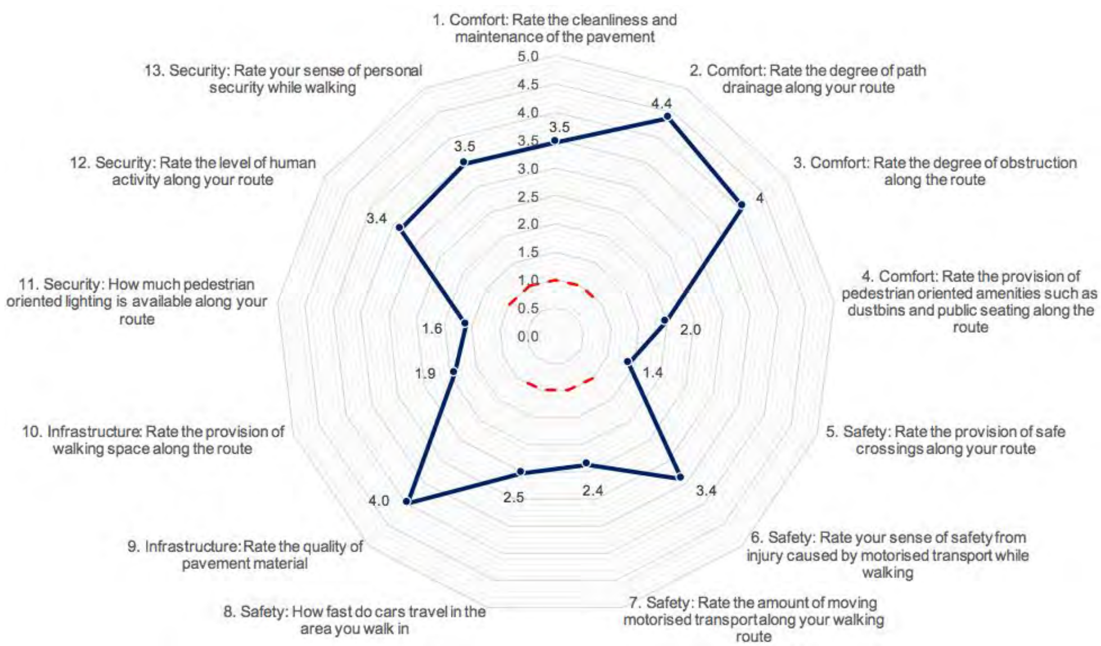


Figure 31: Radar plot of responses to route level questions at Gardens station

A cluster analysis was run on the segment ratings for the Gardens station for each of the walkability dimension, these dimensions were mapped. Only the Safety dimension with the lowest scoring element is discussed, the rest of the maps are in the appendix in chapter 9.

South Africa follows the left hand driving rule and it is interesting to note that the low Safety ratings cluster while respondents are walking along the M3 and on the off-ramp leading down towards the station as shown in Figure 32. High Safety ratings cluster as one moves away from the station towards access streets as well as on the M3 on-ramp. The clustering of high ratings on access streets is to be expected as volumes and speeds can be low, however, a traffic light controlled intersection before the M3 on-ramp may explain the high cluster around the expressway as although vehicle volumes might be high, speeds are likely to be lower as vehicles are starting from a standstill.

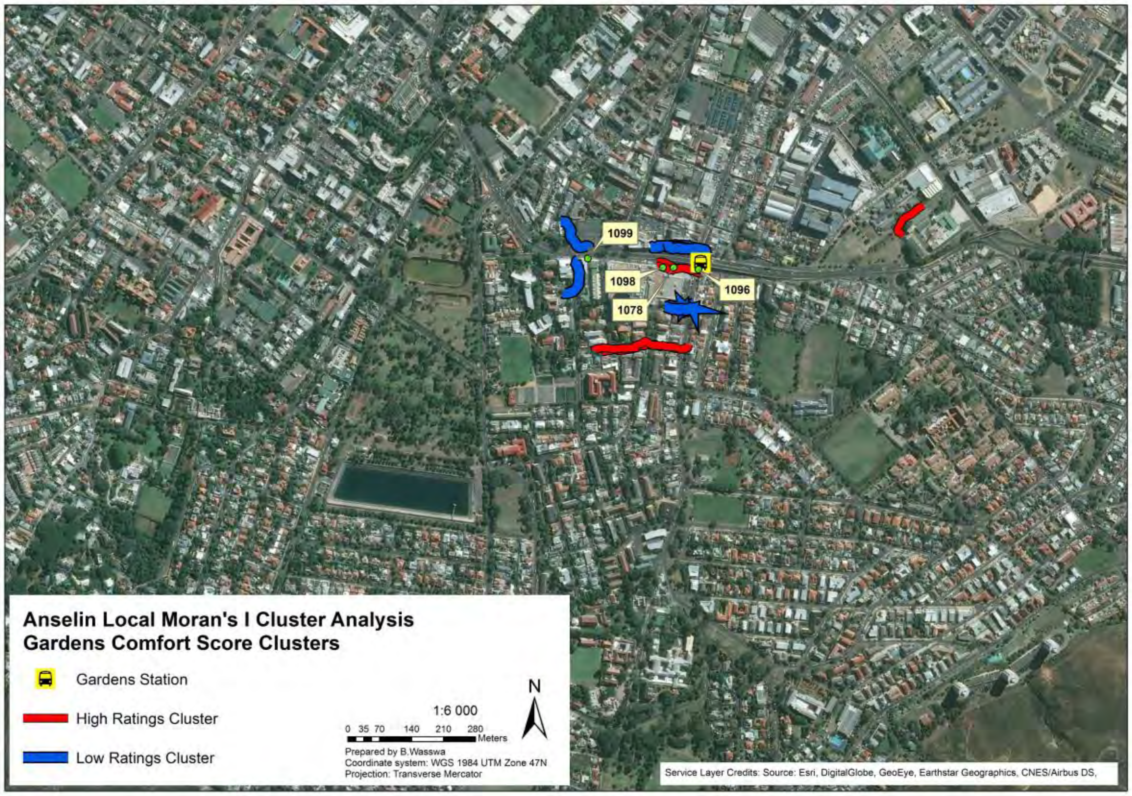


Figure 32: Gardens Safety Cluster Analysis

Media ID numbers have been plotted on the map, showing submissions that are related to Safety. Almost all of the respondents provided voice notes for the station, and the transcripts of the submissions are provided below.

(1096) Female, 18-29, walks daily to public transport in Gardens

*"At the Gardens bus stop, there's always a problem because the **buses park over the pedestrian crossing which makes it unsafe for me to cross the lights** when I arrive in the mornings"*

(1078) Male, 30-49, walks daily to public transport in Gardens

"...[W]hile walking from the shops, ***people always get confused as in how they actually get onto the bus****...Some are not familiar...* ***instead of going to the entrance of the station, they go right to the actual bus****. They get confused on how they actually board the bus****. It's kind of like signage where people actually need information****"*

(1099) Female, 30-49, walks daily to public transport in Gardens

*"****On a daily basis there is hooting, screeching of tires, because it seems that…there is some direction of traffic where the cars never want to wait for the other ones to pass****...it does kind of* ***make me anxious because when you hear screeching of cars you expect to hear a bang that there is an accident****. I never want to be around when that is happening because a car can be coming in any direction, so it does make me a bit anxious. I don't know if they need to work on the way they time these [traffic lights]"*

Media submissions 1096 and 1078 are related to crossing and way finding, which are elements of pedestrian road traffic safety. Figure 33 is an image taken by a survey facilitators showing how these challenges manifest. Due to scheduling shortcomings, buses stack up at the station, encroaching on the pedestrian crossing in order to make space for incoming buses. With respect to way finding, having access doors on the left and right can cause confusion as people approaching this intersection may think they have access to the bus. When unable to board the bus they find themselves in the middle of the intersection which poses a threat to their road traffic safety.

Figure 33: MyCiTi bus encroaching on pedestrian crossing at Gardens Station

Media submission 1099 was provided while walking along the M3, a screen shot from the dashboard was taken while viewing the submission location in Google Street View, with the microphone icon indicating the location where the submission was made.

The intersection referred to by the respondent is the M3 with Breda/Hopeville Street. Feelings of anxiety due to aggressive driving are valid walkability concerns, and if we seek to develop pedestrian safe access to public transport then this needs to be addressed. With a planning paradigm that struggles to reconcile the needs of pedestrians with established automobile planning practices as discussed in section 2.1.2, such anecdotal evidence can be used to push for more pedestrian oriented design around public transport.

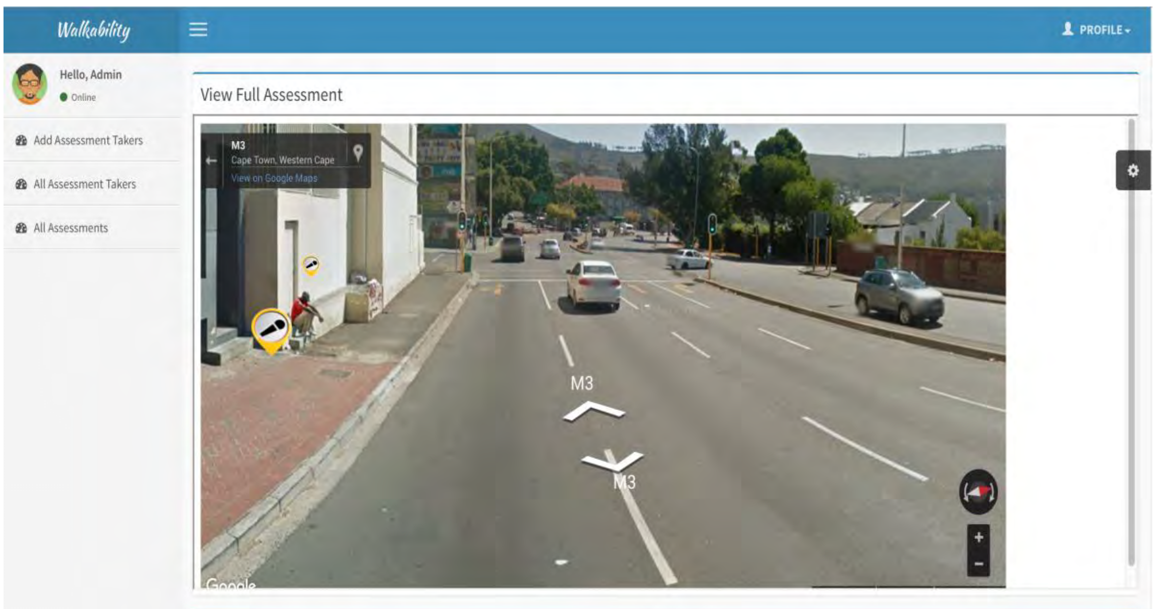


Figure 34: Dashboard Google Street ViewM3/Breda-Hopeville intersection

6.1.2 Woodstock

The majority of the respondents from Woodstock chose to exit the station area by passing over the Esplanade and through the Woodstock Metrorail PRASA train stations, resulting in a lot of overlapping routes along that channel. A lot of respondents were transferring from the MyCiTi bus to the Esplanade/Woodstock trains, which restricted the segments that were evaluated outside of this predominantly transit environment, however, the mean walking distance of 410 m is the greatest among the three cases in South Africa. Once through the Woodstock station, the routes branched out, as can be seen in Figure 35 with the furthest egress trip being 1.4 km.

Table 10: Woodstock walking distance summary

Statistic	Distance (m)
Mean	410
Max	1490
Min	88
75 Percentile	499

Figure 35: Woodstock respondent egress routes

The primary reason for respondents choosing their egress route in Woodstock was indicated as time-saving, however just over 20% of respondents indicated that security was the most important factor in selecting the route. Along with directness of route, security can probably explain why respondents chose to pass through the Woodstock train station in order to access the Woodstock neighbourhood. The station environment is expected to have high volumes of people while the dedicated pedestrian route constructed by MyCiTi passes through an area that does not have human scale development and is not expected to attract pedestrian activity.

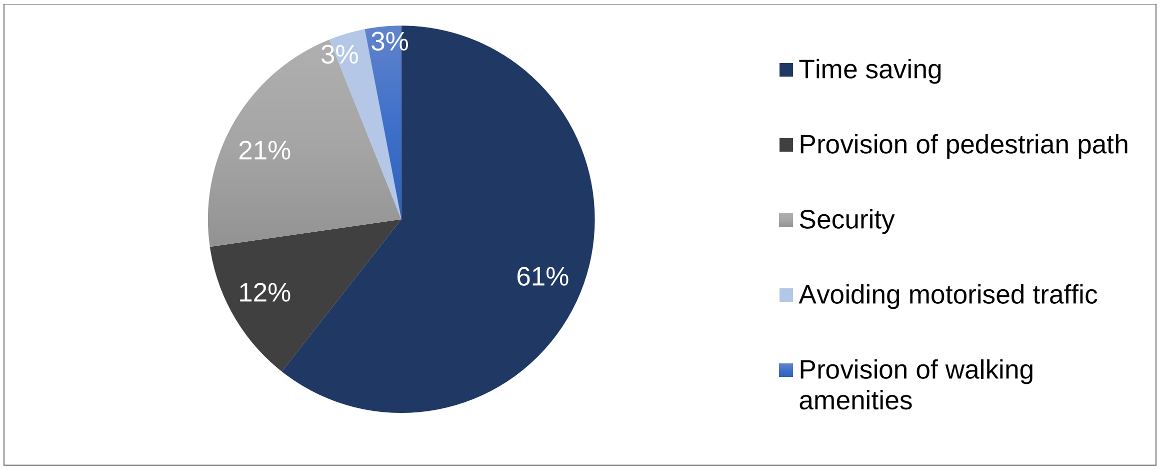


Figure 36: Woodstock station - respondent reasons for choosing egress route

A review of the radar plot, Figure 35, for the Woodstock respondents further reinforces inference made regarding security being second most common response for the reason an egress route was chosen, and respondents passing through the train stations. One can see that the level of human activity has a high average rating, however, a challenge is that respondents did not observe a high degree of pedestrian oriented lighting along their egress routes.

The Safety dimensions performed very well with the provision of safe crossings being the laggard, performing poorly. This is to be expected as most of the respondents walked across a pedestrian bridge, through to the Woodstock train station where interaction with vehicles is limited. The poor performance of the provision of safe crossings is due to the pedestrian over bridge which pedestrian have to make use of in order to pass over Esplanade station. In the mobile app question response drop down menu, examples were given of good crossing facilities vs. poor crossing facilities, with overpasses being listed as being poor provision, as pedestrians have shown a preference for at grade crossings

The poorest performing element was that of the provision of pedestrian oriented amenities under the Comfort dimension, with an average score of 0.7 (0-5 scale). The cluster analysis map, Figure 38, shows that low Comfort ratings cluster in close proximity to the BRT station as well as passing through the Woodstock train station. Once respondents exit the station environment, clusters of high ratings are observed.

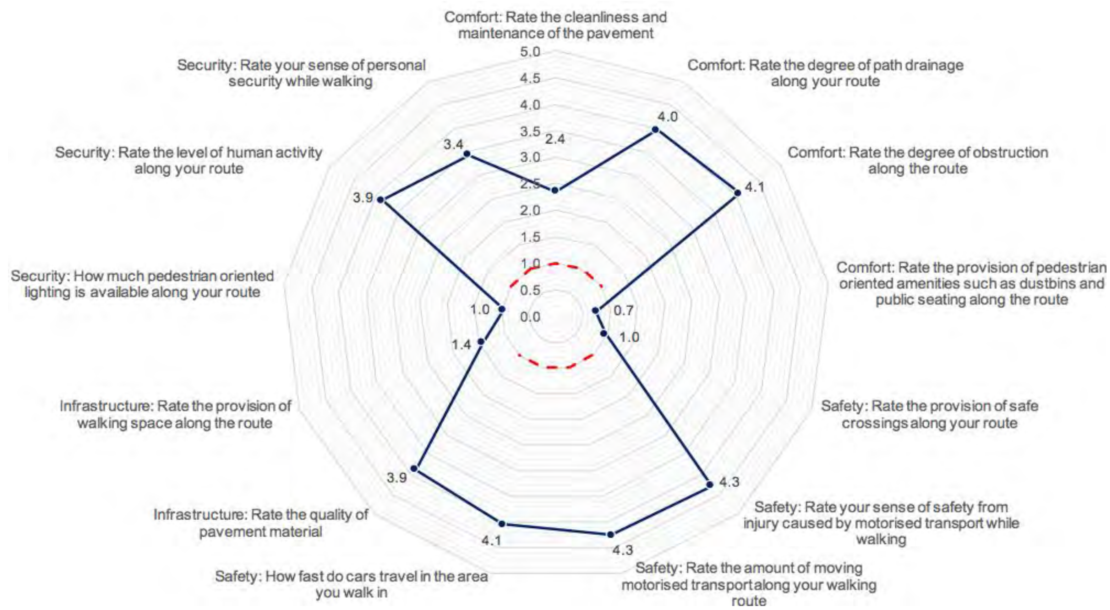


Figure 37: Radar plot of responses to route level questions at Woodstock station

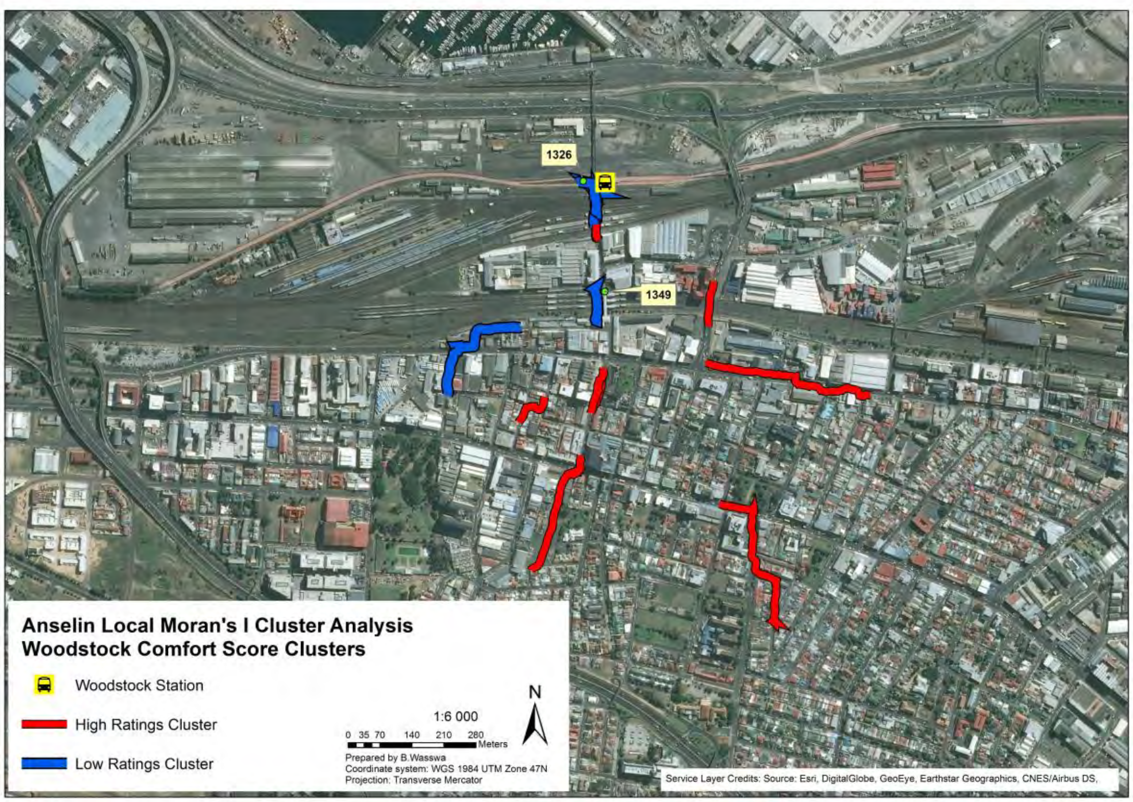


Figure 38: Woodstock Comfort Cluster Analysis

Two media submissions for the Woodstock station were related to the Comfort dimension. Submission 1326 was taken on the pedestrian bridge leading up from the MyCiTi stop, connecting users to the Esplanade pedestrian overpass. Although bins are made available immediately outside the BRT station, none are provided along the pedestrian walkways. As a result, bus users do not have a bin to dispose of their waste, and the environment. Without active cleaning and maintenance of the station environment, this behaviour becomes reinforced as can be seen in the image where new peals have been added to the pile.

Similarly, submission 1349, which is an image taken of what look to be faeces on stairs leading into the Woodstock train station. This was present throughout the time that the intercept surveys were being done at the Woodstock station, and made respondents feel they were not in a clean and well maintained environment.

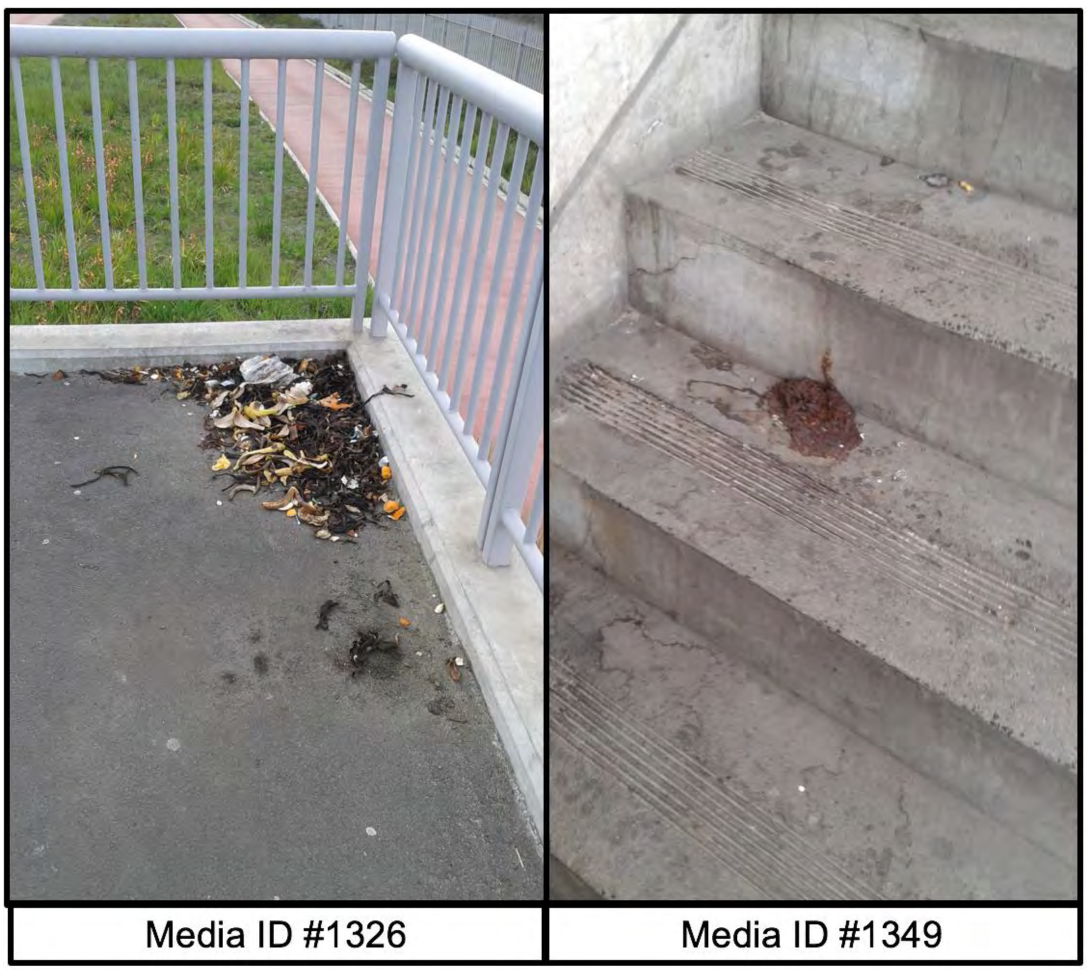


Figure 39: Woodstock respondent media submissions related to Comfort

Addressing the provision of pedestrian oriented amenities that can contribute to a comfortable egress trip is challenging in Woodstock. Respondents opted to use the direct route through the Woodstock/Esplanade stations as opposed to the circuitous route constructed by MyCiTi that links with the M176, leading down to Albert Road. Thus any effort to provide for pedestrian amenities would require coordination between the rail and BRT service providers in order to better serve customers which the mapping of egress trips has shown they share.

1.1.3. Table View

Similar to respondents from the Gardens station, the majority of respondents from Table View made a stop at the shopping malls on either side of the station before moving onwards to their final destination. Due to the design of the pilot, only the first segment of this trip chain could be captured.

The longest egress trip is 1.3 km, while the mean walking distance is 203 m, however the 75th percentile distance is less than the mean distance. This can be attributed to the effects of outliers, where 5% of the egress trips exceeded the mean by over 200%.

Table 11: Table View walking distance summary statistics

Statistic	Distance (m)
Mean	203
Max	1302
Min	43
75 Percentile	173

As with the other two stations, the majority of respondents picked their route due to time savings which it afforded, while one sixth stated security as the most important factor is selecting their route. This has consistently been ranked 2nd across the respondents that formed part of the South African pilot.

Figure 40: Table View respondent egress routes

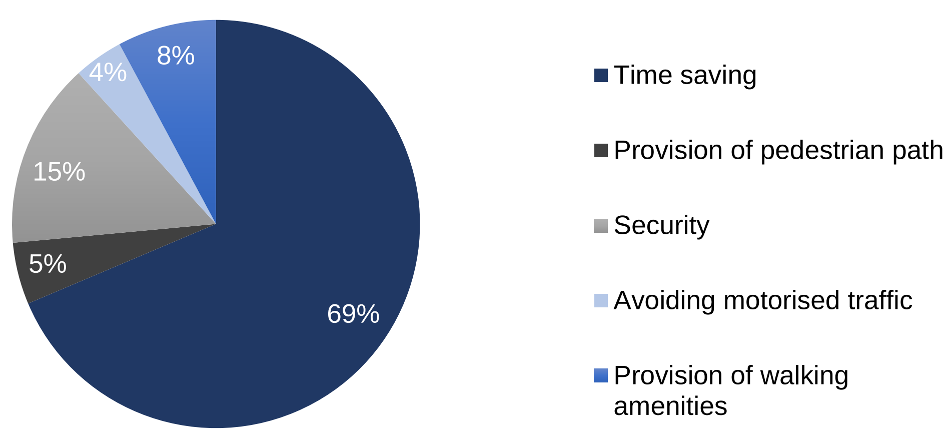


Figure 41: Respondent reasons for choosing egress route, Table View station

Respondents in Table View rated Comfort relatively high, however, there was a lack of provision of pedestrian oriented amenities in the area as can be seen in Figure 41. Although a lot of investment has been made in an effort to make the immediate Table View station environment pedestrian friendly, respondents walking to the shopping malls adjacent to the station pass through parking lots which have been positioned at the entrances of the malls. These environments often provide little in the way of pedestrian amenities and this can explain why the ratings for this element are so low. This presents a challenge to Transportation Planning Authorities, as they may be required to engage with private land owners to support their efforts to improve pedestrian access to their developments and rein in auto-centric development configuration.

As pedestrians leave the station area and continue walking along public neighbourhood streets, a lot of pedestrian provisions are no longer made. This could also explain why the provision of walking space got a poor rating in Table View, as away from the station, access streets within neighbourhoods do not have any sidewalks. It could be argued that these streets have slow moving traffic and low volumes of vehicles, thus sidewalks are not required. However, without dedicated space along streets pedestrians may still be vulnerable if walking in the road under low visibility conditions.

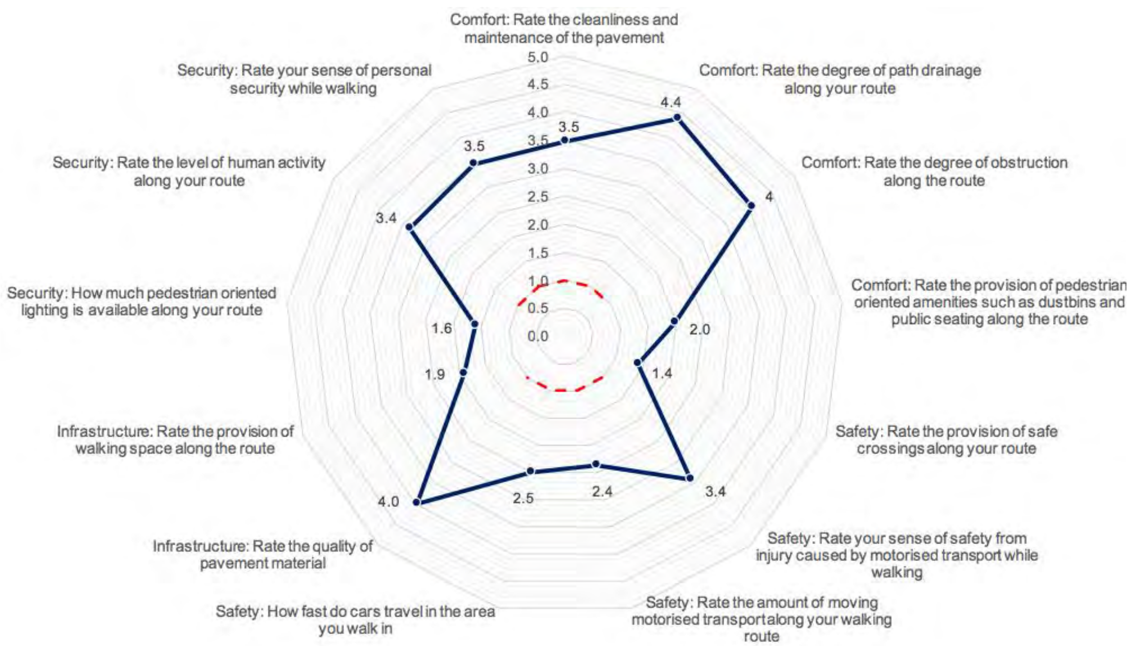


Figure 42: Radar plot of response to route level questions at Table View station

The Safety rating clustering for the Table View station is mirrored around the M14 as shown in Figure 43. High scores clustered on the East bound side of the M14, while high clusters were clustered on the West bound lanes of the M14. A possible explanation for this may be that the conducting the intercept surveys in the evening resulted higher volumes of vehicles entering the Table View area as people may have been returning to the suburb using the R 27.

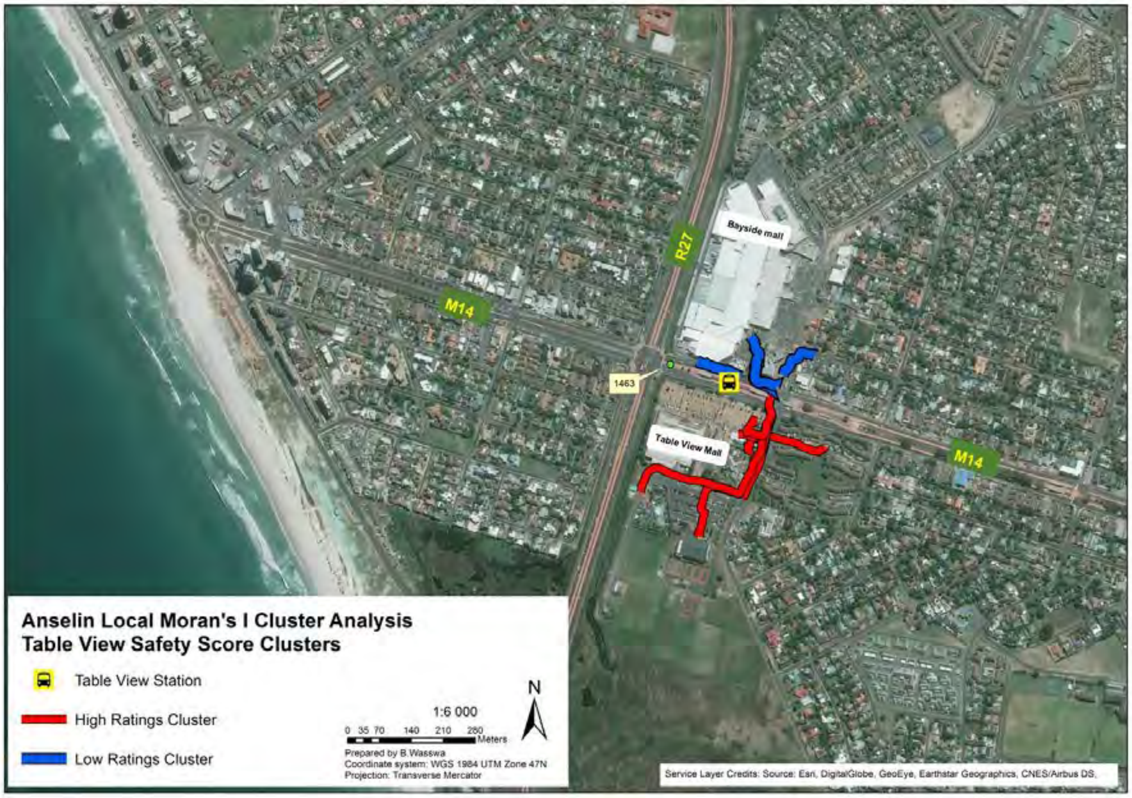


Figure 43: Table View Safety Cluster Analysis

Only one of the respondents submitted media in support of the assessment. A transcription of one of their voice notes, related to road traffic safety, is provided below.

(1463) Female, 30-49, walks daily to public transport in Table View

"This intersection between the R27 and Blaauwberg Road is a very dangerous intersection. So what I used to do is when I cross the road I know it's jaywalking and you not supposed to do that, but there used to be an opening…which was much easier to cross over than at the intersection which is actually quite strange…On the R27 when you turn left to go to town and the arrow for the people to turn left is on, the little [man] that allows us to walk is also on and the motorists don't yield for the pedestrians.

The account speaks to the coping mechanisms that pedestrians have to rely on in environments that are not fully supporting walking trips. Although the respondent acknowledges that she should not be jaywalking, the helplessness felt at the intersection forces her to engage in an activity, which from her account she otherwise would not.

The challenge experienced at the intersection is related to a lack of sensitivity to pedestrians when setting signals at intersection. Although drivers are supposed to yield to pedestrians, this is not occurring, thus putting pedestrians in a precarious position. This challenge is significant for the Table View station, as it has the highest boarding and alighting numbers of outside of the CBD. One would presume that the majority of access and egress trips are made on foot, yet in the immediate station surroundings the needs of pedestrians are still subservient to motorised transport.

6.2 New Delhi analysis

A total of 229 respondents formed part of the New Delhi pilot, fewer women were intercepted at Modi Mills stop, which is located in an Industrial area. However, at Pushpa Bhawan and Sheik Sarai, there was an improved gender split with female respondents representing at least 40% of the cohort at both stations.

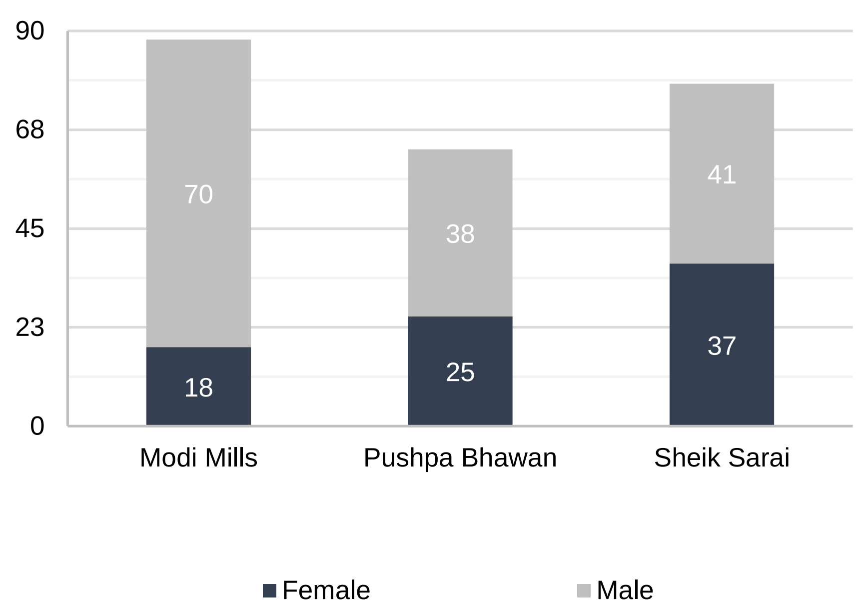


Figure 44: New Delhi pilot gender breakdown

The respondent age breakdown provided in Table 12, indicates that the majority of people in the sample were in the 18-29 age bracket.

Table 12: New Delhi pilot sample age breakdown

Age Bracket	Modi Mills	Pushpa Bhawan	Sheik Sarai
18-29	53	36	39
30-49	29	24	25
50+	6	3	14

New Delhi has a vibrant paratransit system, with motorised auto rickshaws providing last mile services for transit users. Over 50% of respondents from Pushpa Bhawan indicated that they had access to motorised transport for their egress trip, while in Sheik Sarai just a third of people had these services available. As with Cape Town, there is a caveat, as although auto rickshaws (motorised transport) are present alongside bus stations, it may not make economic sense to take them for short egress trips.

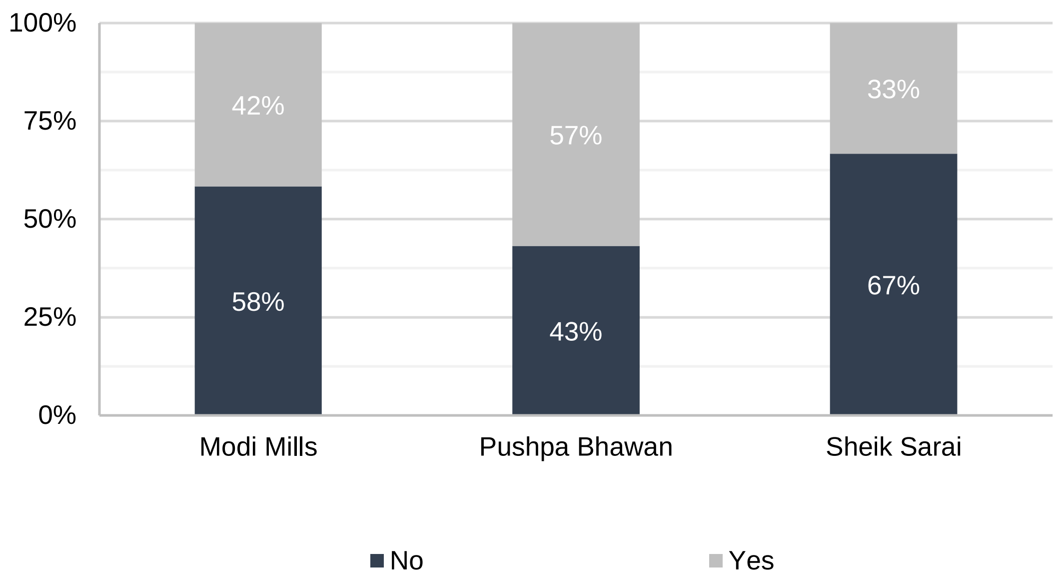


Figure 45: Respondents' access to motorised transport for egress trip, New Delhi

As with Cape Town, the majority of respondents from New Delhi frequently walk to public transport as shown in Figure 45.

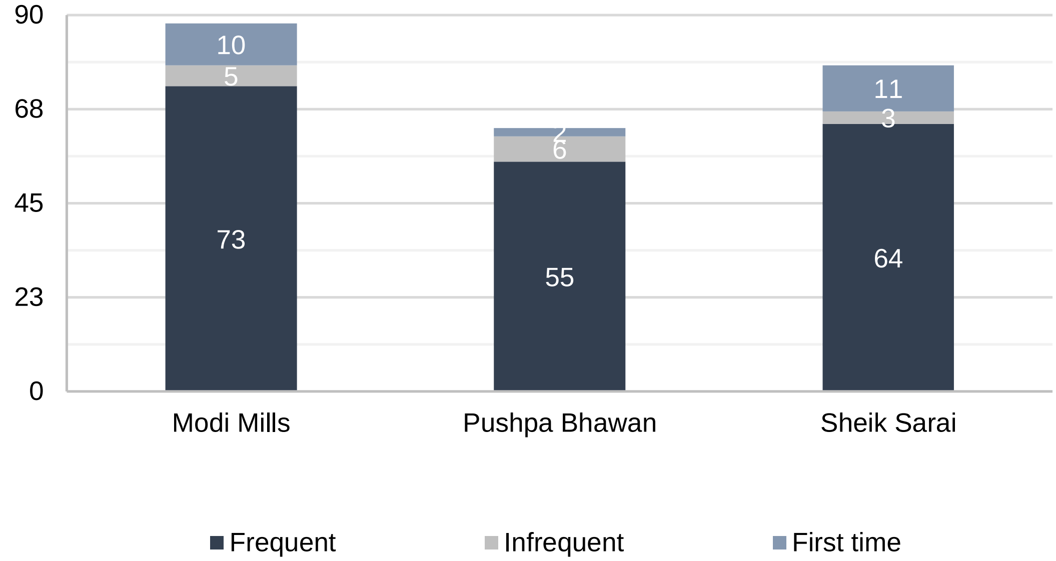


Figure 46: Breakdown of how frequently respondents walk to public transport, New Delhi

6.2.1 Modi Mills

The mapped GPS traces presented in Figure 47 for Modi Mills are concentrated on the southbound side of the road, with many of the egress trips terminating in the Ohkla Phase III industrial area. From the map one can see that the route into the industrial area is circuitous, with only a single access point. Summary statistics from the routes are provided are provided in Table 13, the longest walking trip is 714 m with a mean walking distance of 308 m.

Table 13: Modi Mills walking distance summary statistics

Statistic	Distance (m)
Mean	308
Max	714
Min	48
75 Percentile	437

Figure 47: Modi Mills egress trip routes

The majority of the respondents cited time saving as the primary reason for them choosing their route as shown in however, provision of a pedestrian path and security were the tied as the second most cited reason for choosing walking routes

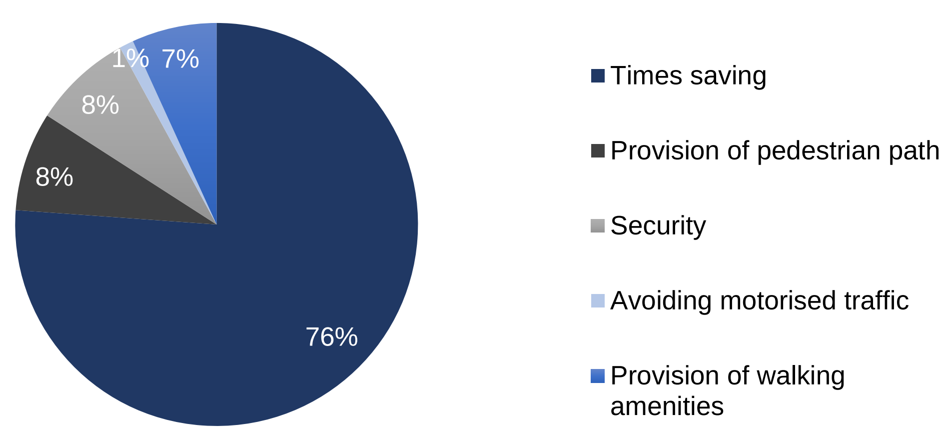


Figure 48: Respondents' reasons for choosing egress route, Modi Mills stop

The Comfort dimension had the lowest scoring element, with users perceiving a lot of obstructions along their egress routes as shown in, Figure 49, while, the Security dimension had the highest average score at 3.4 across all elements.

Global autocorrelation tests for the Modi Mills dataset yielded no statistically significant clustering of segment ratings for the Comfort dimension. All but the Infrastructure segments scores passed global tests of autocorrelation and thus although not the dimension with the weakest element ratings, clusters for the Infrastructure dimension are presented in Figure 50. Clusters of high ratings are seen within a few 100 m of the station, however, moving further away from the station, clusters of low ratings are observed.

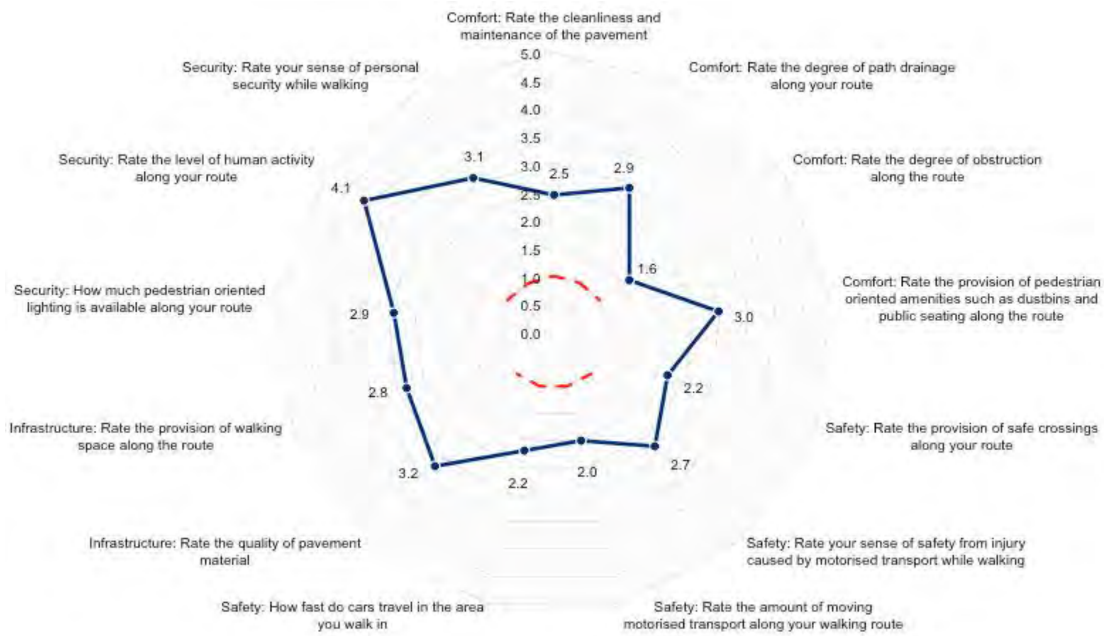


Figure 49: Radar plot of response to route level questions, Modi Mills stop

The media submissions in Figure 51 indicate the massive challenges associated with pedestrian walking infrastructure moving away from the bus stop. The paving is in a state of disrepair as depicted in submission 641 and 592, while manholes missing covers present a threat to pedestrians making use of the sidewalk under low light conditions.

Although the Ohkla Industrial area has provisions for pedestrians, these are either piecemeal with some sections having good provision while others are in a state of disrepair, or they are encroached upon by motorised transport. Images within the Ohkla Industrial area were taken by survey facilitators to provide insight into these low scoring clusters.

Figure 52 presents a segment with good provision for pedestrians side by side with an encroached stretch showing inconsistencies in access to pedestrian infrastructure.

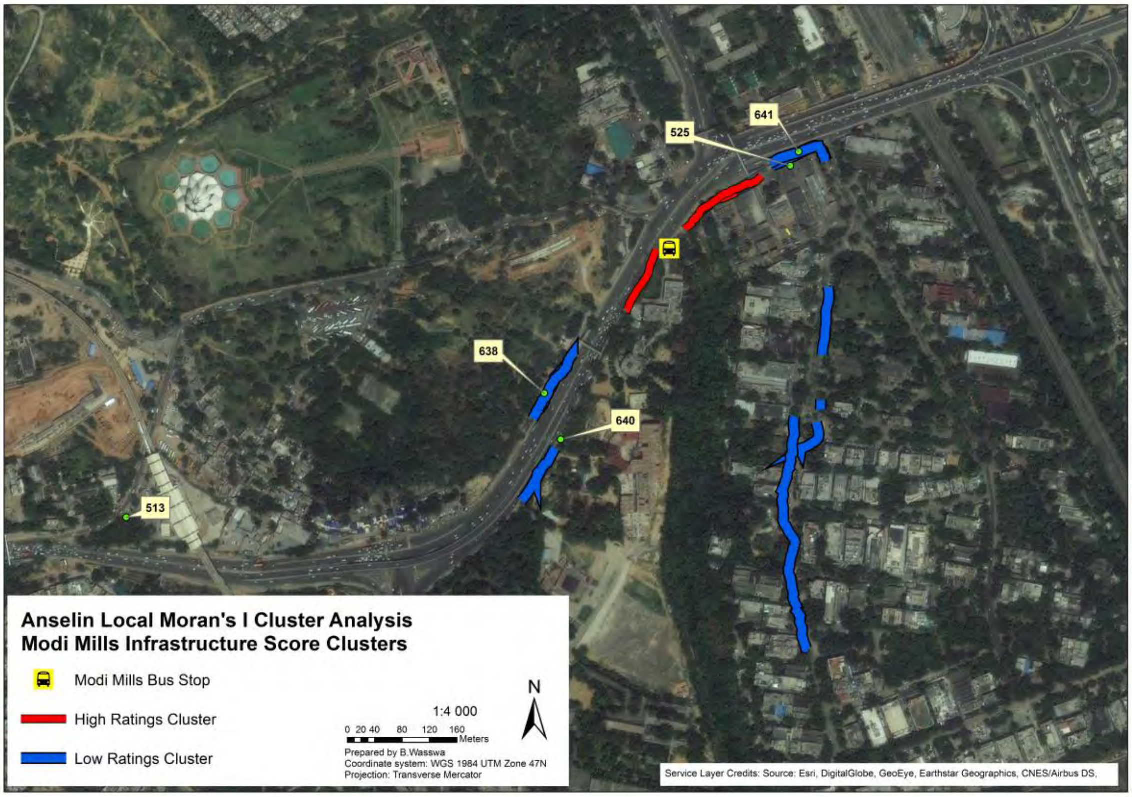


Figure 50: Modi Mills Infrastructure Cluster Analysis

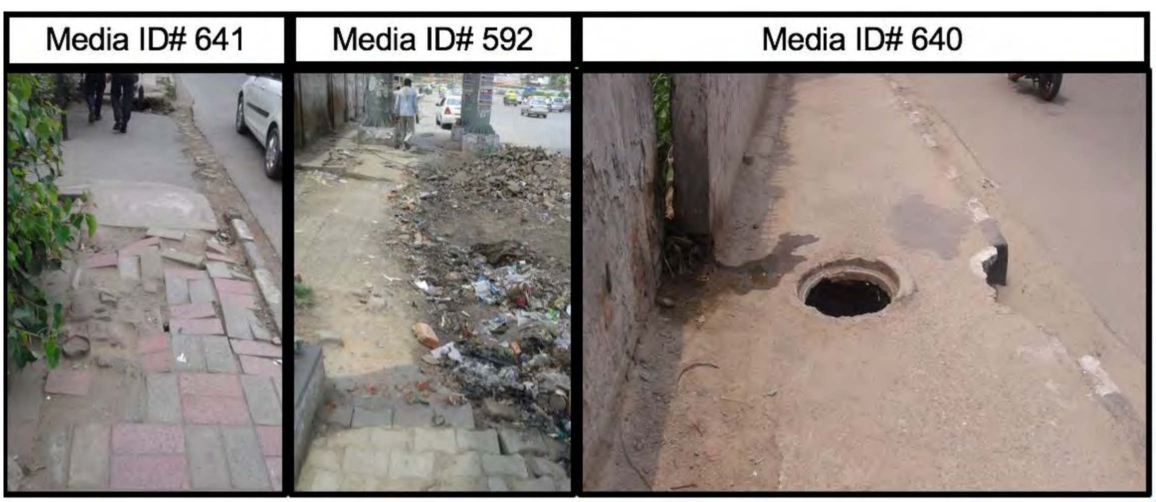


Figure 51: Modi Mills respondent media submissions related to the Comfort dimension

Figure 52: Contrasting pedestrian experiences in Ohkla Industrial Area

6.2.2 Pushpa Bhawan

The majority of egress trips made from the Pushpa Bhawan station were into the Madangir/Dakshin Puri colonies, to the east of the Pushpa Bhawan station. Unlike the egress trips from Cape Town that were dendritic, those made from Pushpa Bhawan are linear in nature. The routes run perpendicular to the bus line, this can partly be explained by the bus stops being within 500 m of one another along the BRT corridor, thus pedestrians get off at the stop with the most direct route to their destination.

Summary statistics from the routes are provided in Table 14, the longest walking trip is 1.2 km with a mean walking distance of 422 m. These statistics were the highest for all the three pilot sites.

Table 14: Pushpa Bhawan walking distance statistics

Statistic	Distance (m)
Mean	422
Max	1179
Min	115
75 Percentile	470

Figure 53: Pushpa Bhawan respondent egress routes

As with the other station, the majority of the respondents cited time saving as the primary reason for them choosing their route, as can be seen in Figure 54, while the second most important factor was security.

The Comfort, Infrastructure and Security dimensions had average ratings under 3, while the lowest scoring walkability element was the degree of obstruction along the walking path. The Comfort dimension cluster map

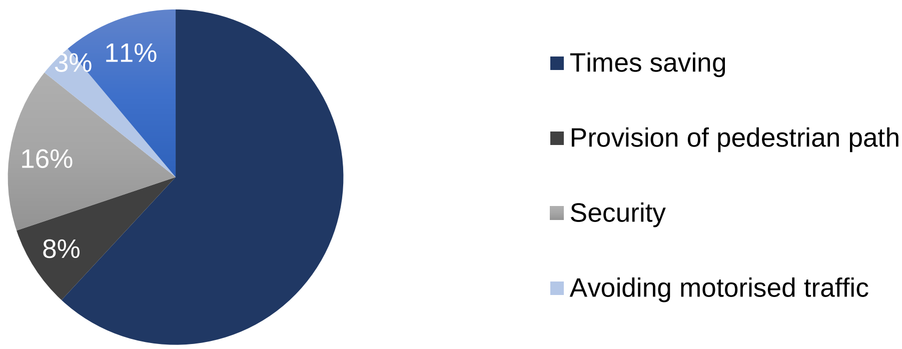


Figure 54: Respondent reasons for choosing egress route, Pushpha Bhawan station

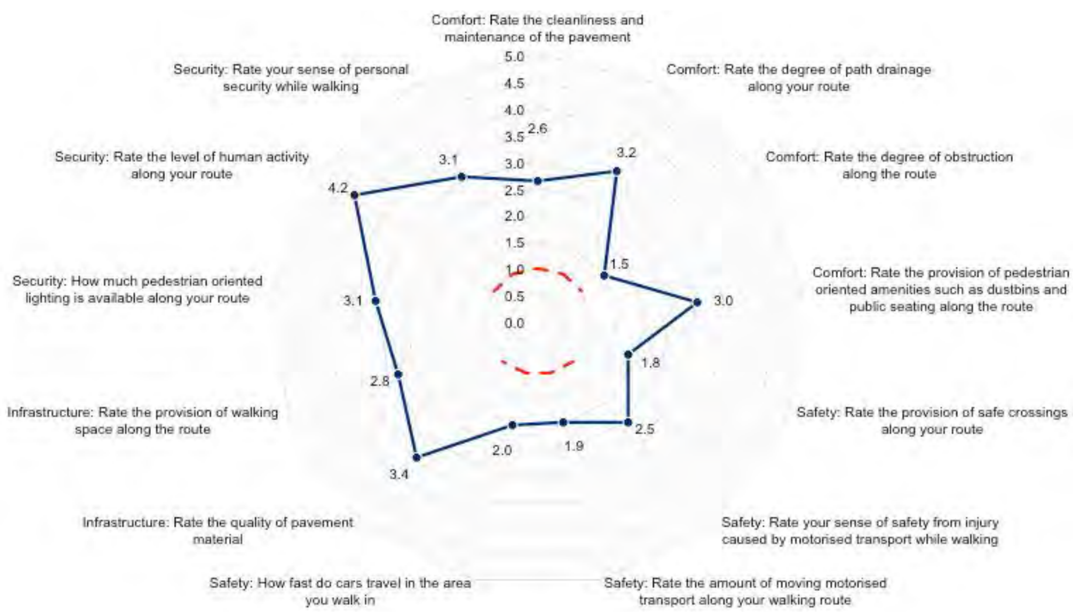


Figure 55: Radar plot of responses to route level questions, Pushpa Bhawan

Only high rating clusters are observed for the Comfort dimension, with the Pushpa Vihar neighbourhood to the west of the study area having all the high value clusters. Media uploads 797 and 788 were both made by respondents travelling to in the direction of Madangir/Dakshin Puri, and transcription of these media uploads are also provided.

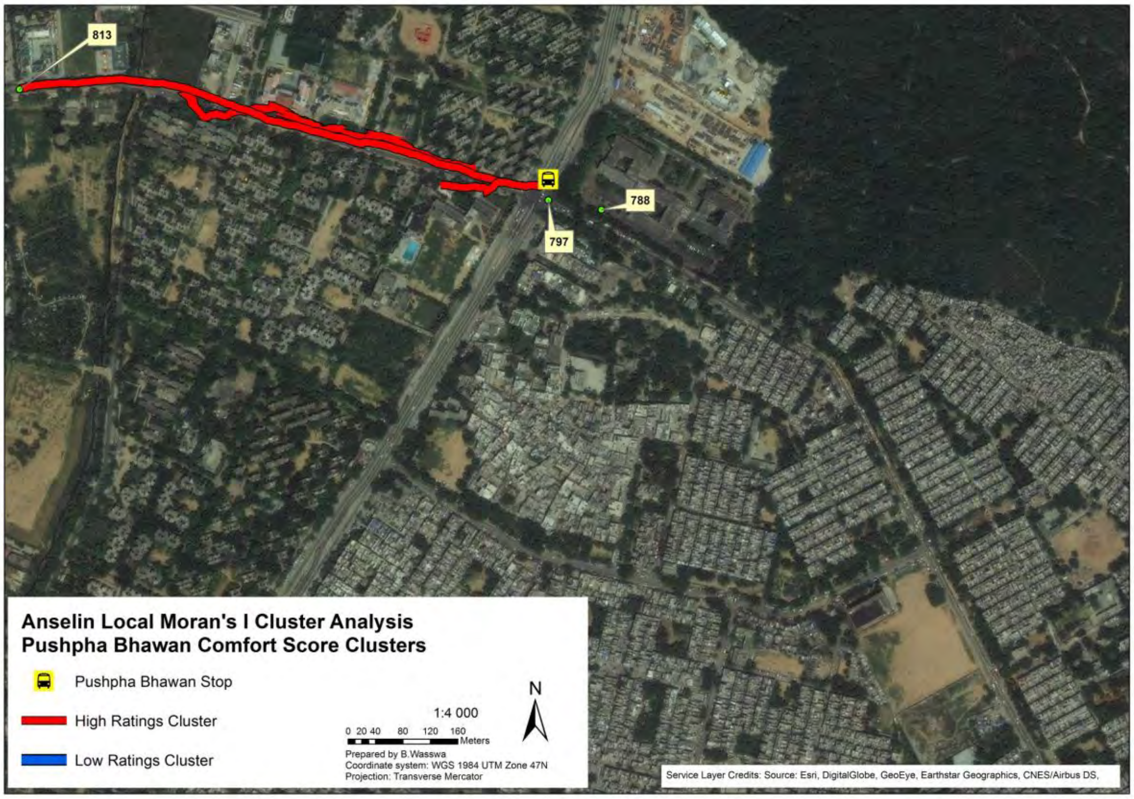


Figure 56: Pushpa Bhawan Comfort Cluster Analysis

(788) Male, 30-49, walks daily to public transport in Pushpa Bhawan

"...Here the footpaths are pretty bad, since they are mostly being encroached. This is why pedestrians have to walk on the road, which exacerbates traffic. The Grameen Seva and auto vehicles park anywhere, leaving no space for the pedestrians to walk anywhere... The police are also mixed up with these illegally parked vehicle owners. You'll see cops standing at the road corners doing nothing about this situation. See all the footpaths - you'll find them all covered by encroachment till the end. Footpaths are not walkable at all, since they are also broken, and you can't do anything about it."

(797) Male, 30-49, walks daily to public transport in Pushpa Bhawan

"Footpaths are all encroached by the vendors, as you can see. Traffic is just increasing day-by-day. The government must think of how to solve these problems."

Both of the uploads speak to encroachment along pedestrian paths presenting a major challenge. The respondent from assessment 788 attributes this to the paratransit vehicles crowding pedestrians and restricting access to sidewalks pointing out a lack of enforcement, with traffic officer not addressing transgressions.

The second challenge is related to the presence of vendors along the footpaths. Street vendors do not ply their trade in environments where their services are not needed, thus they provide useful goods and services to pedestrian in addition to providing eyes on the street in order to engender a sense of security. However, this utility is diminished when their presence inconveniences pedestrians.

Examples of some of the encroachment challenges along the footpaths in the Madangir/Dakshin Puri area were taken by survey facilitators and are shown in Figure 57. The public urinal placed along the footpath show the callous manner in which pedestrian provisions are made. The vendor's display across the whole sidewalk is also shown, however, one can see that their service attracts pedestrians, thus ways have to be found to incorporate them in these areas. Tiwari and Jain (2012) state that provisions have been made for vendors along the corridor, however, consideration has to be made for areas that pedestrians use in proximity to the BRT corridor.

Figure 57: Sidewalk obstruction in Mandangir/Dakshin Puri

6.2.3 Sheikh Sarai

Unlike egress trips at the other two sites, the ones in Sheikh Sarai were not restricted along main streets and spread into the adjacent neighbourhood as shown in Figure 58. Summary statistics from the routes are provided are provided in Table 15, the longest walking trip is 0.9 km with a mean walking distance of 271 m, the lowest among the three sites.

Table 15: Sheikh Sarai walking distance summary statistics

Statistic	Distance (m)
Mean	271
Max	904
Min	43
75 Percentile	367

Figure 58: Sheikh Sarai respondent egress route

Time saving comes out as the top reason for selecting the egress route, as is the case across all the other stations. However, the provision of a pedestrian path and walking amenities were equally listed as the second most important factors.

Similar to Pushpa Bhawan, the lowest scoring element from Sheik Sarai was that of obstructions along the routes, while pedestrians relayed that there was a high degree of human activity in the area.

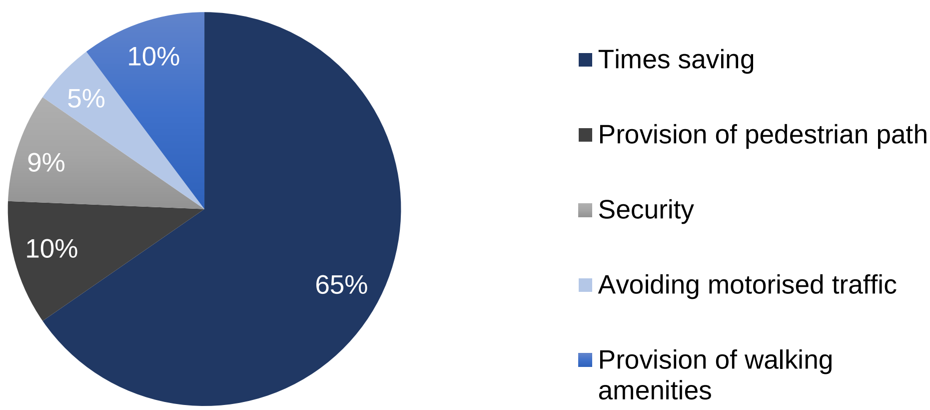


Figure 59: Respondents reason for choosing egress route, Sheikh Sarai

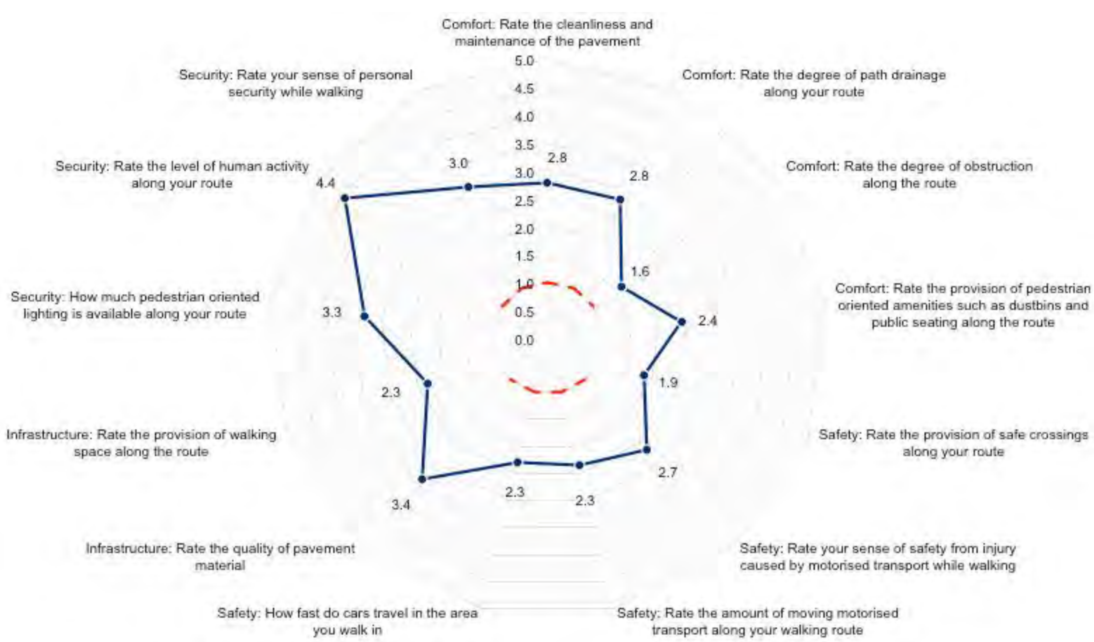


Figure 60: Radar plot of responses to route level questions at Sheik Sara station

The Cluster Analysis for the Comfort dimension did not yield any statistically significant clusters of low ratings, however, high ratings are clustering around the station, parallel to the BRT line. In constructing the system, provision was made parallel to the BRT line and from the results of the analysis, respondents recognise these provisions as contributing to a comfortable walking experience.

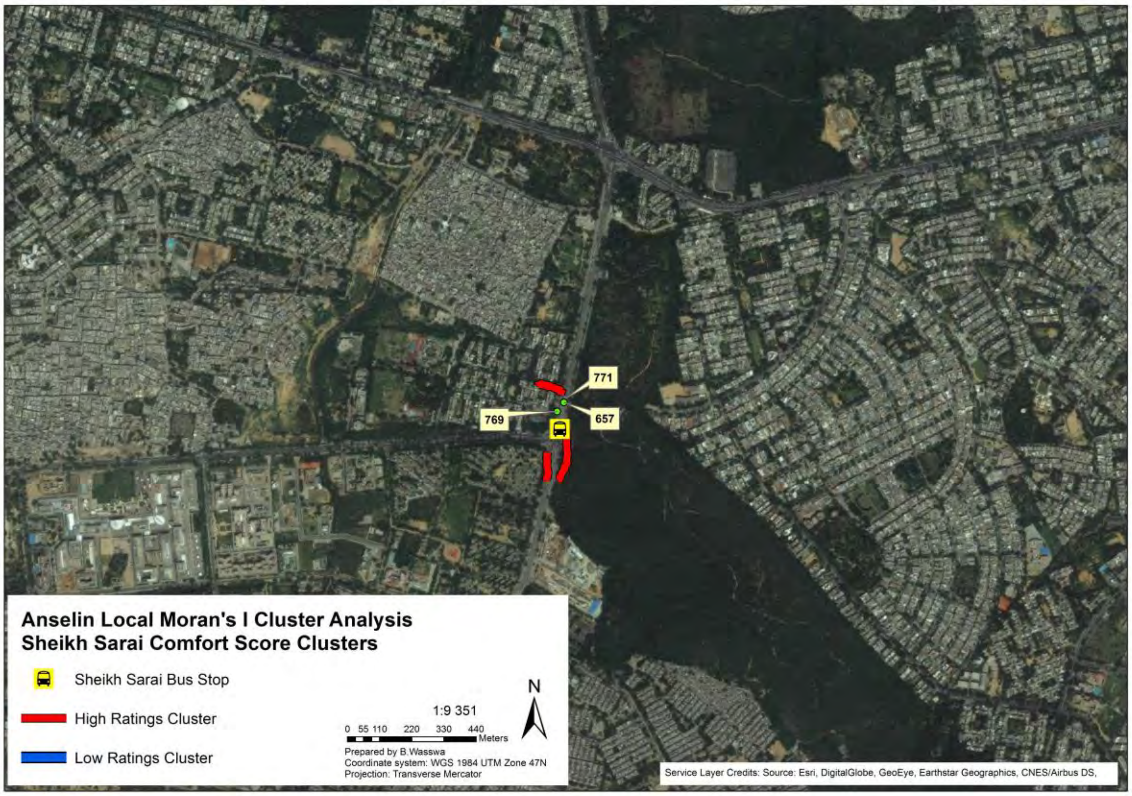


Figure 61: Sheikh Sarai Comfort Cluster Analysis

The image submission 657 shows how parked auto rickshaws obstruct pedestrian infrastructure, resulting in pedestrians walking in the cycle lanes. However, walking in these lanes places pedestrians in even more danger as motorcycles have started using them as indicated in the transcription of voice note 769 and media submission 771.

> (769) Male, 30-49, walks daily to public transport in Pushpa Bhawan
>
> Two-wheeler riders use the pedestrian paths also, driving up and down of footpaths, creating problems for us. There are possibilities of being involved in accidents

Figure 62: Sheik Sarai media submissions related to comfort

7 Discussion of results

The literature review presented the challenges faced by pedestrians due to the neglect of walking as a transportation mode. Poor pedestrian movement networks, and inadequate infrastructure at the streetscape, have been highlighted. These issues affect public transport users, as the multimodal nature of trips including public transport as a mode, requires that one be a pedestrian along access or egress trips.

The methods that are currently being used to evaluate access/egress trips are not in touch with the experience of being a pedestrian. The mobile application that was developed is a response to this shortcoming and the results presented in chapter 6 show the versatility of the tool.

Respondents across Cape Town and New Delhi identified challenges ranging from pedestrian infrastructure not being accessible due to road traffic violations by motorised transport, to having to deal with filthy walking environments that made walking uncomfortable.

However, the inability of the pilot methodology to capture both access and egress routes limited the insights that could be gained from the data. It was not possible to compare, for example, whether different routes were used at different times of the day and probe what the underlying motivators for this may have been. To get these insights the study would need to employ a different approach to recruiting respondents. A possible approach may have been arranging to escort respondents, who were intercepted on their egress trips, later in the day during their access trips. There are limitations to this though, as respondents may not use the same station or they may switch modes at different times of the day. A further shortcoming was that the interfacing between the application and the online dashboard required an active data connection. The requirement for an active connection to the dashboard presented problems if there were interruptions in cell phone coverage when assessments were ended and data had to be transferred to the dashboard. It is thus essential to incorporate offline functionality in future iterations of the application, to allow for data upload when there are reliable internet connections e.g. when on Wi-Fi or when the mobile phone network is not congested.

Notwithstanding the shortcomings of the method employed, the mobile application and the associated dashboard presented a new approach to understanding public transport egress challenges. The successful capture and integration of user ratings, revealed walking routes, media and Spatial Statistical Analysis, point to the promise of the tool and further development would allow for greater insights to be gained through it.

8 Conclusion and recommendations

This chapter presents the conclusions drawn from the research and gives recommendations for future work involving the use of mobile phones in collected user perceptions of walkability. It focuses on the value of the approach in allowing users to present challenges that would not be picked up by tools operating at a spatial level that is inconsistent with the street experience.

8.1 Conclusion

With recognition of the significant role that walking plays in connecting users to public transport, considerable effort will need to be expended to understand the barriers that exist. If public transport is going to be a competitive alternative to door-to-door motorised transportation, then Transportation Planning Authorities are going to have to address the challenges being faced by pedestrians. However, existing tools do not fully address the experience of walking, focusing rather on the functional characteristics for this mode.

Public Transport stations/stops should be environments where pedestrian access and egress are prioritised over other modes. This requires:

- That adequate infrastructure is made available and that it is maintained
- Enforcement of road traffic rules to ensure pedestrian safety
- Ensuring that users feel secure (ridding vulnerable users of undue anxiety)
- Addressing issues of comfort to make for a pleasurable experience

The mobile phone application and the associated dashboard developed in this research contribute towards advancing the state of the practice. By testing how an emic approach can be incorporated in understanding walkability, the research provides a case for how Transportation Planning Authorities can go beyond just the “engineer’s view”.

From the pilots the mobile application was able to capture a variety of challenges along egress routes. The use of clustering algorithms cannot be overstated enough. With the spatial nature of the data that is collected, the analysis method can examine the dataset at a local level and identify locations where there is statistically significant clustering. Filtering may not be capable of reconciling whether overlapping high and low clusters constitute areas where there are outliers or if there is real clustering occurring.

The use of media helps in unpacking the drivers of low ratings. It is very easy to become detached to the challenges being faced by pedestrians if they are merely represented as scores However, examining the media allows one to see the impact poor pedestrian environments have on peoples’ lives. At Modi Mills, the lack of maintenance places pedestrians in danger with uncovered manholes in the middle of pedestrian paths. While in Gardens, the voice notes provided by users allow for the detection of an operational shortcoming in the scheduling of buses resulting in pedestrians no longer having access to crossing facilities.

One of the major challenges with such an approach is that it is only capable of recording revealed routes. This can be indicative of the possible challenges being faced along routes that have been planned for pedestrian use, but are not being used. In Woodstock, only one respondent made use of the dedicated pedestrian path. Although well provisioned, the path suffered because it does not service the directness that is desired by pedestrians. Thus inferences can be gained from what people choose not to use.

The tool that has been developed and piloted in six real life contexts has been shown to have the ability to provide a new dimension in understanding the needs of walkers and in assimilating the information needed in urban design in order to being planning appropriately. In the context of social justice with respect to people's mobility, especially in cities where the marginalized rely on public transport, this is a significant contribution.

8.2 Recommendations

The findings of this thesis indicate how challenging the walking environment can be for pedestrians. Currently tools that are being used do not take into account the full suite of problems that pedestrians are facing. With the built environment being biased towards motorised transport, tools are going to be required that point out where challenges are acute and mobile phone applications such as the one developed in this research can help in doing so

However, there are challenges to making use of mobile phone applications that would need to be addressed:

- Although the Android operating system is available to a large number of people, the exclusion of other mobile phone operating systems may limit the reach of the tool
- The mobile app only used images, voice notes, and text notes. However, some challenges such as speeding vehicles and traffic infringements are best described using videos. Any advancement to such new mobile phone applications would need to incorporate it.
- The tool would truly need to be piloted independently of survey facilitators. The study may have been influenced by the observer effect with people either being increasing critical of their environment, or not wanting to criticise it too much.

Currently the tool is being reworked to improve the dashboard and database management. The changes will make it easier for researcher to adapt the tool for other circumstances and issues, by using simple forms to change questions and allowing for study specific database logins

9 References

Albers, P. N., Wright, C. & Olwoch, J. 2010. Developing a South African pedestrian environment assessment tool: Tshwane case study. *South African Journal of Science,* 106 (9 & 10)**.** 1-8.

Amato, J. A. 2004. *On foot: a history of walking,* New York: NYU Press.

American Association of State Highway and Transportation Officials, A. 2012. *Policy on Geometric Design of Highways and Streets (6th Edition) with 2012 and 2013 Errata,* Washington, DC: American Association of State Highway and Transportation Officials (AASHTO).

American Public Transportation Association 2009. Defining Transit Areas of Influence, Washington, DC.

Andersen, J. L. E. & Landex, A. 2008. Catchment areas for public transport. *In:* Brebbia, C. (ed.) *Urban Transport XIV: Urban Transport and the Environment in the 21st Century.* Southampton: WIT Press.

Anselin, L. 1995. Local indicators of spatial association-LISA. *Geographical analysis,* 27 (2)**.** 93-115.

Anselin, L. & Getis, A. 2010. Spatial Statistical Analysis and Geographic Information Systems. *In:* Anselin, L. & Rey, S. J. (eds.) *Perspectives on Spatial Data Analysis.* Berlin: Springer.

Aparajita, R. 2015. Take a walk or not? Here's an app that'll help decide. *The Times of India*. Available: http://timesofindia.indiatimes.com/city/bengaluru/Take-a-walk-or-not-Heres-an-app-thatll-help-decide/articleshow/48417547.cms [Accessed 12 December 2015].

Appleyard, B. 2012. Sustainable and Healthy Travel Choices and the Built Environment: Analyses of Green and Active Access to Rail Transit Stations Along Individual Corridors. *Transportation Research Record: Journal of the Transportation Research Board,* (2303)**.** 38-45.

Asakura, Y. & Hato, E. 2004. Tracking survey for individual travel behaviour using mobile communication instruments. *Transportation Research Part C: Emerging Technologies,* 12 (3)**.** 273-291.

Banister, D. 2005. *Unsustainable transport: city transport in the new century,* New York: Routledge.

Banister, D. 2008. The sustainable mobility paradigm. *Transport Policy,* 15 (2)**.** 73.

Bauer, B. 2010. Violence Prevention through Urban Upgrading: Experiences from financial cooperation, Frankfurt.

Bauman, A. E., Reis, R. S., Sallis, J. F., Wells, J. C., Loos, R. J. F. & Martin, B. W. 2012. Correlates of physical activity: why are some people physically active and others not? *The Lancet,* 380 (9838)**.** 258-271.

Bayir, M. A., Demirbas, M. & Cosar, A. 2011. A web-based personalized mobility service for smartphone applications. *The Computer Journal,* 54 (5). 800-814.

Behrens, R. 2002. *Matching networks to needs: Travel needs and the configuration and management of local movement networks in South African cities.* Doctor of Philosophy, University of Cape Town.

Behrens, R. 2005. Accommodating walking as a travel mode in South African cities: Towards improved neighbourhood movement network design practices. *Planning Practice & Research,* 20 (2). 163-182.

Berg, J. 2004. Private policing in South Africa: the Cape Town city improvement district—pluralisation in practice. *Society in transition,* 35 (2). 224-250.

Beukes, E. 2011. *Context Sensitive Road Planning For Developing Countries.* Ph.D, University of Cape Town.

Beukes, E., Vanderschuren, M. & Zuidgeest, M. 2011. Context sensitive multimodal road planning: a case study in Cape Town, South Africa. *Journal of Transport Geography,* 19 (3). 452-460.

Blacksher, E. & Lovasi, G. S. 2012. Place-focused physical activity research, human agency, and social justice in public health: taking agency seriously in studies of the built environment. *Health & place,* 18 (2). 172-179.

Booz Allen 2012. Integrating Australia's Transport Systems: A Strategy For An Efficient Transport Future, Sydney: Infrastructure Partnerships Australia.

Brownson, R. C., Hoehner, C. M., Day, K., Forsyth, A. & Sallis, J. F. 2009. Measuring the Built Environment for Physical Activity: State of the Science. *American Journal of Preventive Medicine,* 36 (4, Supplement). S99-S123.e12.

Burns, L. D., Jordan, W. C. & Scarborough, B. A. 2013. Transforming personal mobility. *The Earth Institute*.

CAI Asia. 2012. *Walkability Mobile App* [Online]. Available: http://walkabilityasia.org/2012/10/03/walkability-mobile-app/ [Accessed 12 December 2015].

Canepa, B. 2007. Bursting the bubble - Determining the transit-oriented development's walkable limits. *Transportation Research Record,* (1992). 28-34.

Cao, X., Mokhtarian, P. L. & Handy, S. L. 2007. Do changes in neighborhood characteristics lead to changes in travel behavior? A structural equations modeling approach. *Transportation,* 34 (5). 535-556.

Cervero, R. 1988. Land-use mixing and suburban mobility. *Transportation Quarterly,* 42 (3).

Cervero, R. 2001. Walk-and-ride: factors influencing pedestrian access to transit. *Journal of Public Transportation,* 7 (3).

Cervero, R. 2013. Transport Infrastructure and the Environment: Sustainable Mobility and Urbanism: University of California Berkeley.

Cervero, R. & Kockelman, K. 1997. Travel demand and the 3Ds: density, diversity, and design. *Transportation Research Part D: Transport and Environment,* 2 (3)**.** 199-219.

Chorus, C. & Timmermans, H. 2010. Ubiquitous travel environments and travel control strategies: Prospects and challenges. *In:* Wachowicz, M. (ed.) *Movement-Aware Applications for Sustainable Mobility: Technologies and Approaches: Technologies and Approaches.* Hershey, PA: IGI.

City of Cape Town (CCT) 2013a. Minimum Standards for Civil Engineering Services in Townships. Cape Town: Transport for Cape Town,.

City of Cape Town (CCT) 2013b. Integrated Transport Plan 2013-2018 (Final Draft). Cape Town: City of Cape Town.

Clifton, K. & Muhs, C. 2012. Capturing and representing multimodal trips in travel surveys: Review of the practice. *Transportation Research Record: Journal of the Transportation Research Board,* (2285)**.** 74-83.

Clifton, K. J., Smith, A. D. L. & Rodriguez, D. 2007. The development and testing of an audit for the pedestrian environment. *Landscape and Urban Planning,* 80 (1)**.** 95-110.

Crane, R. 1996. On Form versus Function: Will the New Urbanism Reduce Traffic, or Increase It? *Journal of Planning Education and Research,* 15 (2)**.** 117-126.

Crockett, J. & Hounsell, N. 2005. Role of the Travel Factor Convenience in Rail Travel and a Framework for its Assessment. *Transport Reviews,* 25 (5)**.** 535-555.

Davies, S. R., Selin, C., Gano, G. & Pereira, Â. G. 2012. Citizen engagement and urban change: Three case studies of material deliberation. *Cities,* 29 (6)**.** 351-357.

Day, K., Boarnet, M., Alfonzo, M. & Forsyth, A. 2006. The Irvine–Minnesota inventory to measure built environments: development. *American journal of preventive medicine,* 30 (2)**.** 144-152.

De Cambra, P. J. M. 2012. *Pedestrian Accessibility and Attractiveness Indicators for Walkability Assessment.* Master Degree (MSc) in Urban Studies and Territorial Management, University of Lisbon.

Devkota, B., Dudycha, D. & Andrey, J. 2012. Planning for non-motorized travel in rural Nepal: a role for geographic information systems. *Journal of Transport Geography,* 24 282-291.

Dowling, R., Flannery, A., Ryus, P., Vandehey, M., Petritsch, T., Landis, B., Rouphail, N. & Bonneson, J. 2008. NCHRP Report 616: Multimodal Level of Service Analysis for Urban Streets: Users Guide, WASHINGTON, D.C.: D.

Duncan, M. J., Spence, J. C. & Mummery, W. K. 2005. Perceived environment and physical activity: a meta-analysis of selected environmental characteristics. *International Journal of Behavioral Nutrition and Physical Activity,* 2 (1)**.** 11.

Eboli, L. & Mazzulla, G. 2011. A methodology for evaluating transit service quality based on subjective and objective measures from the passenger's point of view. *Transport Policy,* 18 (1)**.** 172-181.

Efroymson, D. & Rahman, M. 2005. Transportation Policy for Poverty Reduction and Social Equity, Dhaka: WBB Trust.

Ewing, R. & Cervero, R. 2010. Travel and the built environment: a meta-analysis. *Journal of the American planning association,* 76 (3)**.** 265-294.

Ewing, R. & Clemente, O. 2013. *Measuring urban design: Metrics for livable places,* London: Island Press.

Fischer, M. M. & Nijkamp, P. 1992. Geographic information systems and spatial analysis. *The Annals of Regional Science,* 26 (1)**.** 3-17.

Frank, L. D., Sallis, J. F., Conway, T. L., Chapman, J. E., Saelens, B. E. & Bachman, W. 2006. Many pathways from land use to health: associations between neighborhood walkability and active transportation, body mass index, and air quality. *Journal of the American Planning Association,* 72 (1)**.** 75-87.

Fruin, J. J. 1971. *Pedestrian planning and design,* New York, NY: Metropolitan Association of Urban Designers and Environmental Planners.

Gantvoort, J. T. 1971. Pedestrian traffic in town centres. *Traffic Engineering & Control,* 12 (9)**.** 454-456.

Getis, A. 2001. Spatial Statistics. *In:* Longley, P., Goodchild, M. & Maguire, D. (eds.) *Geographical Information Systems and Science.* 2nd ed. Chichester: John Wiley and Sons.

Gould, J. 2013. Cell phone enabled travel surveys: The medium moves the message. *In:* Zmud, J., Lee-Gosselin, M., Carrasco, J. & Munizaga, M. (eds.) *Transport Survey Methods: Best Practice for Decision Making.* Bingley: Emerald.

Handy, S., Cao, X. & Mokhtarian, P. 2005. Correlation or causality between the built environment and travel behavior? Evidence from Northern California. *Transportation Research Part D: Transport and Environment,* 10 (6)**.** 427-444.

Handy, S. L., Boarnet, M. G., Ewing, R. & Killingsworth, R. E. 2002. How the built environment affects physical activity: views from urban planning. *American journal of preventive medicine,* 23 (2)**.** 64-73.

Hebbert, M. 2005. Engineering, Urbanism and the Struggle for Street Design. *Journal of Urban Design,* 10 (1)**.** 39.

Heinen, E., Steiner, R. L. & Geurs, K. T. 2015. Special issue: built environment and travel behaviour. *EJTIR,* 15 (1)**.** 1-5.

Hsiao, S., Lu, J., Sterling, J. & Weatherford, M. 1997. Use of geographic information system for analysis of transit pedestrian access. *Transportation Research Record: Journal of the Transportation Research Board,* (1604)**.** 50-59.

Hull, A. 2008. Policy integration: What will it take to achieve more sustainable transport solutions in cities? *Transport Policy,* 15 (2)**.** 94.

Isaacson, M. & Shoval, N. 2006. Application of Tracking Technologies to the Study of Pedestrian Spatial Behavior. *The Professional Geographer,* 58 (2)**.** 172-183.

Jain, S., Aggarwal, P., Kumar, P., Singhal, S. & Sharma, P. 2014. Identifying public preferences using multi-criteria decision making for assessing the shift of urban commuters from private to public transport: A case study of Delhi. *Transportation Research Part F: Traffic Psychology and Behaviour,* 24 60-70.

Kenworthy, J. R. 2006. The eco-city: ten key transport and planning dimensions for sustainable city development. *Environment and Urbanization,* 18 (1)**.** 67.

Khisty, J. 1994. Evaluation Of Pedestrian Facilities: Beyond The Level-Of-Service Concept. *Transportation Research Record: Journal of the Transportation Research Board,* 1438 45-50.

Kim, S., Park, S. & Lee, J. S. 2014. Meso- or micro-scale? Environmental factors influencing pedestrian satisfaction. *Transportation Research Part D: Transport and Environment,* 30 10-20.

Krygsman, S., Dijst, M. & Arentze, T. 2004. Multimodal public transport: an analysis of travel time elements and the interconnectivity ratio. *Transport Policy,* 11 (3)**.** 265-275.

Labuschagne, K. & Ribbens, H. 2014. Walk the talk on the mainstreaming of non-motorised transport in South Africa. *Proceedings of the 33th Southern African Transport Conference (SATC 2014).* Pretoria.

Leslie, E., Coffee, N., Frank, L., Owen, N., Bauman, A. & Hugo, G. 2007. Walkability of local communities: using geographic information systems to objectively assess relevant environmental attributes. *Health & place,* 13 (1)**.** 111-122.

Lewis, A. 2015a. Poor hardest hit by public transport costs. *Cape Argus*, 04 June 2015. Available: http://www.iol.co.za/news/south-africa/western-cape/poor-hardest-hit-by-public-transport-costs-1.1867506 [Accessed 3 January 2016].

Lewis, A. 2015b. Work begins on new MyCiTi routes. *Cape Argus*. Available: http://www.iol.co.za/news/south-africa/western-cape/work-begins-on-new-MyCiTi-routes-1.1839325 [Accessed 3 January 2016].

Livi-Smith, A. D. 2008. *The relationship between neighborhood environment and walking behavior: The influence of perceptions.* Ph. D., University of Maryland.

Livi-Smith, A. D. 2009. Contribution of perceptions in analysis of walking behavior. *Transportation Research Record: Journal of the Transportation Research Board,* 2140 (1)**.** 128-136.

Lo, R. H. 2009. Walkability: what is it? *Journal of Urbanism,* 2 (2)**.** 145-166.

Loukaitou-Sideris, A. & Fink, C. 2009. Addressing women's fear of victimization in transportation settings A survey of US transit agencies. *Urban Affairs Review,* 44 (4)**.** 554.

Mateo-Babiano, I. & Ieda, H. 2007. Street space sustainability in Asia: The role of the Asian pedestrian and street culture. *Journal of the Eastern Asia Society for Transportation Studies,* 7 1915.

Metz, R. 2013. Every Step You Take, Tracked Automatically. *MIT Technology Review* [Online], Available: https://www.technologyreview.com/s/510491/every-step-you-take-tracked-automatically/ [Accessed 15 May 2015].

Ministry of Urban Development (MoUD) 2006. National Urban Transport Policy. Delhi: Ministry of Urban Development.

Mohan, D. & Tiwari, G. 1999. Sustainable transport systems: linkages between environmental issues, public transport, non-motorised transport and safety. *Economic and Political Weekly,* 1589-1596.

Moniruzzaman, M. & Páez, A. 2012. Accessibility to transit, by transit, and mode share: application of a logistic model with spatial filters. *Journal of Transport Geography,* 24 (0)**.** 198-205.

Moudon, A. V. & Lee, C. 2003. Walking and bicycling: an evaluation of environmental audit instruments. *American Journal of Health Promotion,* 18 (1)**.** 21-37.

Murray, A. T. 2003. A coverage model for improving public transit system accessibility and expanding access. *Annals of Operations Research,* 123 (1-4)**.** 143-156.

Nandi, J. 2014. No car? You might be at risk on 6 Delhi roads. *The Times of India* [Online], Available: http://timesofindia.indiatimes.com/city/delhi/No-car-You-might-be-at-risk-on-6-Delhi-roads/articleshow/37922516.cms? [Accessed 2 February 2015].

National Department of Transport (NDoT) 1996. 1996 White Paper on National Transport Policy. Pretoria: National Department of Transport.

National Department of Transport (NDoT) 2009. National Land Transport Act (5 of 2009). Pretoria: National Department of Transport.

Newman, P. 2003. Walking in a Historical, International and Contemporary Context. *In:* Tolley, R. (ed.) *Sustainable Transport - Planning for Walking and Cycling in Urban Environments.* 1st ed. Sawston, Cambridge: Woodhead Publishing.

Newman, P. & Kenworthy, J. 1999. *Sustainability and cities: overcoming automobile dependence*: Island Press.

Newman, P. W. G. & Kenworthy, J. R. 1996. The land use—transport connection: An overview. *Land Use Policy,* 13 (1)**.** 1.

Nijkamp, P. 1994. Roads toward environmentally sustainable transport. *Transportation Research Part A: Policy and Practice,* 28 (4)**.** 261.

Nijkamp, P., Priemus, H. & Shefer, D. 2000. Network connectivity and multimodality: the context. *Transportation Planning and Technology,* 23 (3)**.** 179-182.

Ord, J. K. & Getis, A. 1995. Local spatial autocorrelation statistics: distributional issues and an application. *Geographical analysis,* 27 (4)**.** 286-306.

Parida, P. & Parida, M. 2011. Appreciation of Gender Differences in Development of Qualitative Level of Service for Sidewalks. *Women's Issues in Transportation,* 246.

Park, S., Choi, K. & Lee, J. S. 2015. To Walk or Not to Walk: Testing the Effect of Path Walkability on Transit Users' Access Mode Choices to the Station. *International Journal of Sustainable Transportation,* 9 (8)**.** 529-541.

Parkyn, N. 2001. *Sir Colin Buchanan (Obituary)* [Online]. The Guardian. Available: http://www.theguardian.com/news/2001/dec/10/guardianobituaries.engineering [Accessed 2nd February 2015].

Pendakur, V. S. 2011. Non-motorized urban transport as neglected modes. *In:* Dimitriou, H. T. & Gakenheimer, R. (eds.) *Urban transport in the developing world: a handbook of policy and practice.* 1st ed. Cheltenham, UK: Edward Elgar Publishing.

Pickrell, D. 1999. Transportation and land use. *In:* Meyer, J. R., Gómez-Ibáñez, J. A., Tye, W. B. & Winston, C. (eds.) *Essays in Transportation Economics and Policy: A Handbook in Honor of John R. Meyer.* Washington, D.C.: Brookings Institution Press.

Pikora, T., Giles-Corti, B., Bull, F., Jamrozik, K. & Donovan, R. 2003. Developing a framework for assessment of the environmental determinants of walking and cycling. *Social science & medicine,* 56 (8)**.** 1693-1703.

Pikora, T. J., Bull, F. C., Jamrozik, K., Knuiman, M., Giles-Corti, B. & Donovan, R. J. 2002. Developing a reliable audit instrument to measure the physical environment for physical activity. *American journal of preventive medicine,* 23 (3)**.** 187-194.

Rankavat, S. & Tiwari, G. 2013. Pedestrian Accident Analysis in Delhi using GIS. *Journal of the Eastern Asia Society for Transportation Studies,* 10.

Rietveld, P. 2000a. The accessibility of railway stations: the role of the bicycle in The Netherlands. *Transportation Research Part D: Transport and Environment,* 5 (1)**.** 71-75.

Rietveld, P. 2000b. Non-motorised modes in transport systems: a multimodal chain perspective for The Netherlands. *Transportation Research Part D: Transport and Environment,* 5 (1)**.** 31-36.

Rodríguez, D. A., Brisson, E. M. & Estupiñán, N. 2009. The relationship between segment-level built environment attributes and pedestrian activity around Bogota's BRT stations. *Transportation research part D: transport and environment,* 14 (7)**.** 470-478.

Saelens, B. E. & Handy, S. L. 2008. Built environment correlates of walking: a review. *Medicine and science in sports and exercise,* 40 (7 Suppl)**.** S550.

Saelens, B. E., Sallis, J. F. & Frank, L. D. 2003. Environmental correlates of walking and cycling: findings from the transportation, urban design, and planning literatures. *Annals of behavioral medicine,* 25 (2)**.** 80-91.

Sallis, J. F., Bowles, H. R., Bauman, A., Ainsworth, B. E., Bull, F. C., Craig, C. L., Sjöström, M., De Bourdeaudhuij, I., Lefevre, J. & Matsudo, V. 2009. Neighborhood environments and physical activity among adults in 11 countries. *American journal of preventive medicine,* 36 (6)**.** 484-490.

Sallis, J. F., Cervero, R. B., Ascher, W., Henderson, K. A., Kraft, M. K. & Kerr, J. 2006. An ecological approach to creating active living communities. *Annu. Rev. Public Health,* 27 297-322.

Sanders, P., Zuidgeest, M. & Geurs, K. 2015. Liveable streets in Hanoi: A principal component analysis. *Habitat International,* 49 547-558.

Santos, G., Behrendt, H. & Teytelboym, A. 2010. Part II: Policy instruments for sustainable road transport. *Research in Transportation Economics,* 28 (1)**.** 46.

Schlossberg, M., Evers, C., Kato, K. & Brehm, C. 2012. Active transportation, citizen engagement and livability: Coupling citizens and smartphones to make the change. *URISA Journal,* 25 (2)**.** 61-70.

Schlossberg, M., Johnson-Shelton, D., Evers, C. & Moreno-Black, G. 2015. Refining the grain: using resident-based walkability audits to better understand walkable urban form. *Journal of Urbanism: International Research on Placemaking and Urban Sustainability,* 8 (3)**.** 260-278.

Schneider, R. J., Ryznar, R. M. & Khattak, A. J. 2004. An accident waiting to happen: a spatial approach to proactive pedestrian planning. *Accident Analysis & Prevention,* 36 (2)**.** 193-211.

Schoon, J. G. 2010. *Pedestrian facilities: engineering and geometric design,* London: Thomas Telford.

Shumi, S., Zuidgeest, M., Martinez, J., Efroymson, D. & Van Maarseveen, M. 2013. Understanding the Relationship Between Walkability and Quality-of-Life of Women Garment Workers in Dhaka, Bangladesh. *Applied Research in Quality of Life,* 10 (2)**.** 263-287.

Simon, D. 2002. *Transport and development in the Third World,* London: Routledge.

Sinclair, M. & Zuidgeest, M. 2015. Investigations into pedestrian crossing choices on Cape Town freeways. *Transportation Research Part F: Traffic Psychology and Behaviour*.

Southworth, M. 2005. Designing the Walkable City. *Journal of Urban Planning and Development,* 131 (4)**.** 246-257.

Steinfeld, A., Zimmerman, J., Tomasic, A., Yoo, D. & Aziz, R. D. 2011. Mobile transit information from universal design and crowdsourcing. *Transportation Research Record: Journal of the Transportation Research Board,* 2217 (1)**.** 95-102.

Stork, C., Calandro, E. & Gamage, R. 2014. The future of broadband in Africa. *info,* 16 (1)**.** 76-93.

The Organisation for Economic Co-Operation and Development (OECD). 1997. Towards Sustainable Transportation, March 1996 Vancouver. Paris: The Organisation for Economic Co-operation and Development.

Tiwari, G. 1999. Towards a sustainable urban transport system: Planning for non-motorized vehicles in cities. *Transport and Communications Bulletin for Asia and the Pacific,* 68 49.

Tiwari, G. 2002. Urban transport priorities: meeting the challenge of socio-economic diversity in cities, a case study of Delhi, India. *Cities,* 19 (2)**.** 95-103.

Tiwari, G. 2007. *Urban Transport in Indian Cities* [Online]. Available: http://lsecities.net/media/objects/articles/urban-transport-in-indian-cities/en-gb/ [Accessed 5 February 2015].

Tiwari, G. & Jain, D. 2012. Accessibility and safety indicators for all road users: case study Delhi BRT. *Journal of Transport Geography,* 22 87-95.

Transportation Research Board 2010. *Highway Capacity Manual (HCM 2010),* Washington, DC: TRB.

United Nations Environment Programme (UNEP) 2010. Share the Road: Investment in Walking and Cycling Road Infrastructure, Nairobi: UNEP.

Vajjhala, S. P. & Walker, W. M. 2010. Roads to participatory planning: Integrating cognitive mapping and GIS for transport prioritization in rural Lesotho. *Journal of Maps,* 6 (1)**.** 488-504.

Wall, K. 2010. 1910–2010: How infrastructure grew our nation. *South African Institution of Civil Engineering,* 52 (2)**.** 12.

Wallace, R. R., Rodriguez, D. A., White, C. & Levine, J. 1999. Who Noticed, Who Cares? Passenger Reactions to Transit Safety Measure. *Transportation Research Record,* (1666)**.** 133.

Watkins, J., Kitner, K. R. & Mehta, D. 2012. Mobile and smartphone use in urban and rural India. *Continuum,* 26 (5)**.** 685-697.

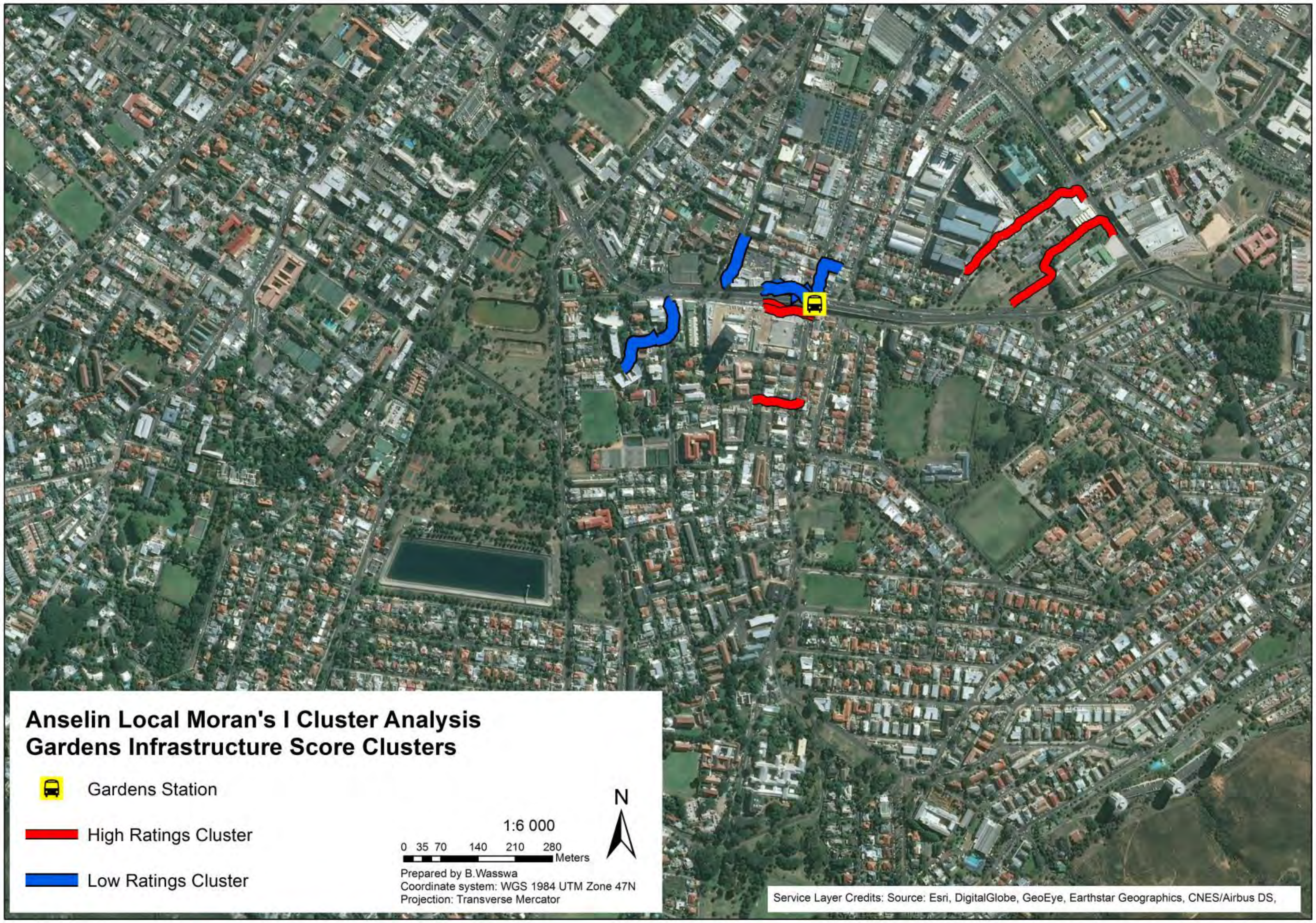
Weinstein Agrawal, A., Schlossberg, M. & Irvin, K. 2008. How far, by which route and why? A spatial analysis of pedestrian preference. *Journal of urban design,* 13 (1)**.** 81-98.

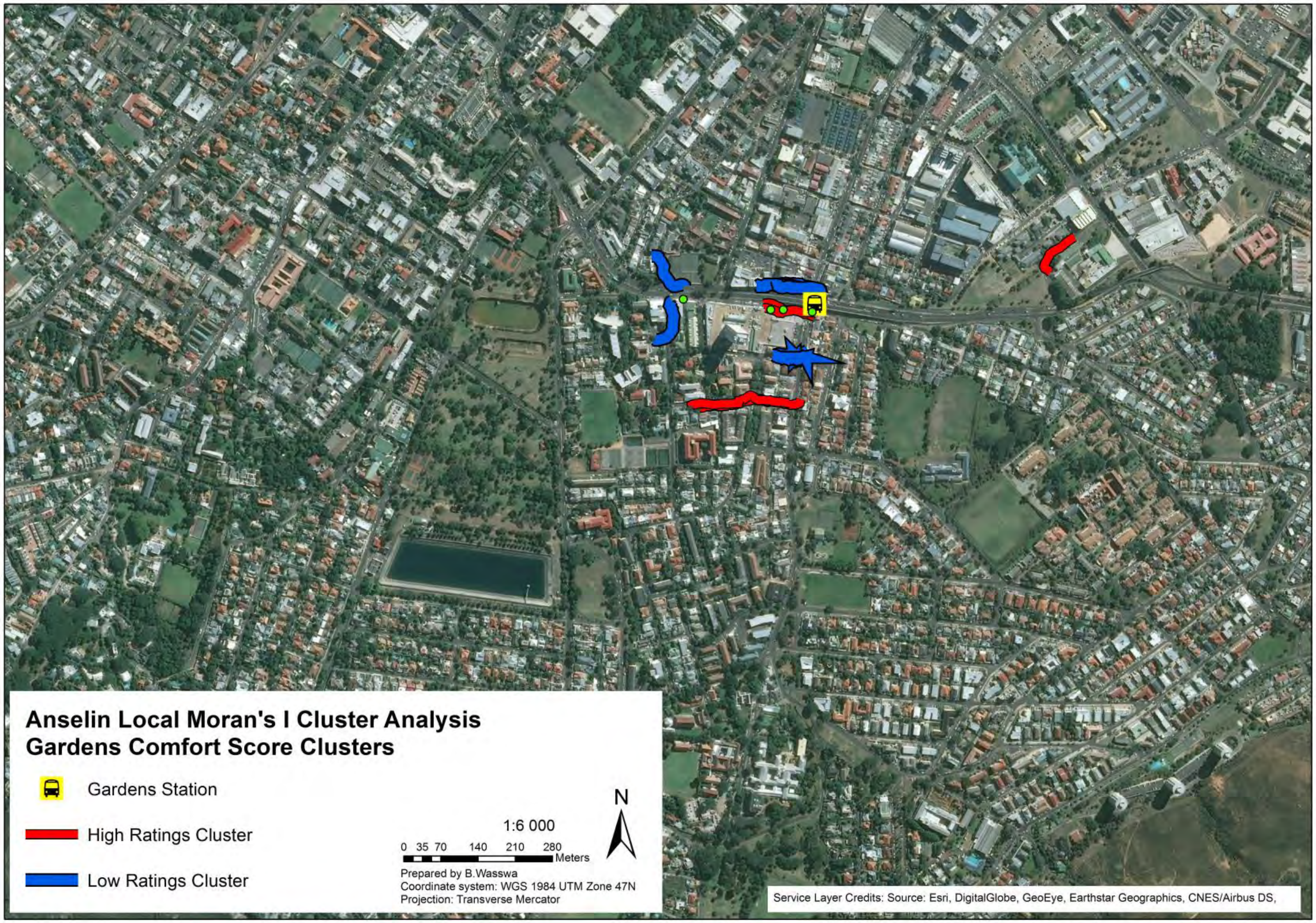
World Health Organization (WHO) 2013. WHO global status report on road safety 2013: supporting a decade of action, Geneva: WHO.

Widhalm, P., Nitsche, P. & Brandie, N. Transport mode detection with realistic smartphone sensor data. Pattern Recognition (ICPR), 2012 21st International Conference on, 2012. IEEE, 573-576.

Wulder, M. & Boots, B. 1998. Local spatial autocorrelation characteristics of remotely sensed imagery assessed with the Getis statistic. *International Journal of Remote Sensing,* 19 (11)**.** 2223-2231.

10 Appendix A: Cluster analysis maps





Anselin Local Moran's I Cluster Analysis
Gardens Comfort Score Clusters
Gardens Station
High Ratings Cluster
Low Ratings Cluster
1:6 000
0 35 70 140 210 280
Meters
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Prepared by B.Wasswa
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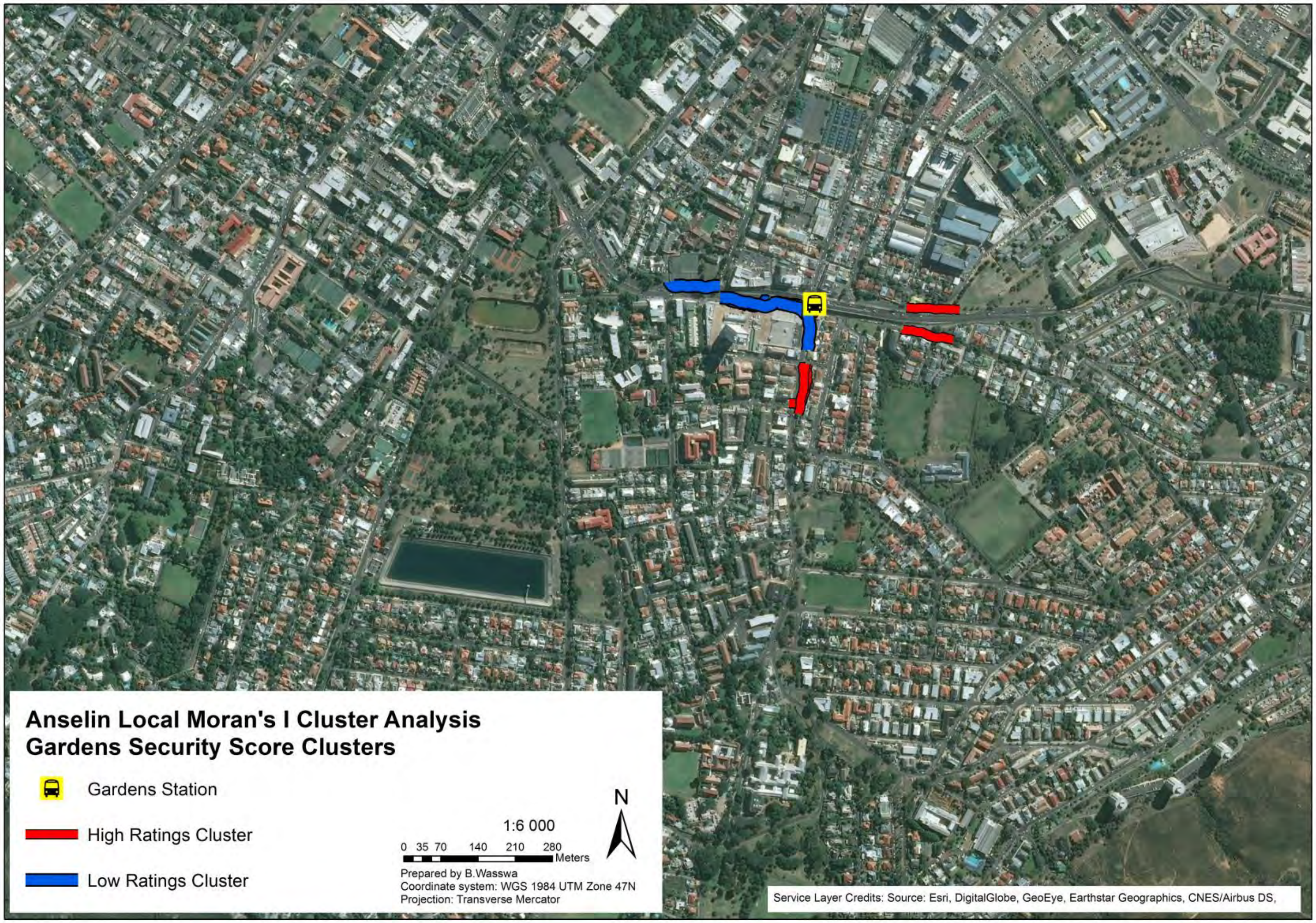
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Gardens Station
High Ratings Cluster
Low Ratings Cluster
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Prepared by B.Wasswa
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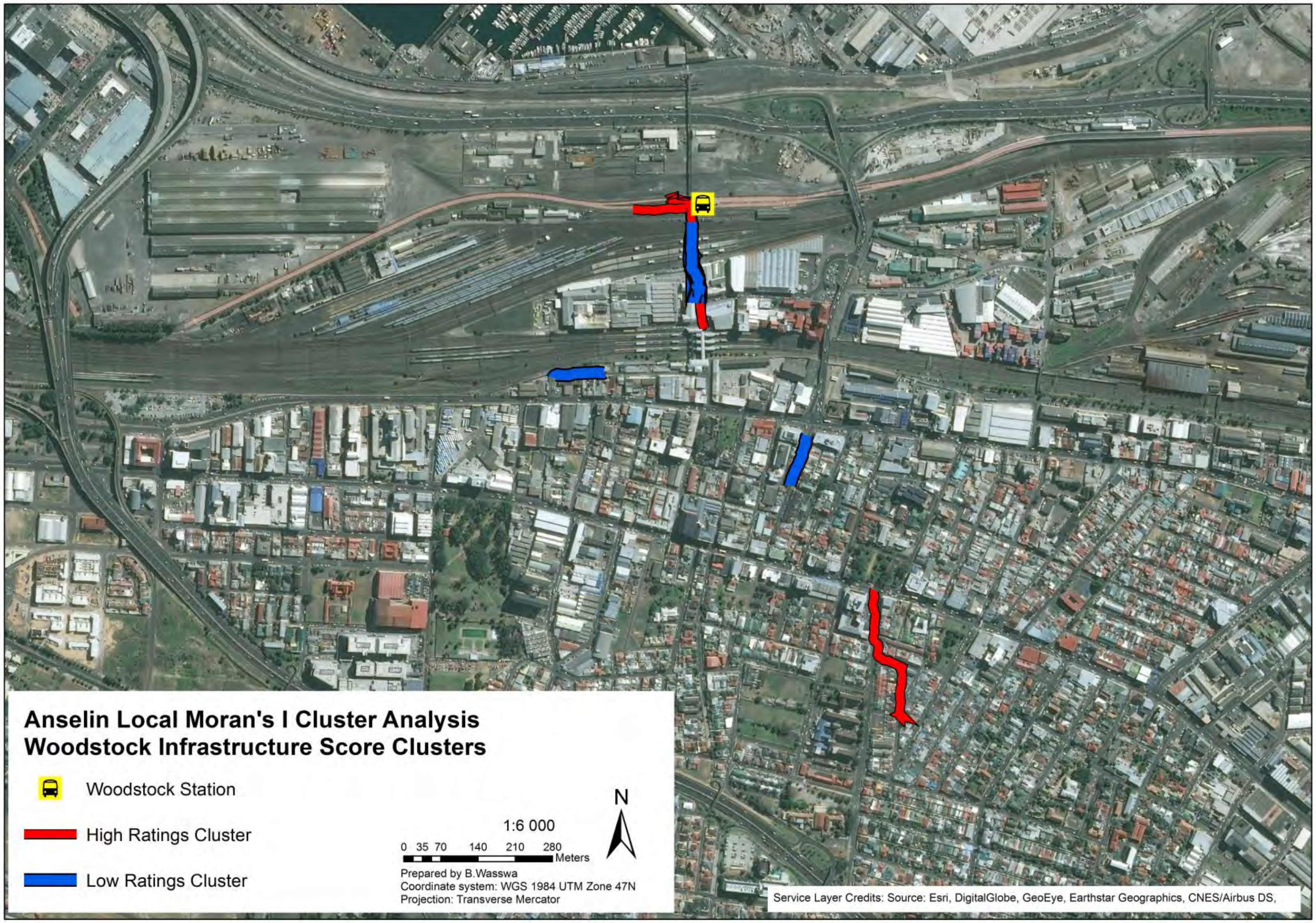
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Woodstock Infrastructure Score Clusters
Woodstock Station
High Ratings Cluster
Low Ratings Cluster
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Prepared by B.Wasswa
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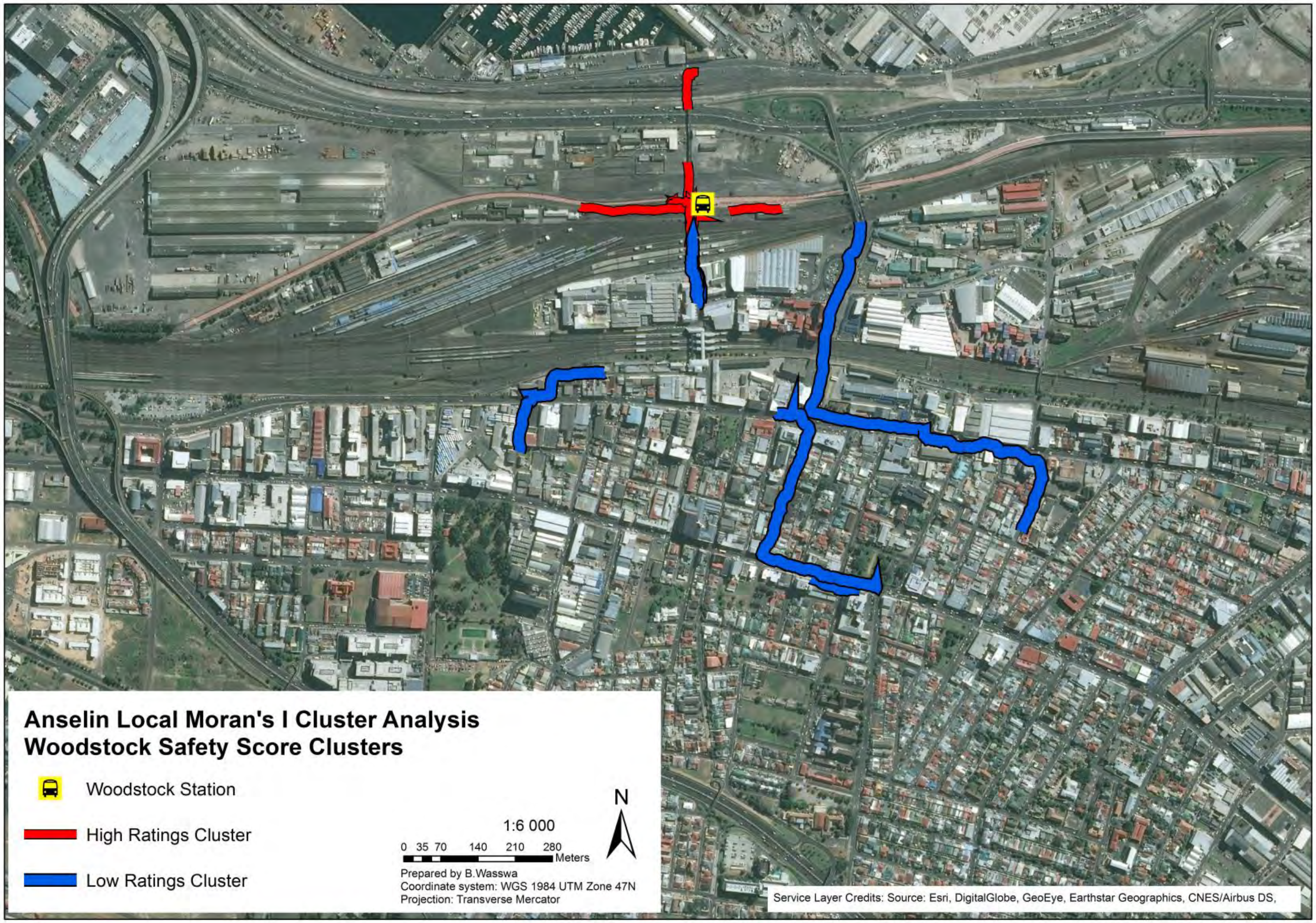
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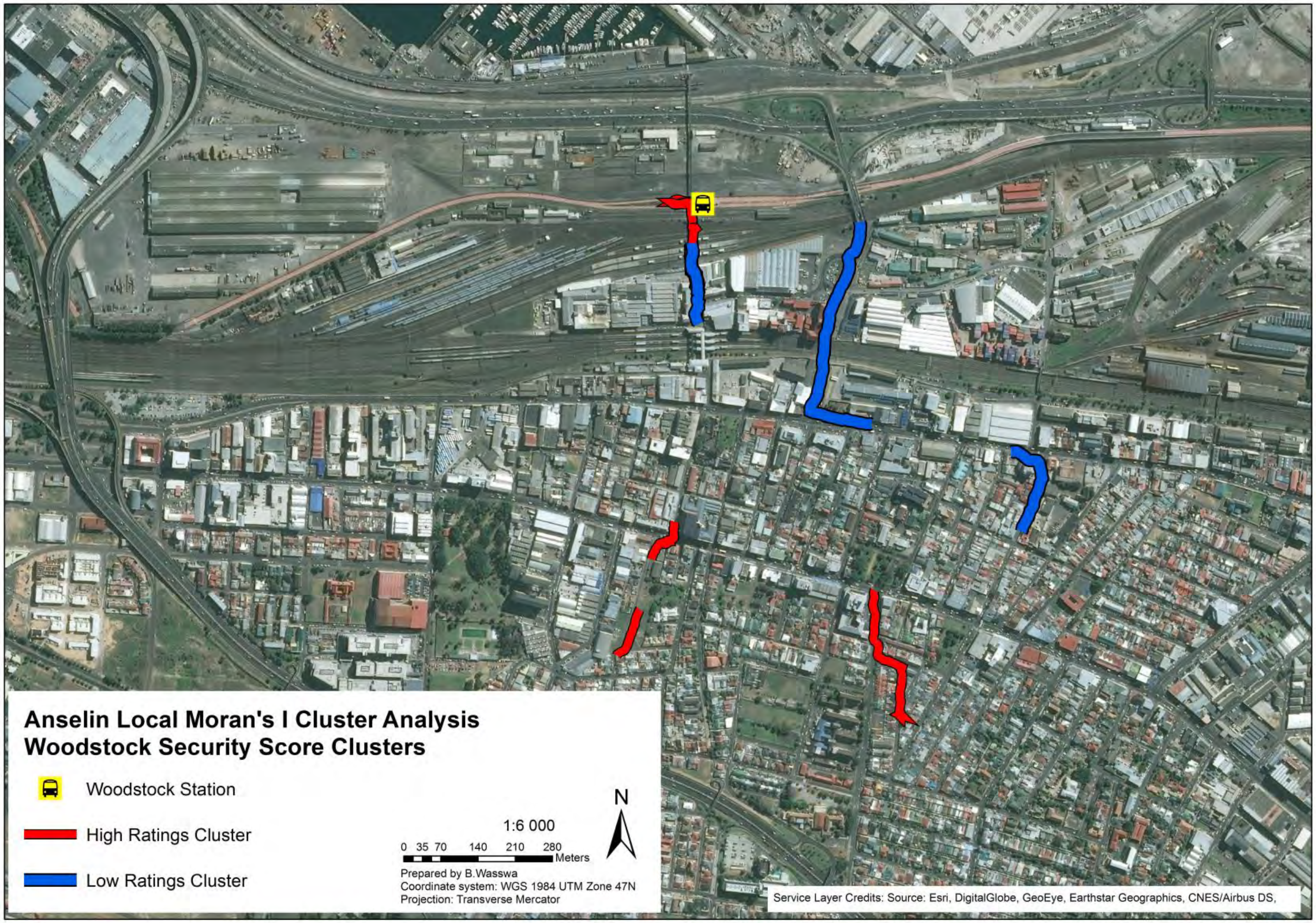
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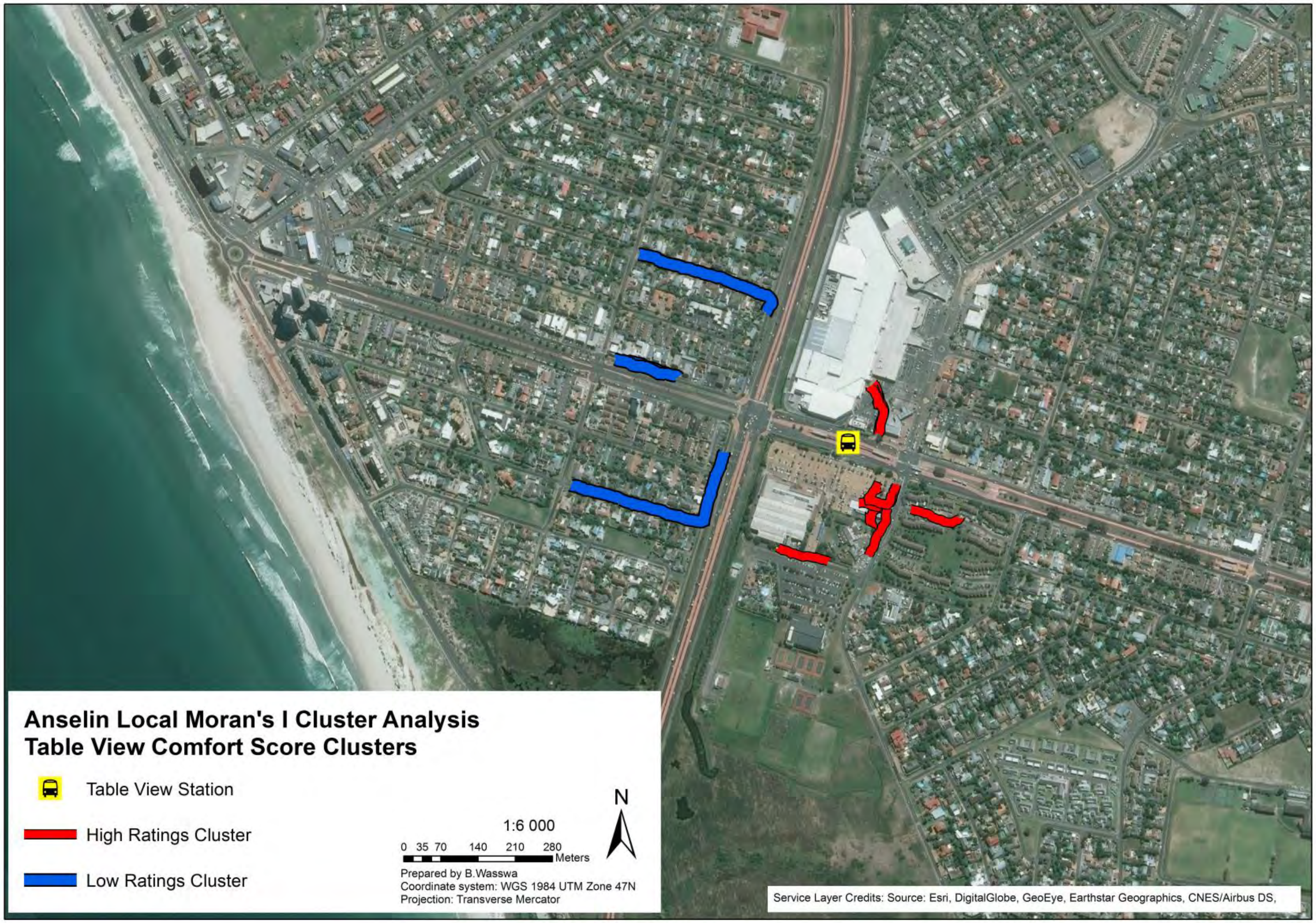
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Table View Station
High Ratings Cluster
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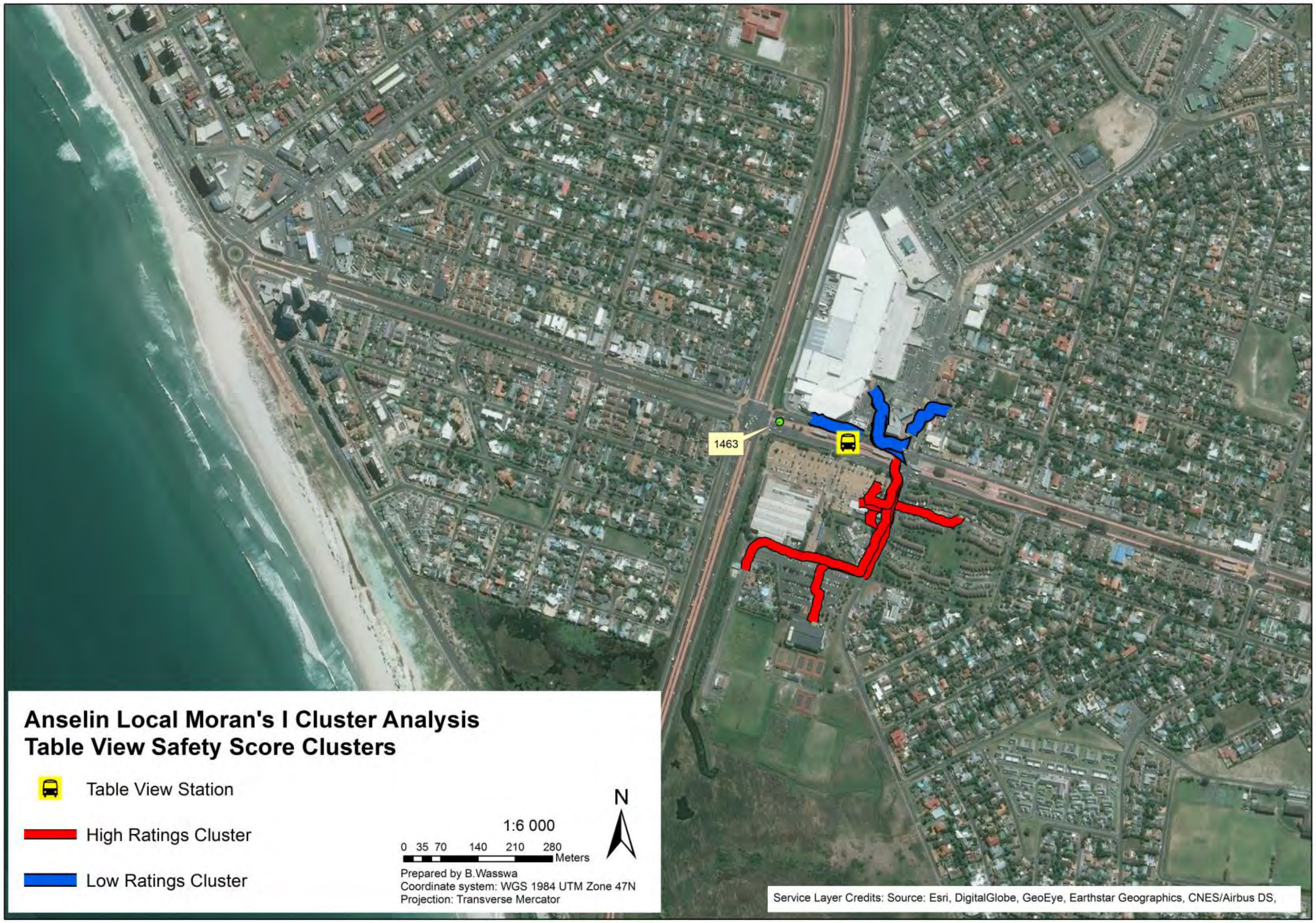

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Low Ratings Cluster
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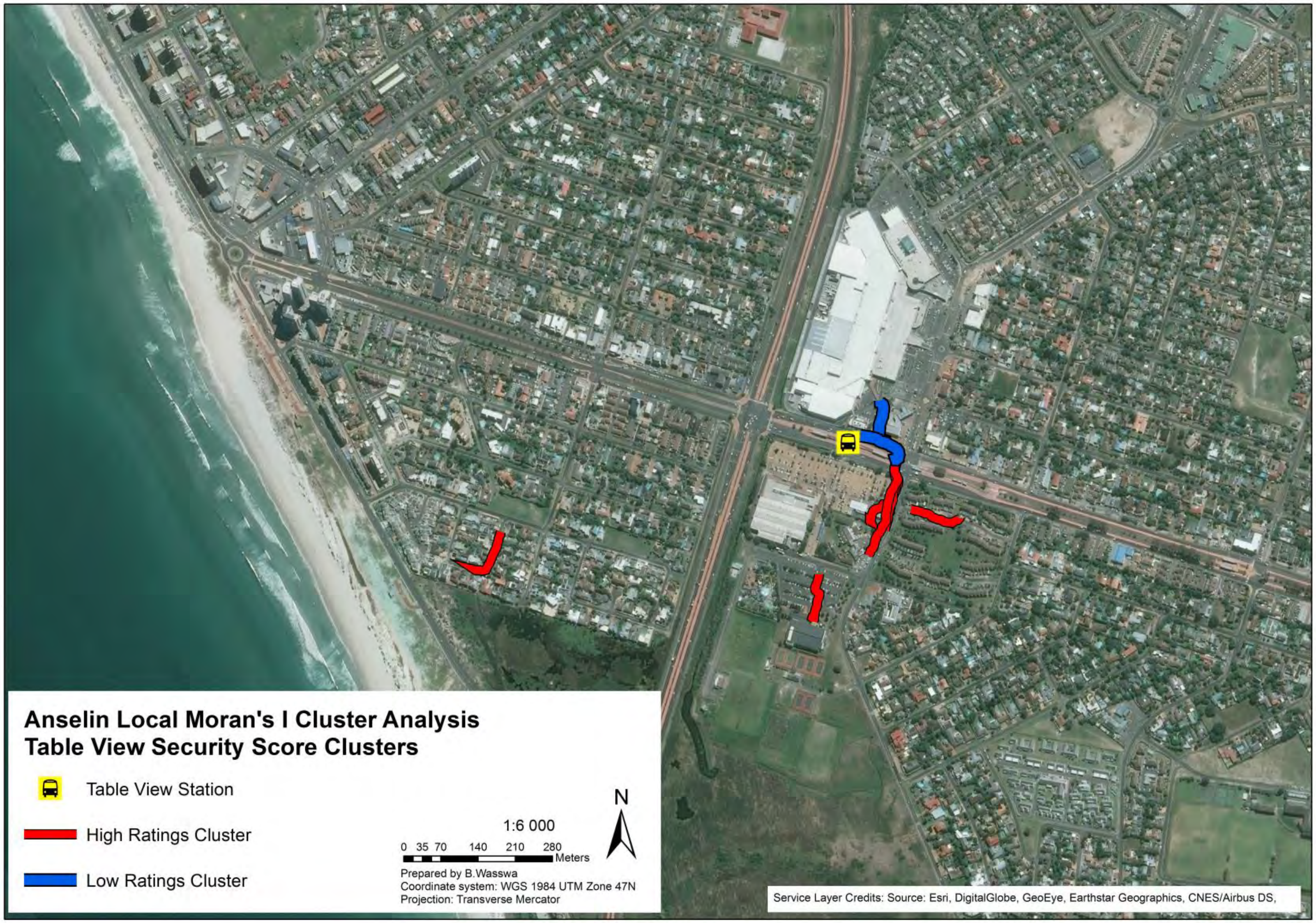
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Low Ratings Cluster
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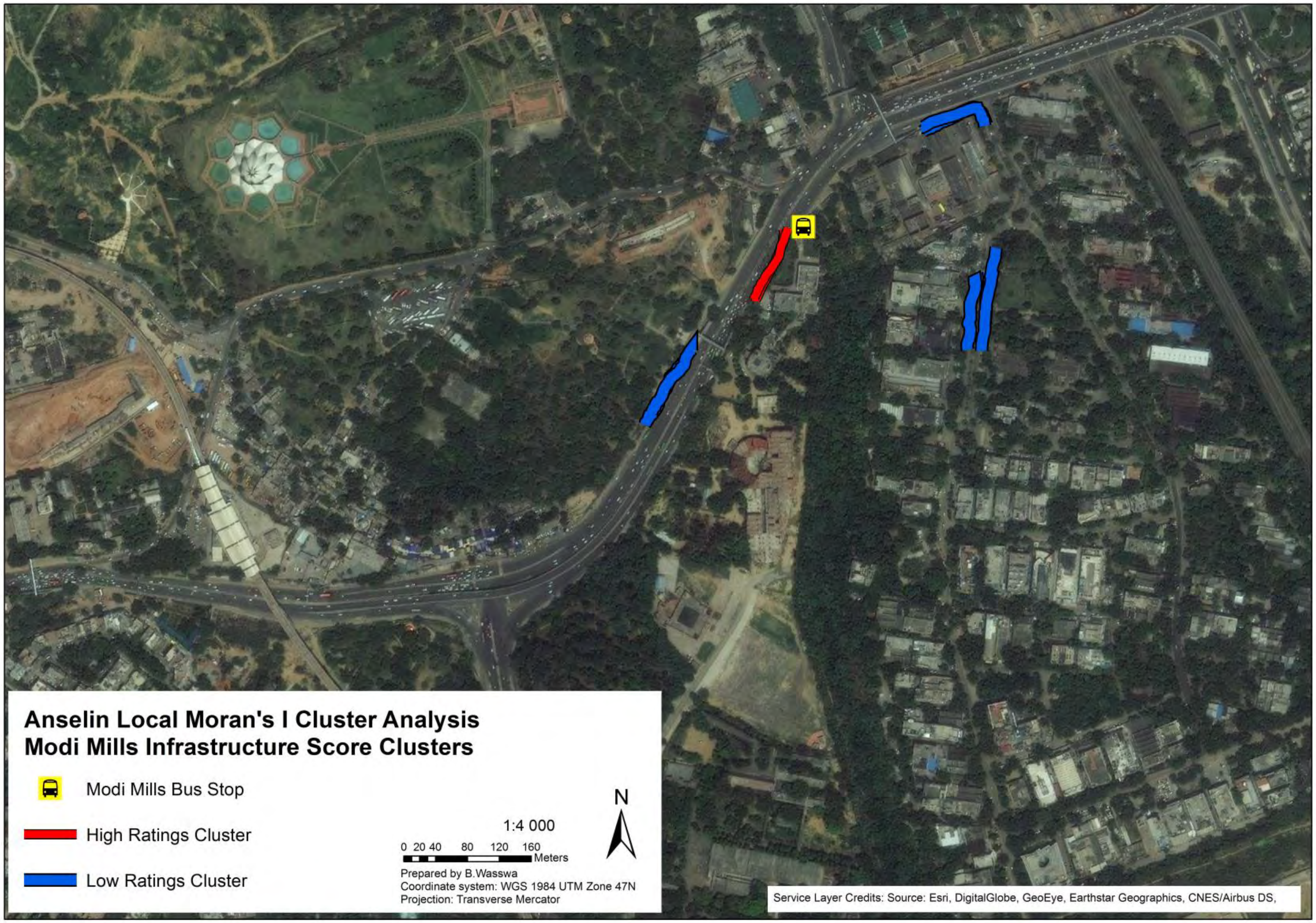
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Modi Mills Infrastructure Score Clusters
Modi Mills Bus Stop
High Ratings Cluster
Low Ratings Cluster
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Prepared by B.Wasswa
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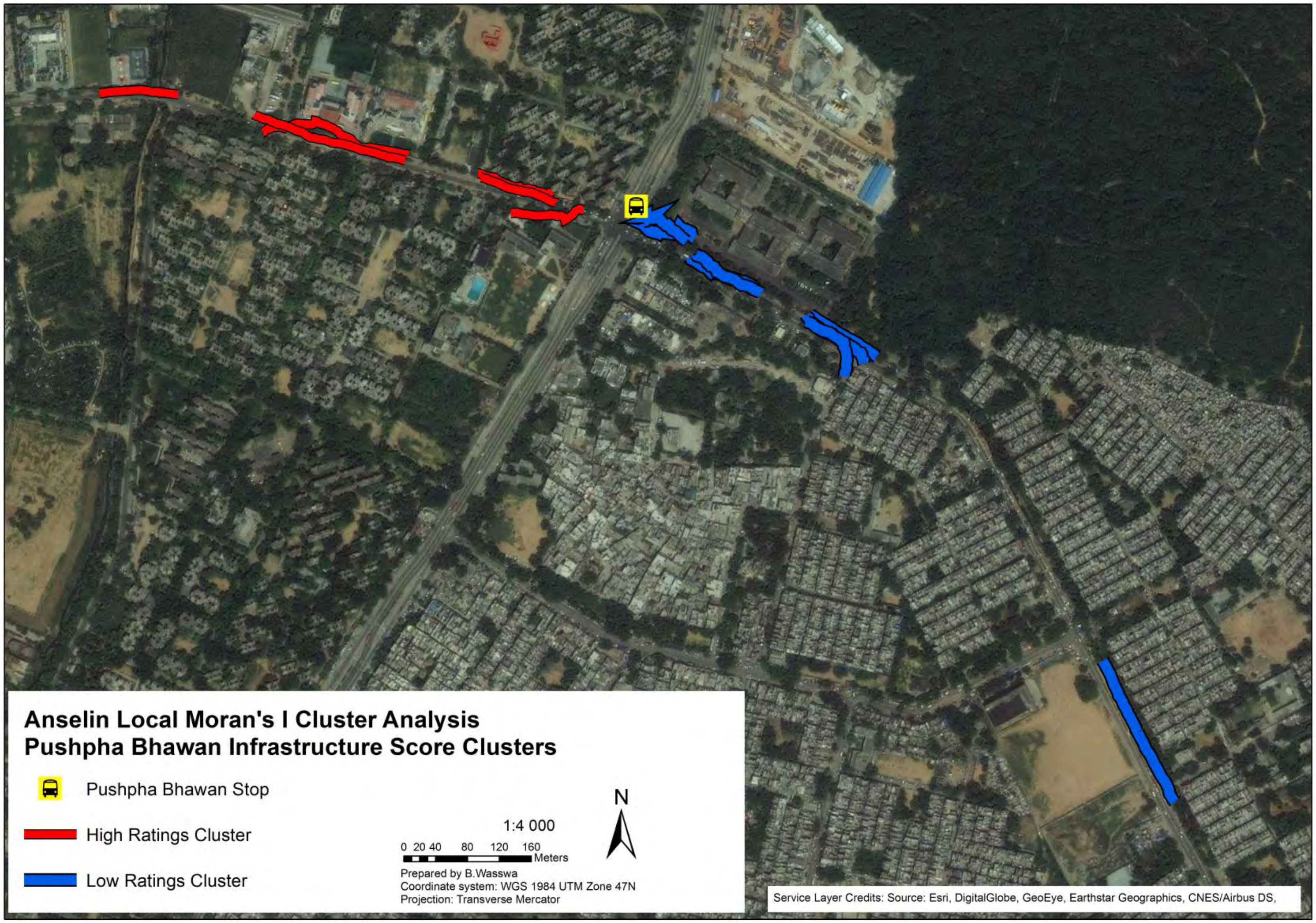
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Pushpha Bhawan Infrastructure Score Clusters
Pushpha Bhawan Stop
High Ratings Cluster
Low Ratings Cluster
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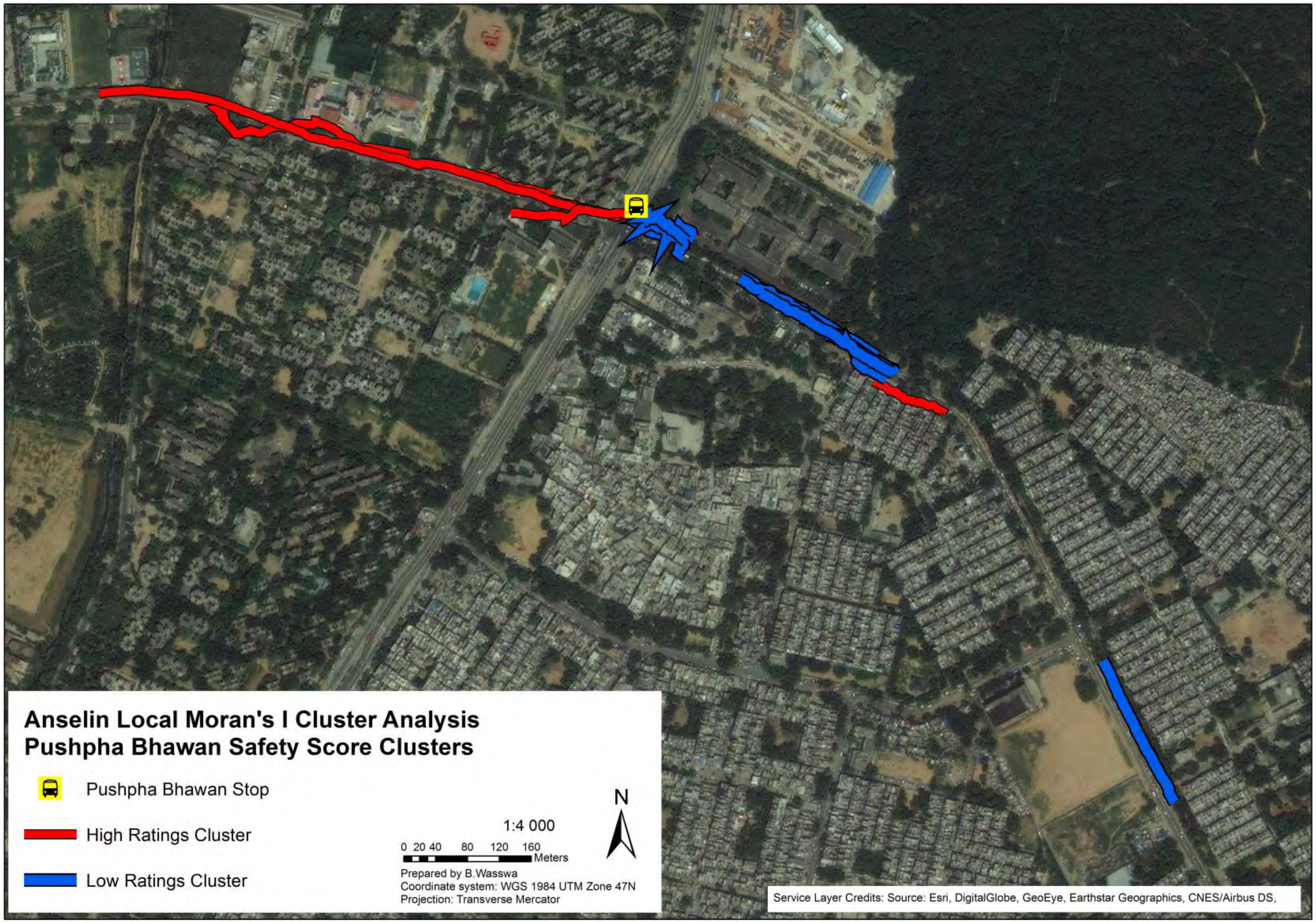
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Pushpha Bhawan Stop
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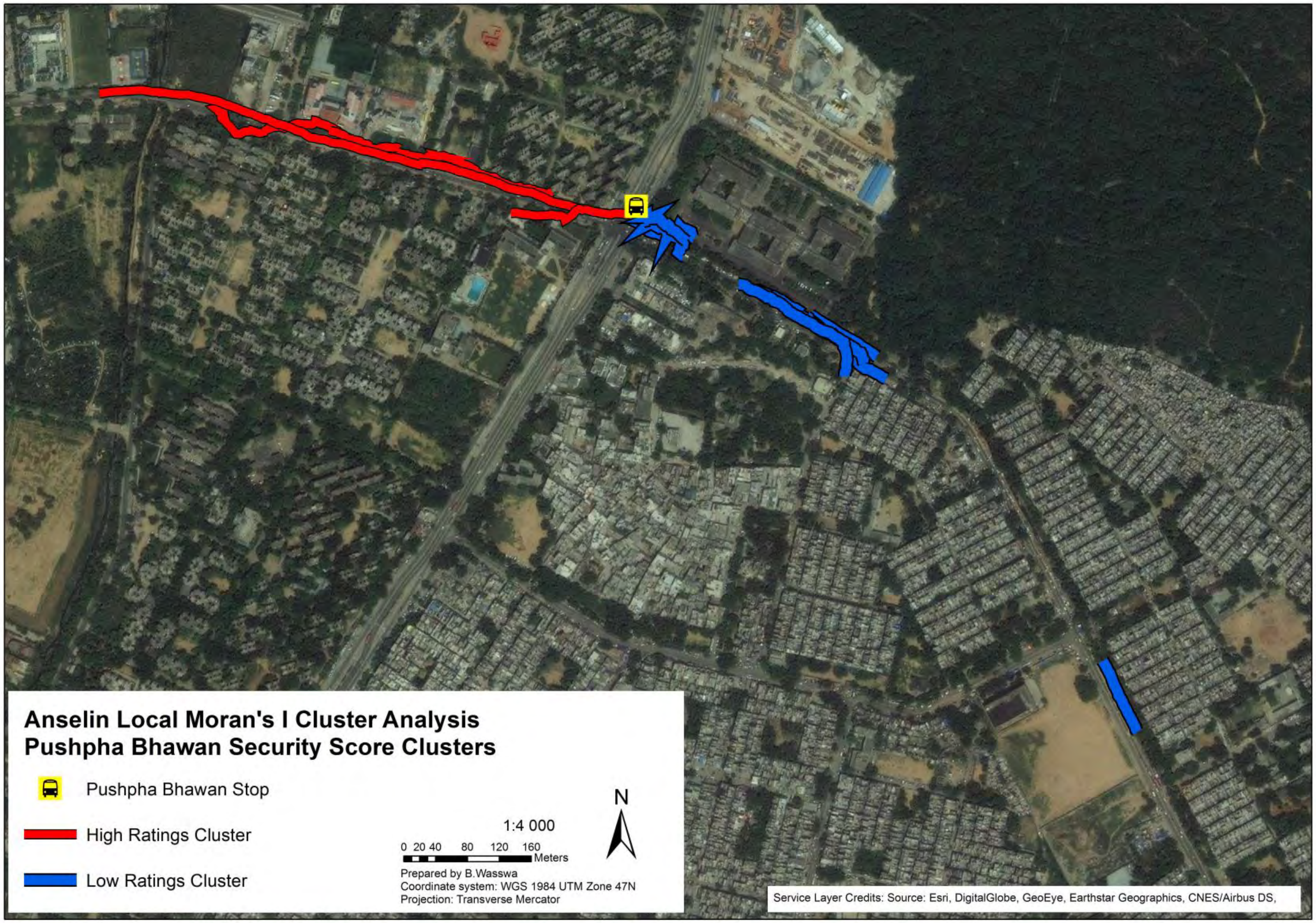
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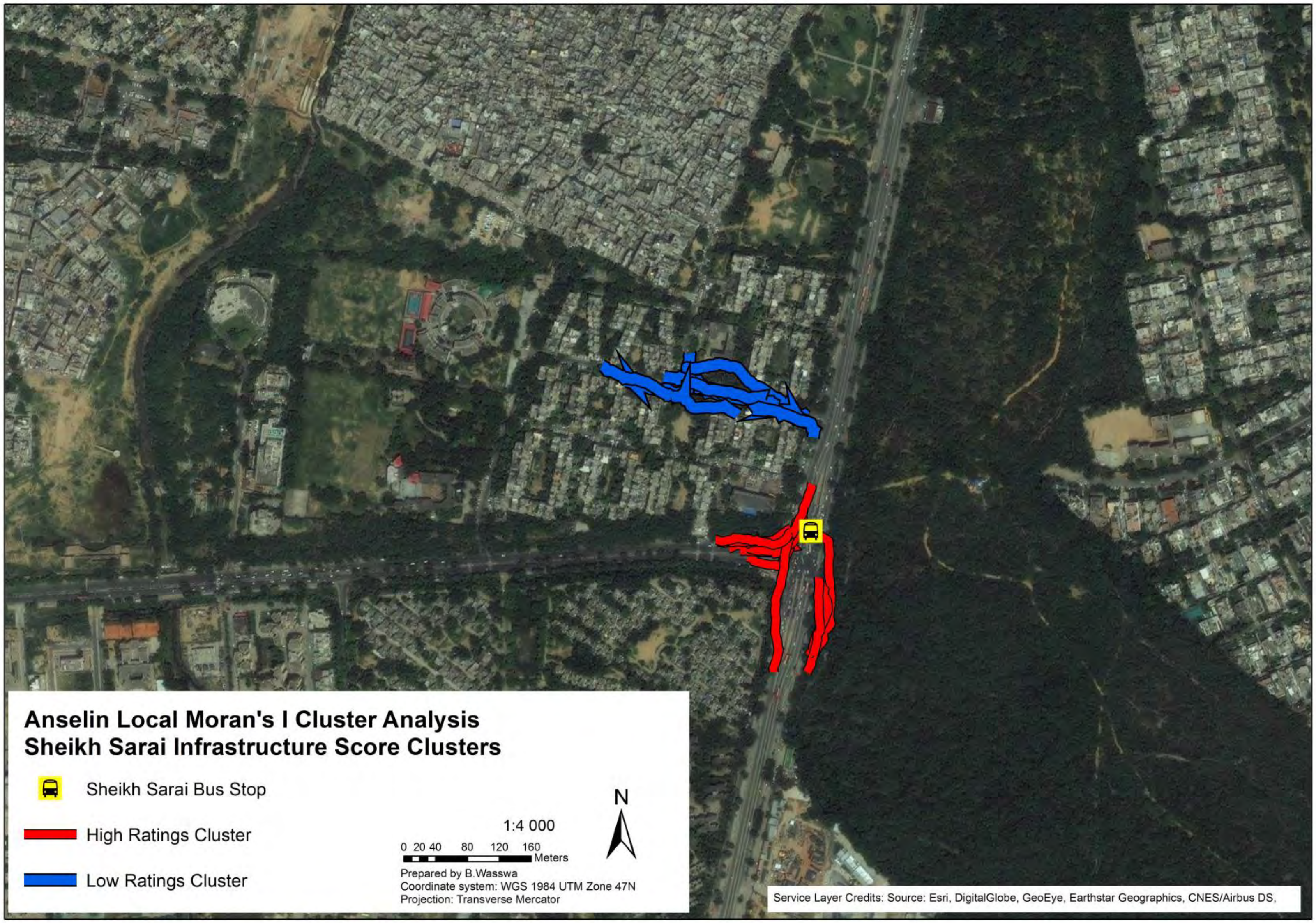
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Sheikh Sarai Infrastructure Score Clusters
Sheikh Sarai Bus Stop
High Ratings Cluster
Low Ratings Cluster
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Prepared by B.Wasswa
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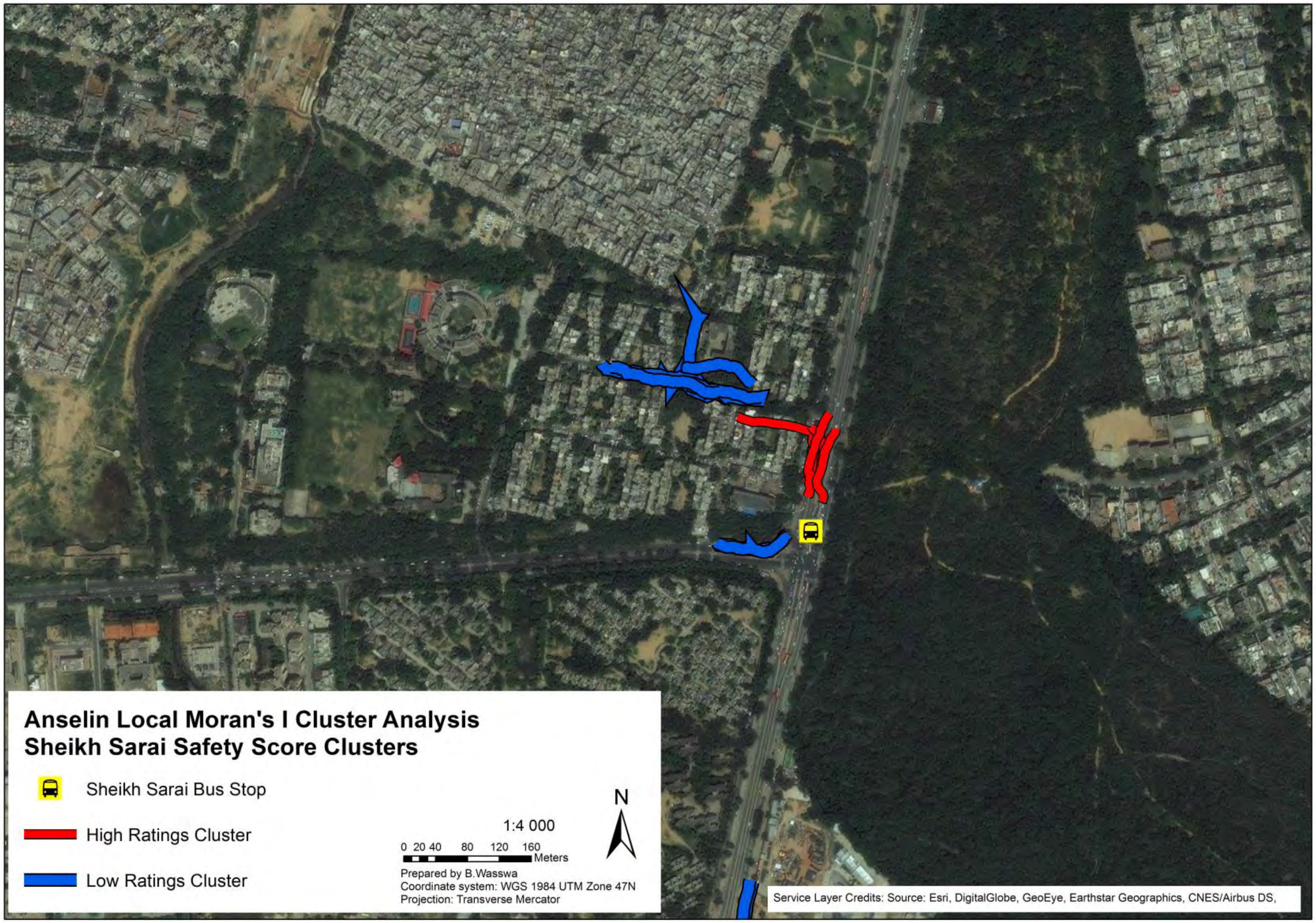
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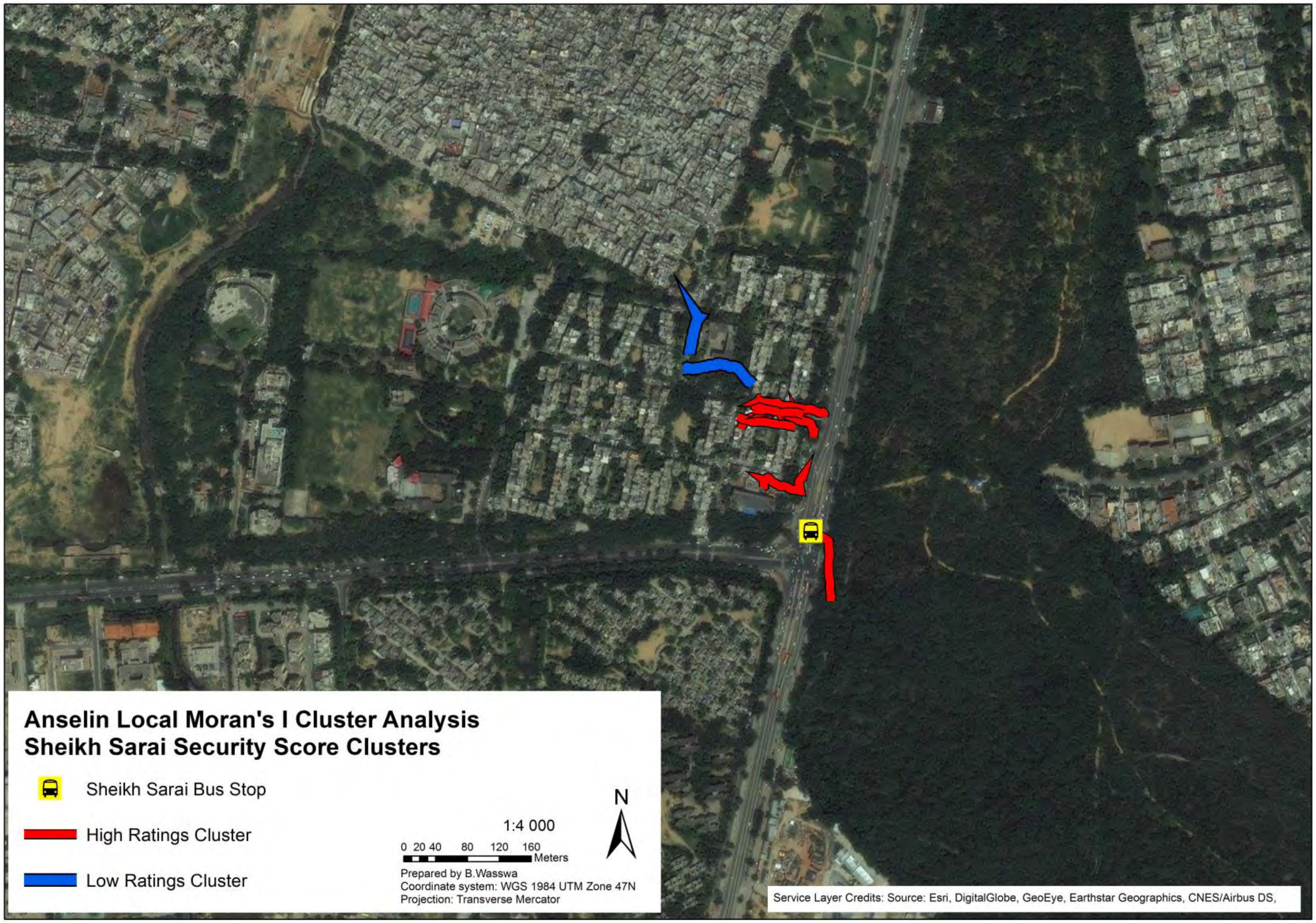
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11 Appendix B: Ethics clearance form

EBE Faculty: Assessment of Ethics in Research Projects (Rev2)

Any person planning to undertake research in the Faculty of Engineering and the Built Environment at the University of Cape Town is required to complete this form before collecting or analysing data. When completed it should be submitted to the supervisor (where applicable) and from there to the Head of Department. If any of the questions below have been answered YES, and the applicant is NOT a fourth year student, the Head should forward this form for approval by the Faculty EIR committee: submit to Ms Zulpha Geyer (Zulpha.Geyer@uct.ac.za; Chem Eng Building, Ph 021 650 4791).
NB: A copy of this signed form must be included with the thesis/dissertation/report when it is submitted for examination

This form must only be completed once the most recent revision EBE EiR Handbook has been read.

Name of Principal Researcher/Student: **Banele Wasswa** Department: **Civil Engineering**

Preferred email address of the applicant: wssban001@myuct.ac.za

If a Student: Degree: **MSc. Civil** Supervisor: **Mark Zuidgeest**

If a Research Contract indicate source of funding/sponsorship: **Volvo Educational Foundation-ACET**

Research Project Title: **Mobile phone technology in evaluating walkability levels in Cape Town and Delhi**

Overview of ethics issues in your research project:

Question 1: Is there a possibility that your research could cause harm to a third party (i.e. a person not involved in your project)?		NO
Question 2: Is your research making use of human subjects as sources of data? If your answer is YES, please complete Addendum 2.	**YES**	
Question 3: Does your research involve the participation of or provision of services to communities? If your answer is YES, please complete Addendum 3.		NO
Question 4: If your research is sponsored, is there any potential for conflicts of interest? If your answer is YES, please complete Addendum 4.		NO

If you have answered YES to any of the above questions, please append a copy of your research proposal, as well as any interview schedules or questionnaires (Addendum 1) and please complete further addenda as appropriate. Ensure that you refer to the EiR Handbook to assist you in completing the documentation requirements for this form.

I hereby undertake to carry out my research in such a way that

- there is no apparent legal objection to the nature or the method of research; and
- the research will not compromise staff or students or the other responsibilities of the University;
- the stated objective will be achieved, and the findings will have a high degree of validity;
- limitations and alternative interpretations will be considered;
- the findings could be subject to peer review and publicly available; and
- I will comply with the conventions of copyright and avoid any practice that would constitute plagiarism.

Signed by:

	Full name and signature	Date
Principal Researcher/Student:	Banele Wasswa Signed	17 Feb. 15
This application is approved by:		
Supervisor (if applicable):	Signed Mark Zuidgeest	25/03/15
HOD (or delegated nominee): *Final authority for all assessments with NO to all questions and for all undergraduate research.*		
Chair : Faculty EIR Committee	Signed G. Sithole	13/04/2015

For applicants other than undergraduate students who have answered YES to any of the above questions.		

ADDENDUM 2: To be completed if you answered YES to Question 2:

It is assumed that you have read the UCT Code for Research involving Human Subjects (available at http://web.uct.ac.za/depts/educate/download/uctcodeforresearchinvolvinghumansubjects.pdf) in order to be able to answer the questions in this addendum.

2.1 Does the research discriminate against participation by individuals, or differentiate between participants, on the grounds of gender, race or ethnic group, age range, religion, income, handicap, illness or any similar classification?		NO
2.2 Does the research require the participation of socially or physically vulnerable people (children, aged, disabled, etc) or legally restricted groups?		NO
2.3 Will you not be able to secure the informed consent of all participants in the research? (In the case of children, will you not be able to obtain the consent of their guardians or parents?)		NO
2.4 Will any confidential data be collected or will identifiable records of individuals be kept?	**Yes**	
2.5 In reporting on this research is there any possibility that you will not be able to keep the identities of the individuals involved anonymous?		NO
2.6 Are there any foreseeable risks of physical, psychological or social harm to participants that might occur in the course of the research?		NO
2.7 Does the research include making payments or giving gifts to any participants?		NO

If you have answered YES to any of these questions, please describe below how you plan to address these issues:

- If a respondent chooses to record voice notes using the mobile phone application, this voice data will be stored on the mobile phone and synced to a secure server which only the research team will have access to. When choosing to give voice notes, respondent will be requested not to mention names or give any personal information, only descriptions of the built environment

- All maps representing GPS traces will not contain street names

12 Appendix C: Consent form

Mobile phone technology in evaluating walkability levels in Cape Town and Delhi

You are invited to participate in a research study being conducted by Mr Banele Wasswa, a research at the University of Cape Town, in the Civil Engineering Department. This study is part of my Masters research, which concerns evaluating how the environment supports or detracts from the walking experience of public transport users through the use of mobile phone technology.

You are being asked to participate in this project because you are a public transport user that access public transport via walking. Please read the information below and ask any questions if you want clarification regarding items you may not understand.

- **Participation is voluntary:** You have the right to withdraw from this project at any stage and are under no obligation to participate.
- **Academic research and publications:** You response will be used solely for education and research purposes, which may then be published in academic journals.
- **Privacy:** Voice recording will only be done with your consent, no identifiable records will be kept. Maps produced with GPS tracks will note contain street identifiers.
- **Compensation:** You will not be compensated for your participation.

By signing below, you are indicating that you under the procedures described above, your questions have been answered to your satisfaction, and that you have been given a copy of this form. If you agree to participate in this study please sign below.

☐ **I agree to use the voice record function in the mobile app, and consent to this being used for the study**

Signature: ______________________________ **Date:**

13 Appendix D: Interviewer script

Oral Introduction by Intercept Interviewer:

Hello. My name is Banele Wasswa. I am conducting research towards my Master's Degree. I am undertaking a study understand the walking experience of public transport users in getting to/from public transport

Would you be willing to participate in an "on the move survey"? An on the move survey entails me escorting you to your destination and asking you to give ratings of the environment, while also allowing you to point out items which you feel have an impact on your experience, pictures can be taken of the items or you can provide voice descriptions which will be recorded. Responses to the survey questions will be anonymous; our location will be recorded throughout the survey via GPS on the mobile phone.

The choice to participate is yours alone. If you choose not to participate, there will be no negative consequence. If you choose to participate, but wish to withdraw at any time, you will be free to do so without negative consequence.

If no, say "Thank you for your time. I hope you have a pleasant day." If yes, hand consent form answer any questions and ensure signature on consent form. Continue with script.

This survey takes place as we are moving, I will ask that you point out any items natural or "man made" which support your walking experience and those that take away from it as we walk to your destination. Every 100 meters, you will be prompted to give a rating of 4 factors associated with walking,

1. Infrastructure
2. Comfort
3. Safety
4. Security

- Infrastructure relates to the walking path material and how wide it is along the segment
- Comfort relates to the provision of pedestrian oriented amenities along your route, the cleanliness of the walking environment, whether or not there are obstructions along the route and if your route has adequate path drainage
- Safety is related to your perceived risk of being injured due to interactions with motorised transport
- Security is related to your perceived risk of being harassed or mugged

If you choose to utilise the voice function, please note that this data will be saved as well. Once we have reached that street of your first destination, I will ask a few questions which should take no longer than 2 minutes to complete.

If yes, begin the survey and engage mobile phone application.

14 Appendix E: Incremental spatial autocorrelation test results

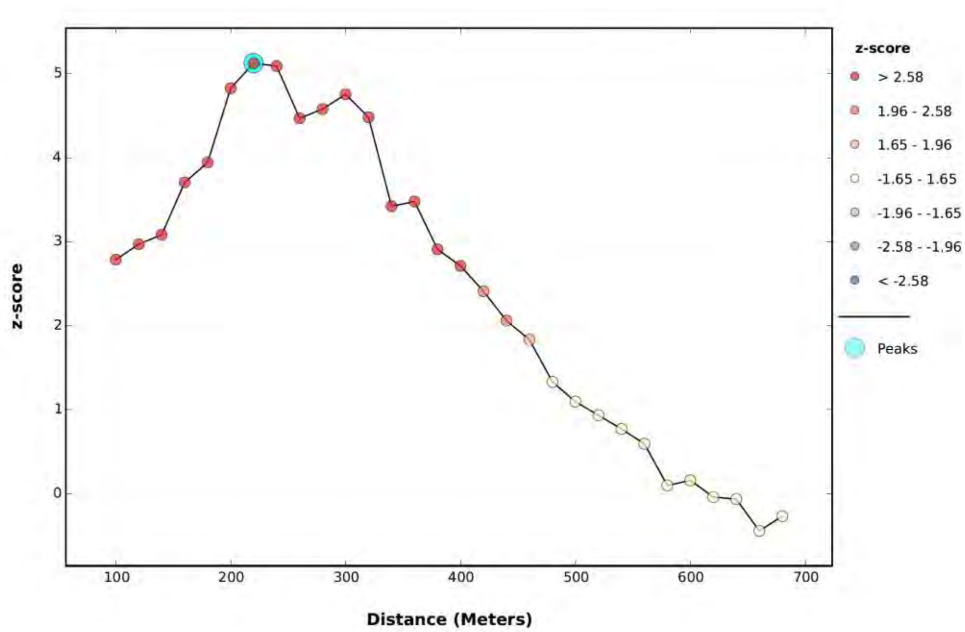

Figure 63: Incremental spatial autocorrelation results, Gardens: Comfort

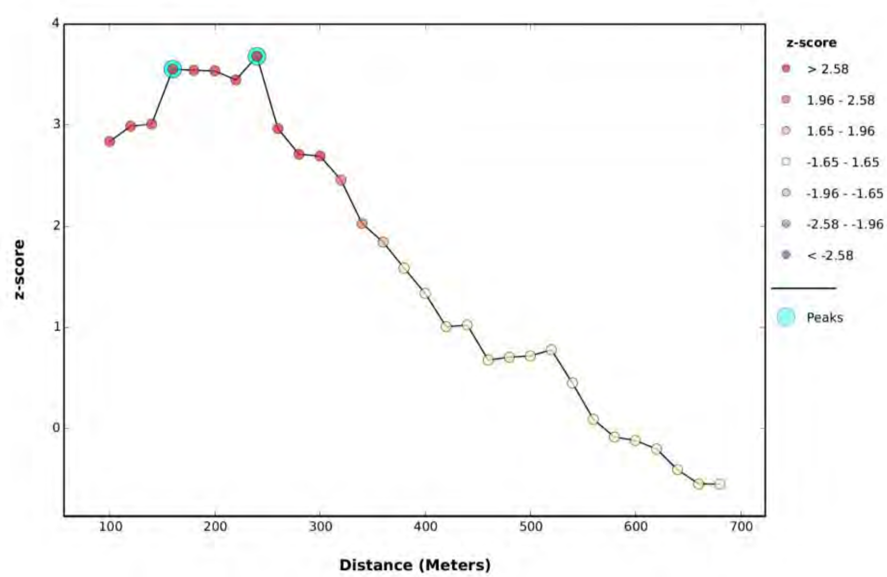

Figure 64: Incremental spatial autocorrelation results, Gardens: Infrastructure

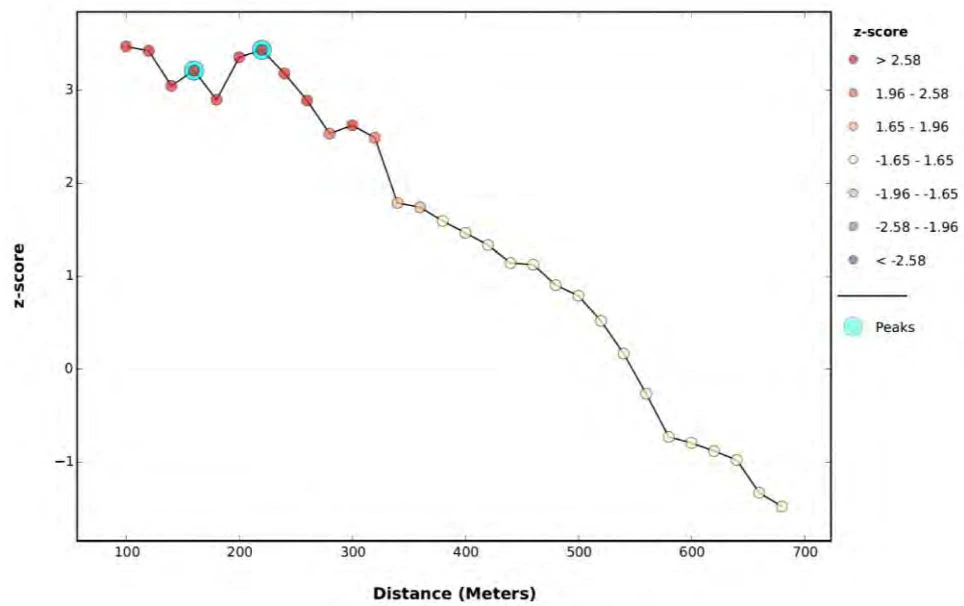

Figure 65: Incremental spatial autocorrelation results, Gardens: Safety

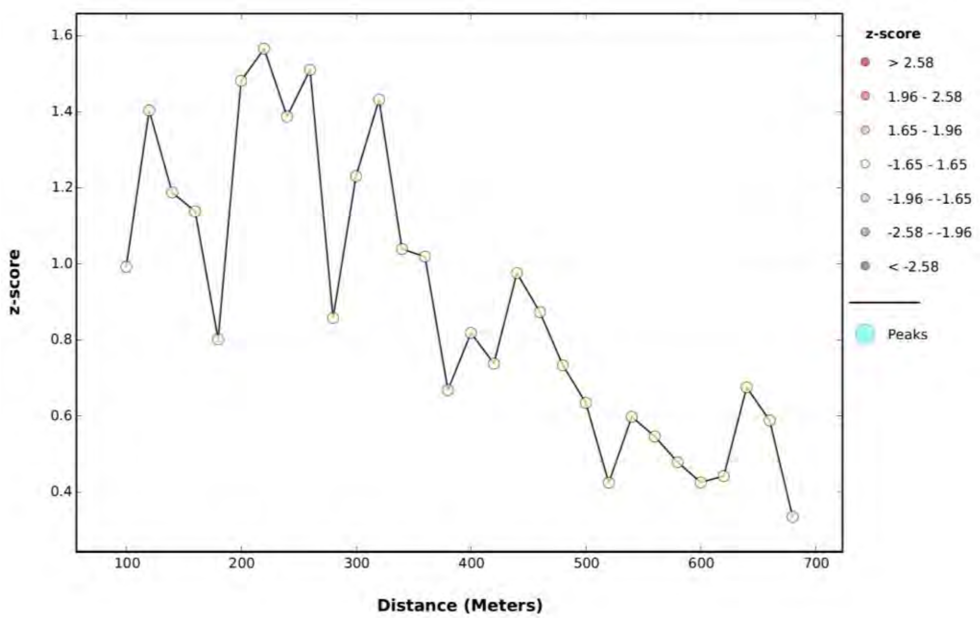

Figure 66: Incremental spatial autocorrelation results, Gardens: Security

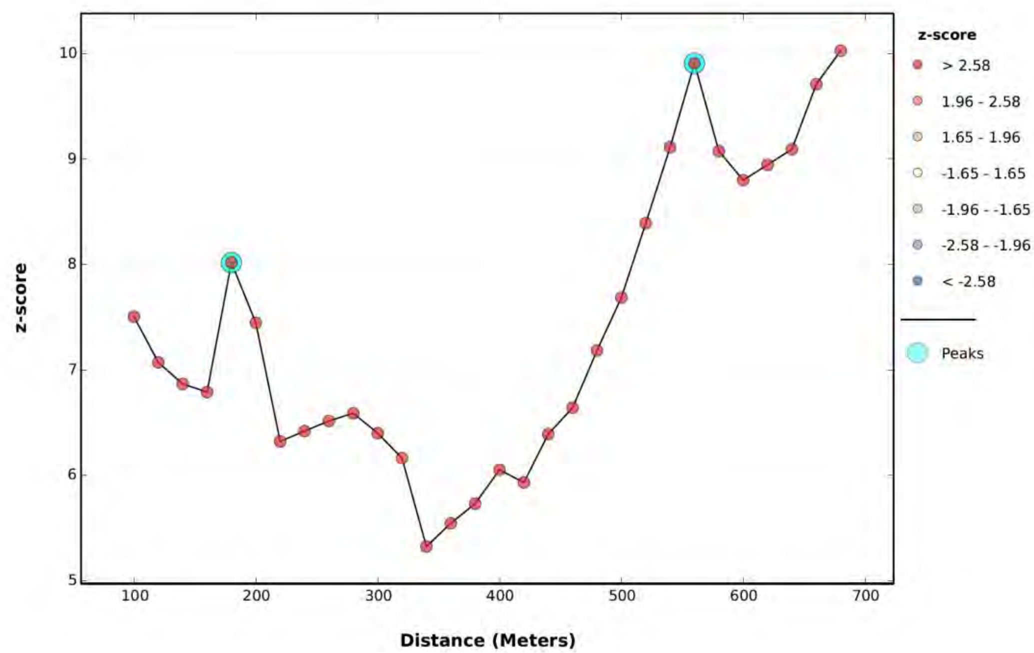

Figure 67: Incremental spatial autocorrelation results, Woodstock: Comfort

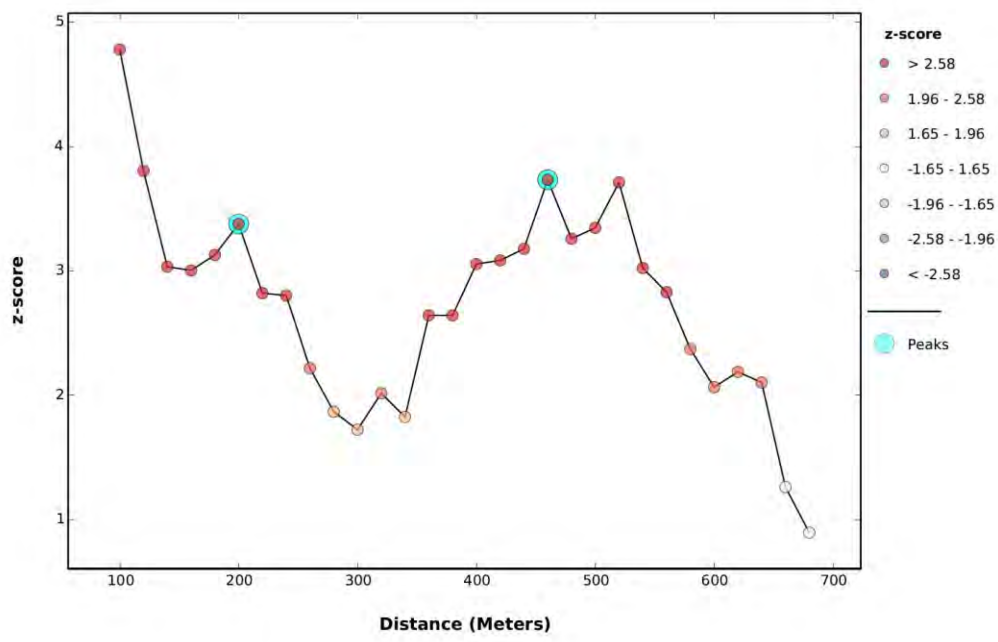

Figure 68: Incremental spatial autocorrelation results, Woodstock: Infrastructure

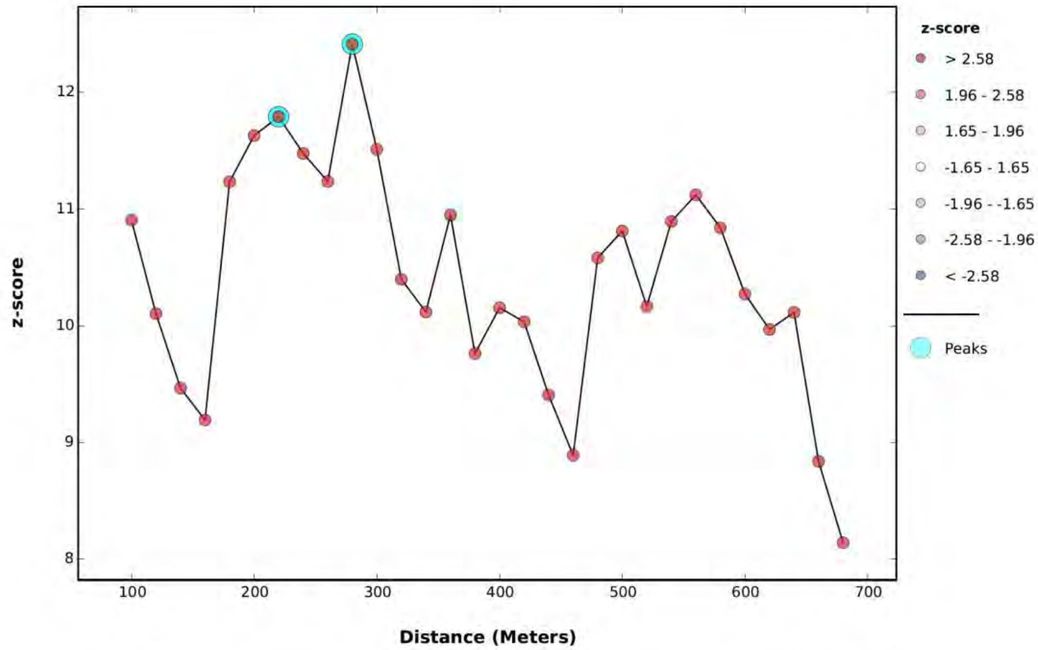

Figure 69: Incremental spatial autocorrelation results, Woodstock: Safety

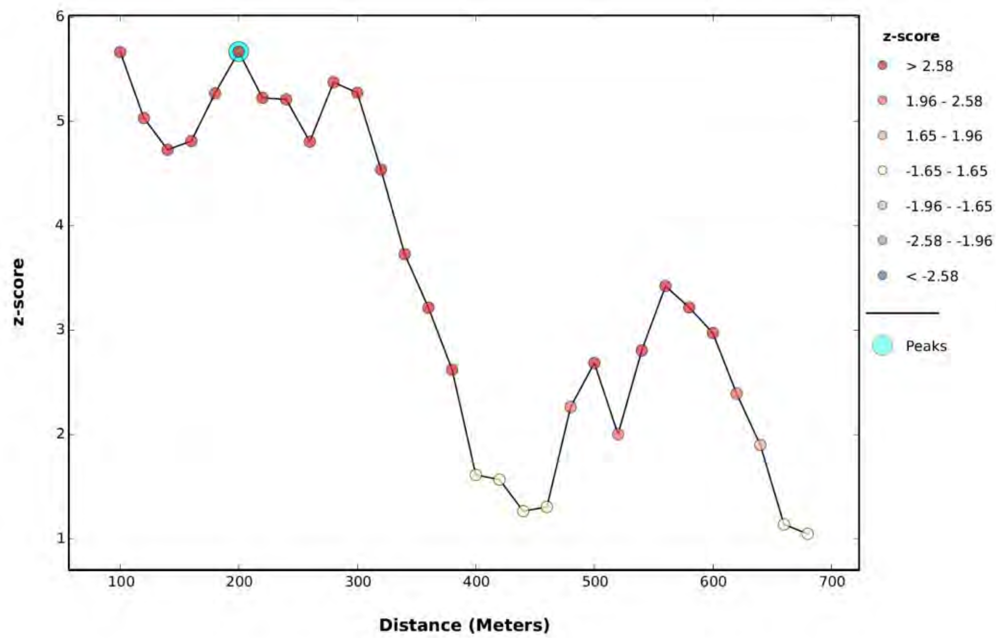

Figure 70: Incremental spatial autocorrelation results, Woodstock: Security

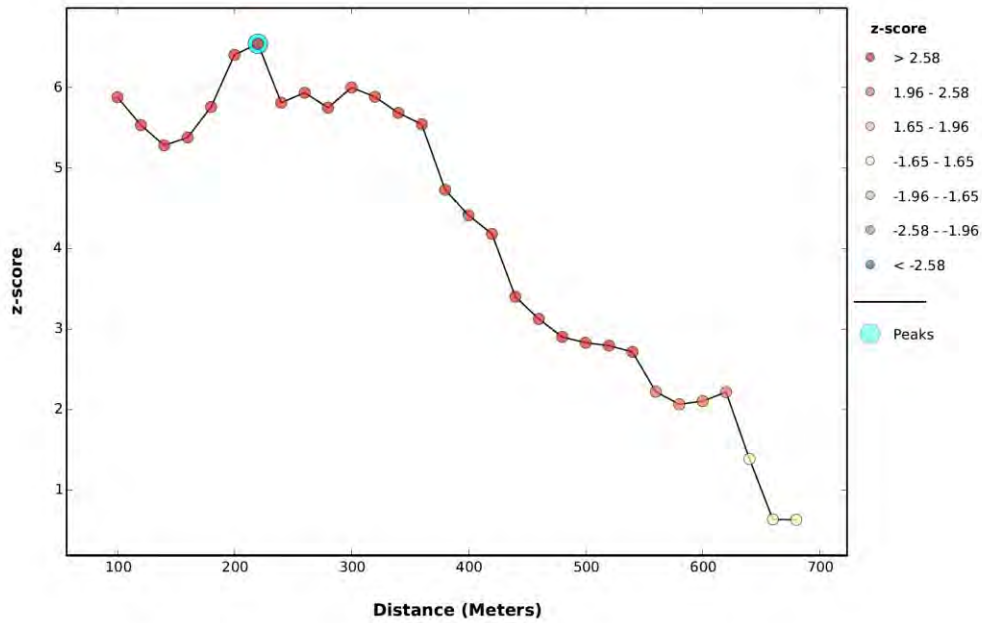

Figure 71: Incremental spatial autocorrelation results, Table Vewi: Comfort

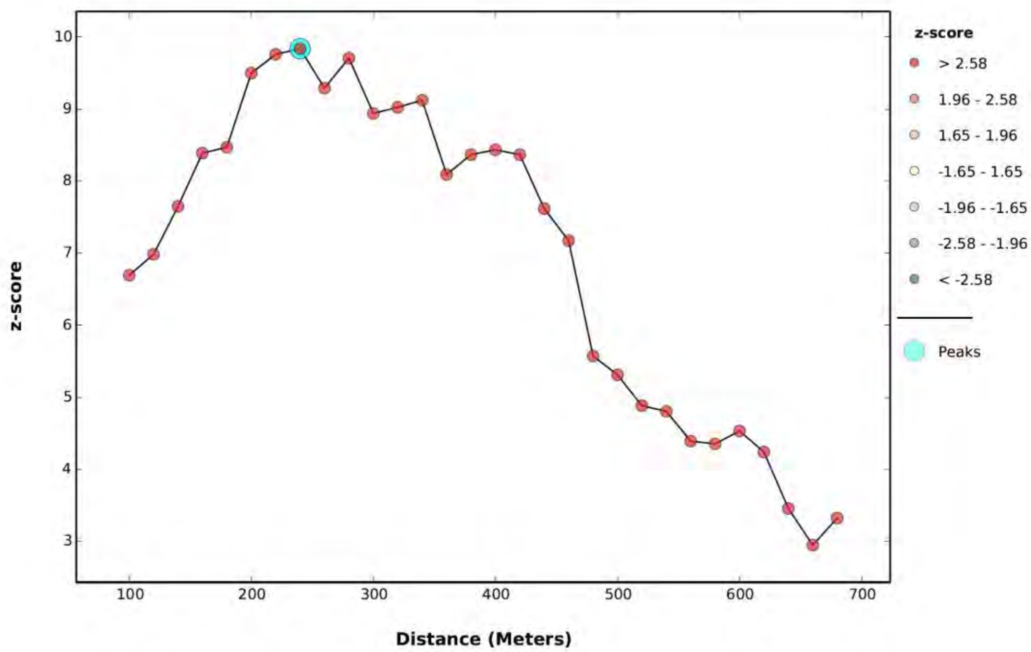

Figure 72: Incremental spatial autocorrelation results, Table View: Infrastructure

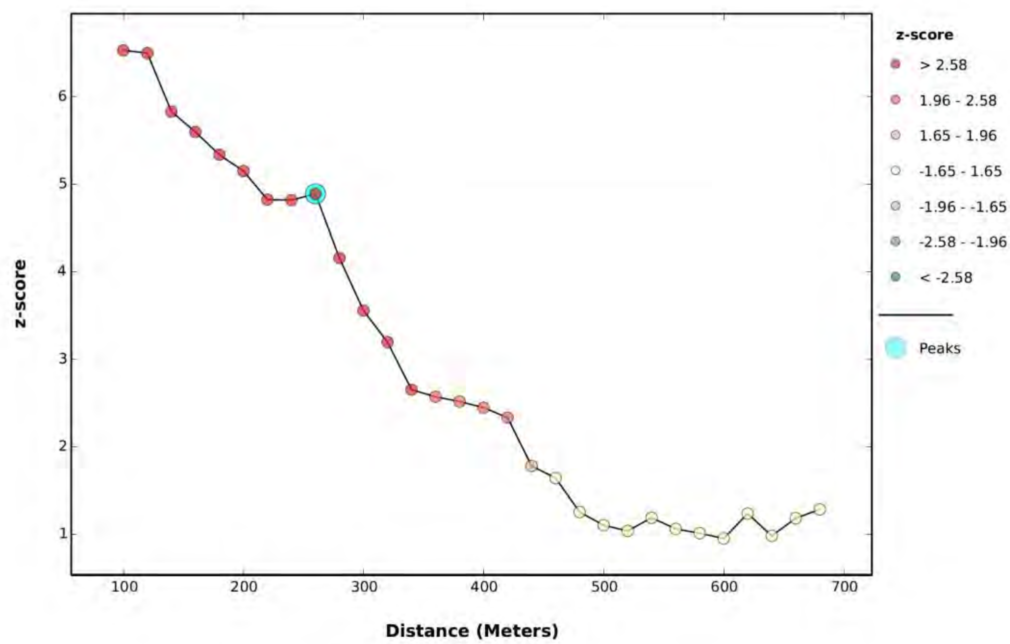

Figure 73: Incremental spatial autocorrelation results, Table Views: Safety

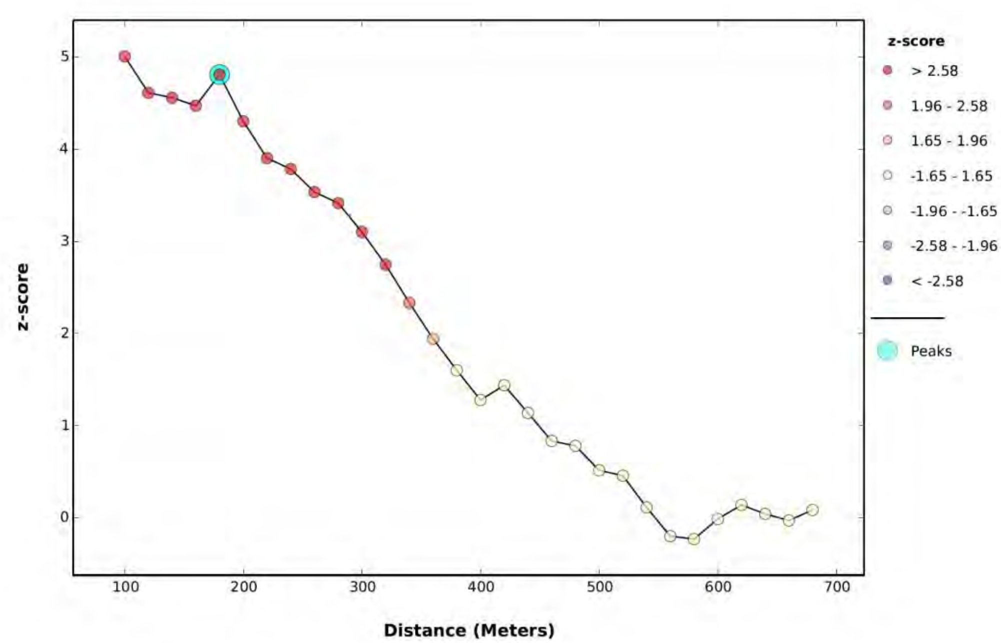

Figure 74: Incremental spatial autocorrelation results, Table View: Security

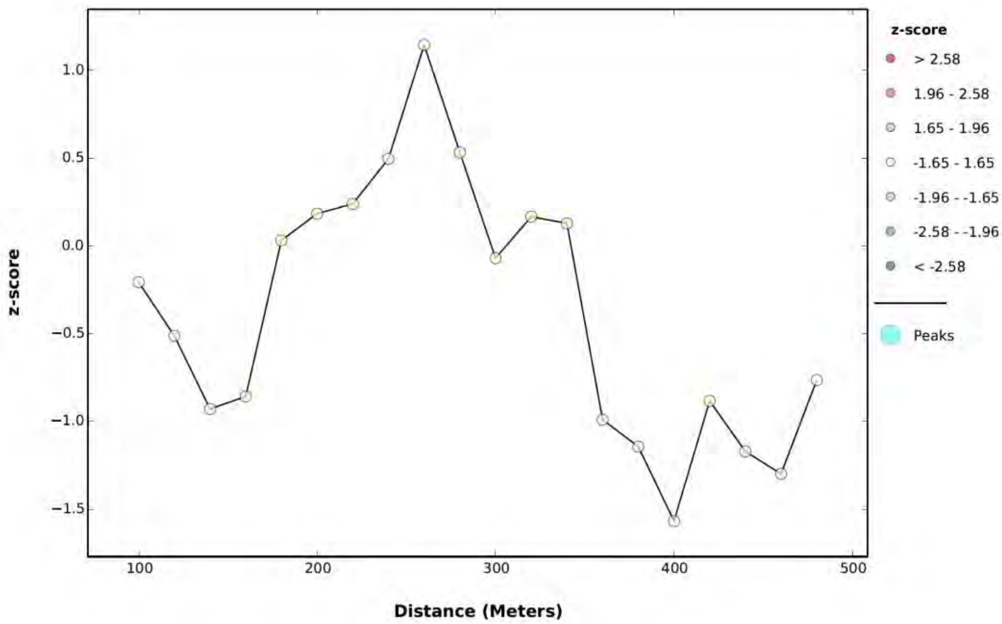

Figure 75: Incremental spatial autocorrelation results, Modi Mills: Comfort

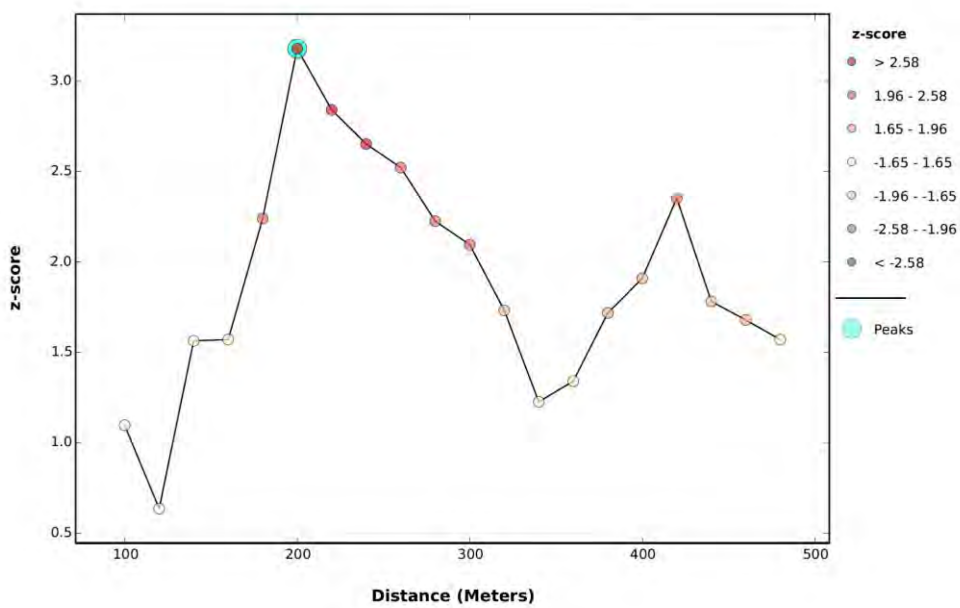

Figure 76: Incremental spatial autocorrelation results, Modi Mills: Infrastructure

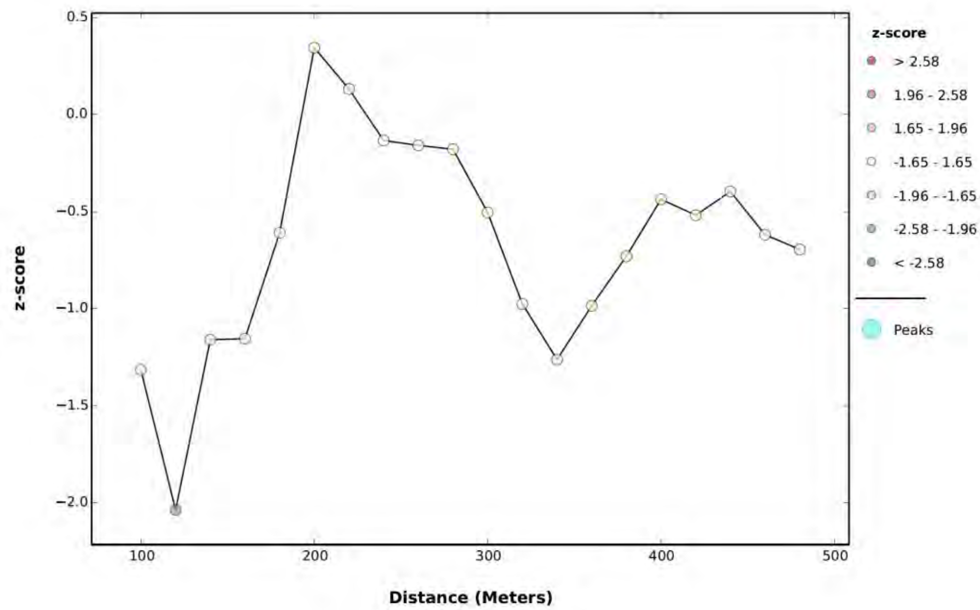

Figure 77: Incremental spatial autocorrelation results, Modi Mills: Safety

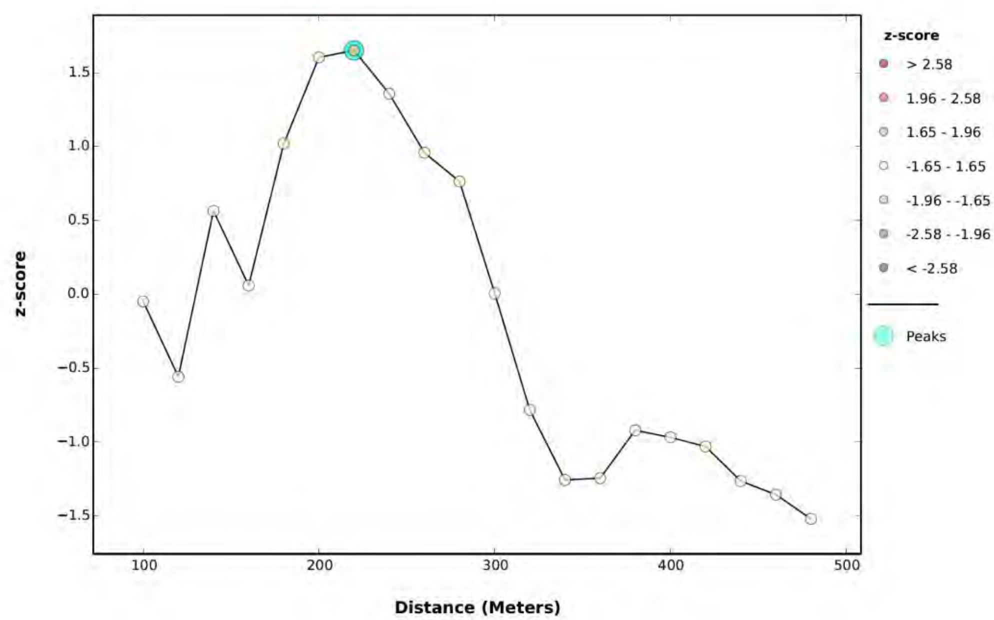

Figure 78: Incremental spatial autocorrelation results, Modi Mills: Security

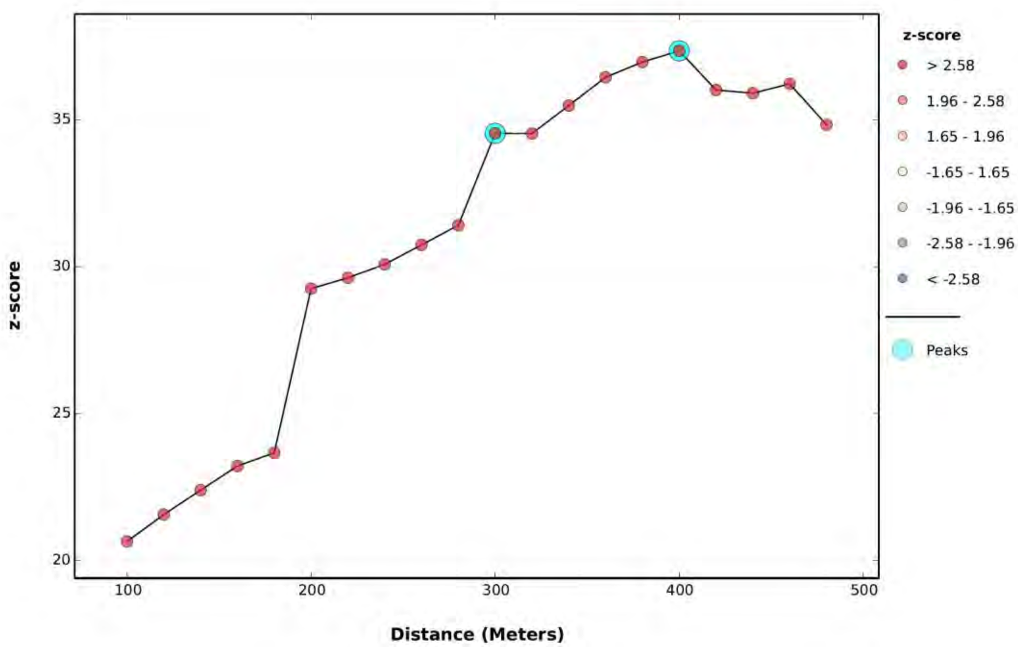

Figure 79: Incremental spatial autocorrelation results, Pushpha Bhawan: Comfort

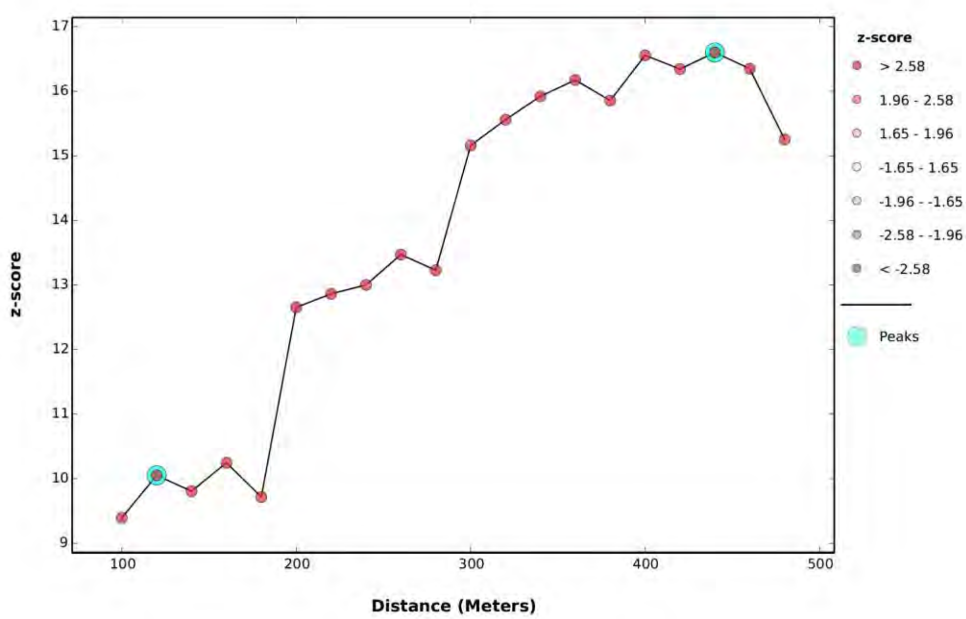

Figure 80: Incremental spatial autocorrelation results, Pushpa Bhawan: Infrastructure

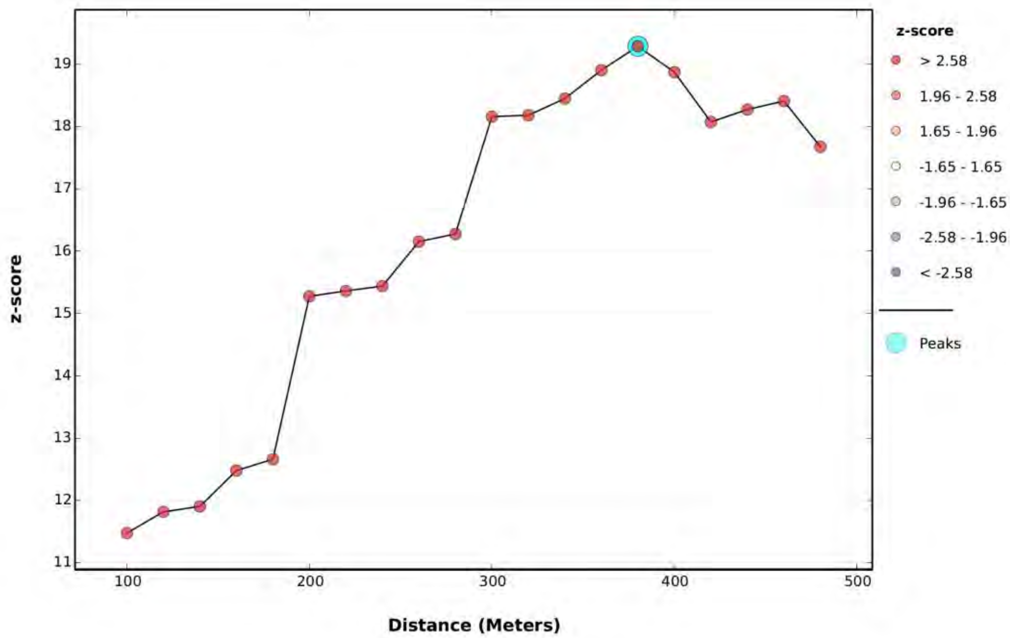

Figure 81: Incremental spatial autocorrelation results, Pushpa Bhawan: Safety

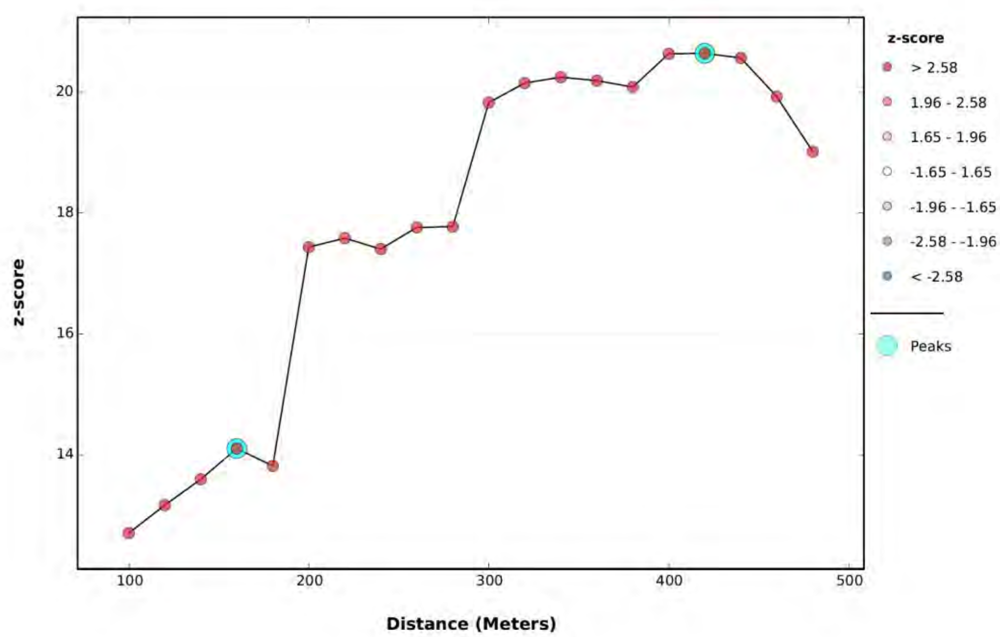

Figure 82: Incremental spatial autocorrelation results, Pushpa Bhawan: Security

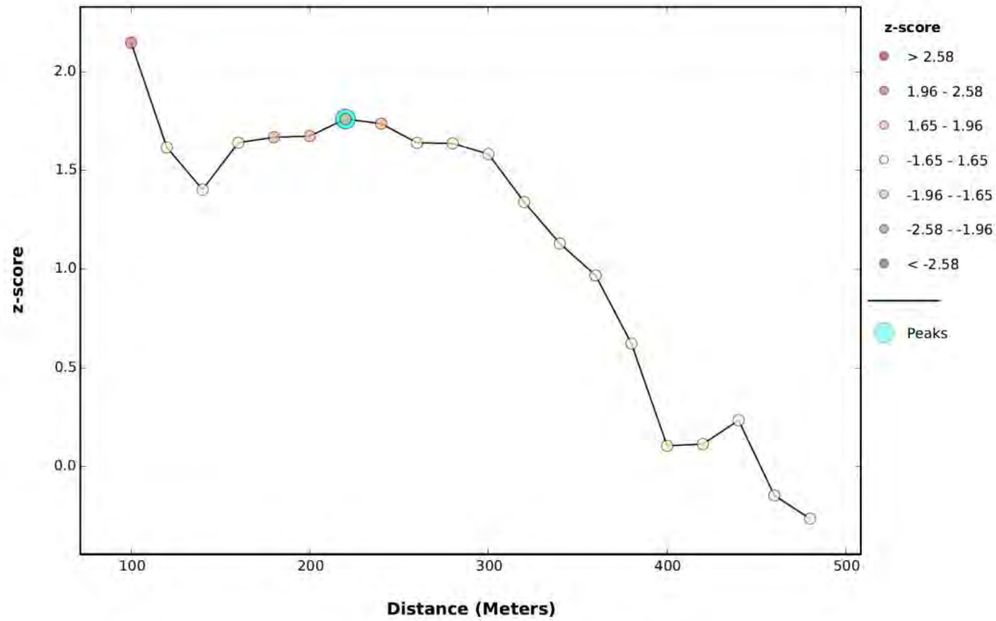

Figure 83: Incremental spatial autocorrelation results, Sheikh Sarai: Comfort

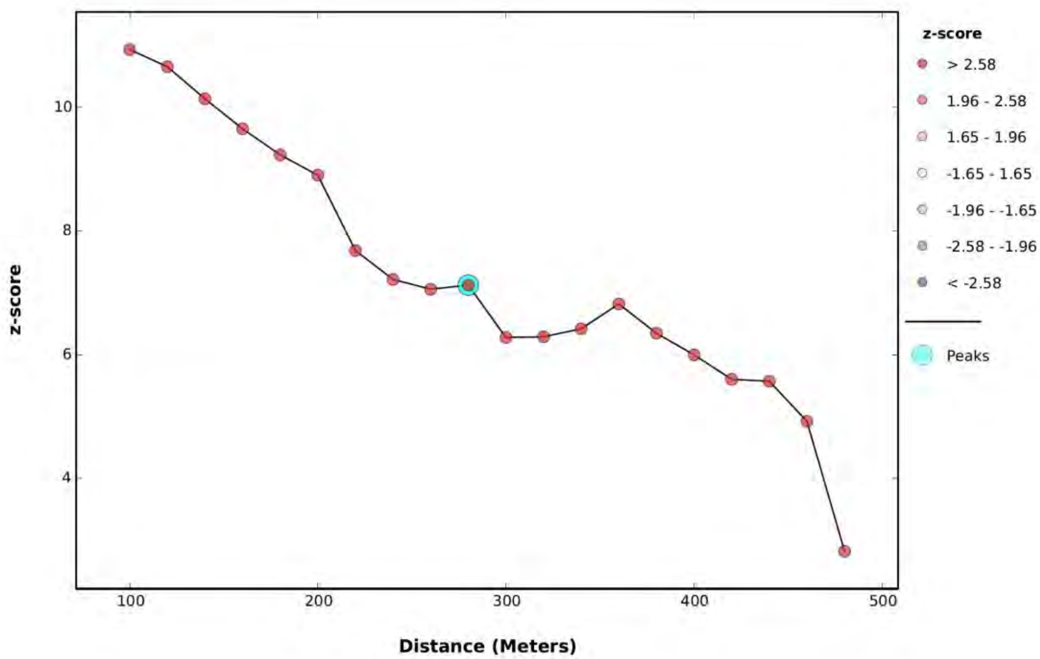

Figure 84: Incremental spatial autocorrelation results, Sheikh Sarai: Infrastructure

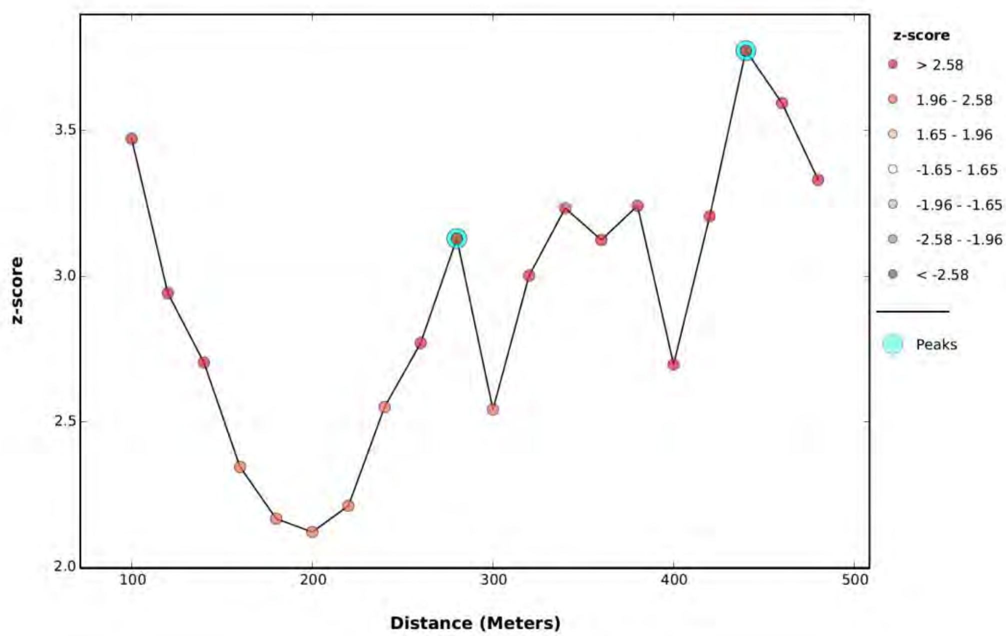

Figure 85: Incremental spatial autocorrelation results, Sheikh Sarai: Safety

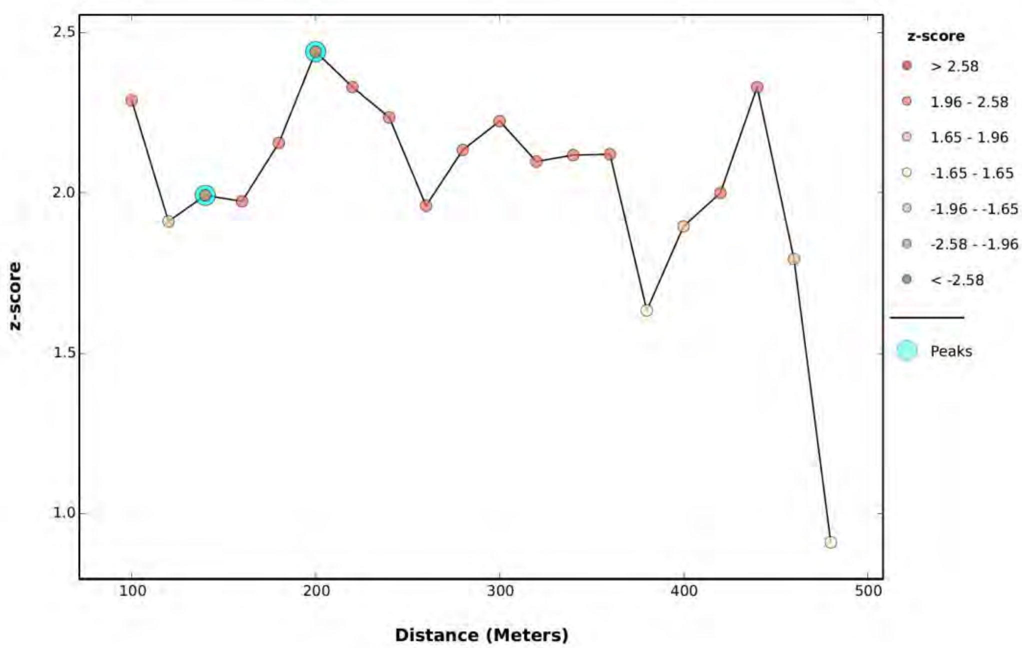

Figure 86: Incremental spatial autocorrelation results, Sheikh Sarai: Security