Predicting walkability
August 2011

S Abley – Abley Transportation Consultants Ltd
Dr S Turner – Beca Infrastructure Ltd

An important note for the reader

Acknowledgements

Abbreviations and acronyms

- CSR   community street review

- LOS   level of service

- NZTA   NZ Transport Agency

- TRL   Transport Research Laboratory

Contents

Executive summary

Walking is often considered the 'forgotten' mode of transport, but every journey, no matter how big or small, starts and ends with a single step.

Other modes of transport, and especially the private motor vehicle, have a high degree of measurability because those other modes have previously undergone significant study. Walking, on the other hand, requires limited infrastructure and it lags behind those other modes in terms of research.

This research project fills some of the 'walking' knowledge gap and provides practitioners with a technique to quantify the quality of the pedestrian environment in a way that is similar to that which is used for other modes of travel.

This research combined the methodology for collecting people's perceptions of the walking environment that is outlined in the NZTA's *Guide to undertaking community street reviews* (2010), with the method for systematically collecting physical and operational variables that is outlined in *Walkability research tools – variables collection methodology* (Abley 2006). These publications and other background material can be found at www.levelofservice.com.

This research, which was carried out from mid-2009 to early 2011, included undertaking a number of surveys of the physical and operational characteristics of the street environments in Christchurch, Gisborne, Auckland and Wellington (New Zealand), and correlating those measurements with how people felt about those environments in terms of safety, pleasantness and other variables. A number of predictive mathematical formulas were derived that enabled the perception of the qualitative quality of the street environment to be calculated using quantitative measurements.

The main products of this research are:

- the derivation of formulas for the quality of the walking environment when walking along the road (path length)

- the derivation of formulas for the quality of the walking environment when crossing the road (road crossing).

A number of formulas were produced, and the overall formulas recommended for use by practitioners are as follows:

Path lengths:

$Walkability_{PL}$ = 4.426 + 0.561 footcon + 0.300 green - 0.378 vspeed + 0.294 comfort - 0.464 devi + 0.415 pa+res + 0.170 min ewidth - 0.186 numhide - 0.0034 Avg stepav + 0.201 dese   ....

Road crossings:

$Walkability_{zebra\ crossings}$ = 5.51 + 1.40 rdcon + 0.477 tpva - 0.052 crosdi - 0.01 delay

$Walkability_{uncontrolled\ crossings}$ = 5.06 - 0.819 vspeed + 0.640 vis tra - 0.091 delay + 0.377 footcon + 0.706 rist - 0.05 crosdi

The following recommendations are suggested as a result of this research:

- **Data collection for sites at LOS D, E and F:** The sample set used in this study did not include a sufficient number of sites at LOS D, E and F to enable closer assessment and prediction of walkability scores for such sites. Future studies should focus on data collection from a broader range of sites, including an adequate number of sites with low pedestrian LOS ratings.

- **Data collection for road crossings:** The limited availability of relevant data meant that a sufficiently converging model for signalised road crossings could not be built as part of this study. In addition, the sample set included data from only 13 zebra crossing sites. Further research is needed to carefully examine the pedestrian walkability of these crossing types by utilising data from additional sites.

- **Collection of traffic-volume data:** Because of the limited availability of data on traffic volumes at path lengths and road crossings, traffic flow could not be included in the final walkability models. Efforts to use the logarithmic relationship between noise and traffic volume to develop a surrogate variable for traffic flow resulted in numerical complications during the modelling process. It is recommended that traffic flow data be utilised in future analyses of the walkability of path lengths and road crossings.

- **Walkability at different times of day:** The data utilised for developing the walkability prediction models was obtained from CSR surveys that were held at various times during the day. Future studies could look at examining the walkability of sections at specific times of the day, especially in busy CBD areas where the walking environment can differ markedly between peak and non-peak times, and between daytime and the hours of darkness.

- **Model validation:** A comprehensive model validation exercise has not been undertaken as part of this study, and could be the focus of follow-on research.

- **Walkability for impaired pedestrians:** Further research is also recommended on analysis of the differences in walkability ratings between able-bodied pedestrians and those with physical and/or visual impairments.

Abstract

This research provides a number of mathematical formulas for predicting the quality of the walking environment from the perspective of the user using operational and physical variables. The formulas were derived by combining the perception data gathered from participants in the community street reviews with measurements of the walking environment.

The two main areas that were researched to enable the derivation of formulas were:

- when walking along the road (path length)

- when crossing the road (road crossing).

This research describes the process for obtaining the data and deriving the formulas, and recommends the formulas most suitable for practitioner use. This research and the background resource material can be referenced at www.levelofservice.com.

1   Introduction

1.1   Motivation

This research has been produced to help practitioners quantify the quality of a walking environment. Other modes of transport (especially the private motor vehicle) have been subject to widespread study, and therefore have a high degree of measurability – but the research on walking lags behind. This research report fills some of the 'walking' knowledge gap and provides practitioners with a technique for quantifying the quality of the pedestrian environment in a way that is similar to that which is used for other modes of travel. This process will allow practitioners to give the topic of walking more care and attention, and facilitate the country's progress towards an affordable, integrated, safe, responsive and sustainable land transport system.

1.2   Background

Abley Transportation Consultants Ltd (Abley) and Beca Infrastructure Ltd (Beca) were commissioned by the NZ Transport Agency (NZTA) to undertake research into predicting the walkability of urban road environments in New Zealand. This project builds on previous research undertaken by Abley and Beca, including:

- the development of *Walkability research tools – variable collection methodology* (Abley 2006)

- the *Community street review (CSR)* methodology that was developed in 2007, and the correction of errata in 2010 (Abley 2010)

- the NZTA *Pedestrian planning and design guide* (2007), of which Beca was a principal author.

1.3   Research objective

The purpose of the research was to provide practitioners with a tool that used engineering measurements to predict the quality of walking environments. The research objective was to develop prediction equations for path lengths and road crossings that would allow the input of a number of operational and physical measurements to derive a 'level of service' (LOS) for the path length or road crossing. This would enable practitioners to identify areas of poor performance and potential improvements, and to test proposals. The tool would also help practitioners measure the significance of proposals.

1.4   Report structure

This report consists of the following sections:

- Section 1: Introduction – outlines the research purpose

- Section 2: Background – walkability definitions such as pedestrian 'level of service'

- Section 3: Literature review – international research on pedestrian modelling

- Section 4: Data collection methodology

- Section 5: Model development methodology

- Section 6: Prediction models – the derivation of the various models

- Section 7: Discussion

- Section 8: Recommendations

2   Background

2.1   Introduction

In transportation planning circles, walking is generally considered the 'forgotten' mode, and there are very few analytical techniques that enable practitioners to improve the provision for this mode of travel.

However, walking is a key element of a balanced transportation system. Overall, it is the second most popular form of travel in New Zealand, and nearly 20% of all household trips are made on foot (NZTA 2007). Walking is an especially vital mode of transport for the 10% of households that have no car, for those in those households with no access to a car for much of the day, and for those who cannot (or choose not to) drive (ibid). Walking is often the only way that many people (eg the elderly, people with impaired mobility, and those in low-income groups) can access everyday activities such as grocery shopping, chemists and other services.

A low-quality walking environment can adversely affect an individuals' ability to walk. Therefore it is vitally important to identify and improve any infrastructure that is failing the needs of people who wish to use walking as a mode of transport for practical, social and physical fitness reasons.

The fact that the quality of journeys undertaken on foot is not measured probably contributes to walking being considered an after-thought for most decision makers. When the walkability of an area is considered, it is usually left to urban designers and landscape architects to determine the visual appeal of the walking environment, and to engineers to assess the functionality of specific walking schemes. This often results in contradictory recommendations. For example, landscape architects might recommend features that engineers find unsafe, and engineers might recommend features that landscape architects find unattractive. In addition, the community – the end-user of walking schemes – rarely understands the subtle details between engineering or urban design issues.

Unlike the range of tools that are available to measure the quality of provision for other transport modes (especially the use of private motor vehicles), the tools that are currently available for practitioners to measure the quality of the walking environment are limited. This is further complicated by the difficulty of quantifying an area's walkability because of the wide range of possible individual perceptions.

For the walking network to be included in network planning and the economic analysis of transport decisions, analysis tools that can evaluate the quality of a walking environment before it is constructed, and provide a balance to the recommendations made for other transport modes, need to be developed.

2.1.1   Walkability – a definition

'Walkability' and 'walkable' are terms that have become common in the fields of engineering, planning and health, partly because walking is widely recognised as having benefits for the social, health and economic well-being of a society.

The term 'walkability' was defined in 2005 as '...the extent to which the built environment is walking friendly' (Abley 2005), and this definition was incorporated into the NZTA's *Pedestrian planning and design guide* (NZTA 2007). The Design Guide also noted that walkability is '...a useful way to assess the characteristics of an area or a route, although it can be subjective'.

It is this subjectivity that is the focus of this research, specifically to develop the ability to calculate *qualitative* walkability results from *quantitative* measurements.

2.2   Problem identification

Problems in the built environment, and specifically in the highway and pedestrian environments, can be identified through proactive methods such as consultation, measuring the safety or efficiency of links, or from recommendations made by the road controlling authority. Problems can also be identified through resident or user complaints – but these measures are reactive and do not promote forward planning. This means the cost of reactive or remedial work is difficult to factor into yearly budgets, apart from taking a broad-brush guess. Additionally, working reactively means that funds may not be directed to the most urgent projects and improvements, which might include unreported problems. This is clearly not an inefficient use of finite funds.

Large capital projects are exempt from this reactive process because they are usually well planned and budgeted for in advance, and can be quantified using strong economic measures such as a detailed cost–benefit ratio. In contrast, the low cost of most walking infrastructure could be one reason for the scarcity of quantifiable tools for measuring the quality of walking environments.

When a problem in the built environment is identified, it can either be viewed as:

- a maintenance issue that can be acted upon immediately, or have plans put in place to rectify it at the first available opportunity

- an issue that requires further investigation, using one of the proactive or reactive measures described above.

Professionals in this field favour taking active measures to improve the quality of the built environment, and they are increasingly using performance design techniques (eg reviewing, auditing and rating) to test performance measures such as walkability, and to understand problems and identify solutions.

2.3   Assessment techniques

In 2005, Abley Transportation Consultants Ltd developed the following three broad techniques for assessing the performance of the built environment (and therefore walkability):

- Reviewing: This applies to existing situations and may include auditing and rating, as well as other assessment tools. It can be used to assess the degree to which proposed options will improve walkability at the qualitative level.

- Auditing: This can be applied to existing and proposed designs. It identifies deficiencies against recognised standards, and can propose solutions. It is an ideal way of identifying maintenance issues and simple remedies, both qualitatively and quantitatively.

- Rating: This is a tool for scoring the walkability of an environment or facility. It can be used on existing or proposed designs, and allows a practitioner to compare different walking environments at the quantitative level.

This earlier work identified the need for a consumer-style audit that combined with a rating system to meet both the qualitative and quantitative aspects of measuring walking environments. This is slightly different to the methodologies that are applied when determining the quality of provision for, say, motorised vehicles – these tend to be based on efficiency and safety issues, and are typically reported as 'quality of service' (or 'level of service').

2.4   Level of service (LOS)

2.4.1   Community street reviews (CSR)

Past publications on the topic of pedestrian 'level of service' (LOS), such as Fruin (1971) and the US Transportation Research Board's *Highway capacity manual* (HCM) (2000), mentioned environmental factors, but they did not attempt to substantiate or qualify the effects of these on the perceived quality of the pedestrian environment.

The absence of well-publicised tools to assess the quality of the walking environment has led to the development of a number of independent walkability LOS rating systems. Three tools that have been tested in New Zealand are:

* PERS: Pedestrian Environment Review System – Transport Research Laboratory (TRL)

* Walking Audit Methodology – Boulter and Rutherford, New Zealand, 2004

* Centres for Disease Control and Prevention (CDC) – Walkability Audit Tool – USA, 2000.

In 2007, a joint project by the New Zealand Health Sponsorship Council, Living Streets Aotearoa and Abley Transportation Consultants developed a new tool called *Community street review* (Abley 2010), which built upon the UK *DIY community street audits* (Living Streets 2002) concept and combined it with a numerical rating system. The NZTA recently published an easy-to-read online CSR guide (NZTA 2010).

The CSR methodology provides a standard tool for measuring walkability in New Zealand and assesses the walkability of a route from the point of view of the people using the route. It focuses on peoples' perceptions regarding the road or road-crossing environment, and how they feel when walking. It collects data on safety, the functionality of the pedestrian space, the ease of road crossings, the effects of urban design, and other relevant factors. CSRs thus include not only a qualitative consumer audit, but also a quantitative rating. A CSR benefits the immediate community (through the auditing process) and also provides practitioners with an asset management tool (through the rating process) for prioritising potential walking schemes.

CSR data was collected in conjunction with physical and operational data as a pilot for this project. The results of this earlier project were reported in the NZTA report *Walkability research tools – summary report* (Abley 2008).

The database that was created to facilitate the collection of this data is housed at www.levelofservice.com, and the website provides a store for research on measuring walkability and the promotion of CSRs. Additional CSR data and physical and operational measurements were gathered for this current research project, and the database was updated to allow for increased functionality. The data has been used to develop linear regression equations that link the raw walkability scores that were collected during the CSR

surveys with various physical and operational variables that affect the quality of the pedestrian environment.

These mathematical equations can be used to calculate the perceived walkability in an existing or proposed walking environment from its measured physical and operational factors, in order to allow practitioners to estimate the LOS for journeys undertaken on foot in a similar manner to that currently used for other modes of travel.

3   Literature review

3.1   Introduction

The principal aim of the literature review was to evaluate the various pedestrian LOS modelling methodologies that have been developed internationally, in order to develop pedestrian LOS prediction models for roadside segments (path lengths) and road crossings in New Zealand.

Section 3.2 summarises several international research documents on pedestrian modelling for different roadside environments. Section 3.3 describes the applications of pedestrian LOS prediction models. Section 3.4 summarises the current research on pedestrian LOS prediction models and the variables that they each assess.

3.2   Pedestrian LOS modelling

3.2.1   Pedestrian LOS prediction models for the roadside environment between intersections

3.2.1.1   Landis et al – Modelling the roadside walking environment (2001)

Landis et al developed a LOS model in a US metropolitan area, using the results from an earlier pedestrian LOS perception survey that had collected more than 1200 observations from 75 participants walking on one route in Florida. The purpose of that survey had been to evaluate the LOS of the individual roadway segments within that route, rather than just the intersections.

The route consisted of 24 road segments with near-equal length, but with varying traffic characteristics, roadside features and roadway conditions. Some segments did not have footpaths. The participants were instructed to disregard the conditions at intersections and the immediate approaches, and also the surrounding aesthetics, when assessing the quality of the walking infrastructure. The participants evaluated each segment for how safe/comfortable they felt as they walked along it, using a 6-point (A–F) scale (A being the best and F being the worst).

The researchers identified the following variables that could affect the preliminary structure and testing of the pedestrian LOS model:

- lateral separation elements between pedestrian and motor vehicle traffic, including:
    - the presence of a footpath
    - the width of the footpath
    - buffers (verges) between a footpath and motor vehicle travel lanes
    - the presence of barriers within the buffer area
    - the presence of on-street parking
    - the width of the outside travel lane
    - the presence and width of shoulder or cycle lanes

- motor vehicle traffic volume

- the effect of vehicle speed

- the percentage of heavy vehicles

- driveway access frequency and volume.

Landis et al pointed out that the variables listed above were 'considered the most probable primary factors affecting pedestrians' sense of safety'. The variables were identified using several Pearson Correlation Analyses and extensive iterative testing of roadside segment groupings with common levels of independent variables.

The researchers conducted step-wise regression analysis using over 1200 real-time observations. Consequently, the following model was developed:

$$Ped\ LOS = -1.2021\ ln\ (W_{ol} + W_l + f_p x\ \%OSP + f_b\ x\ W_b + f_{sw}\ x\ W_s) + 0.253\ ln\ (Vol_{15}/L) + 0.0005\ SPD^2 + 5.3876$$
(Equation 3.1)

where:

- W_{ol} = width of outside lane (feet)

- W_l = width of shoulder or bike lane (feet)

- f_p = on-street parking effect coefficient (= 0.20)

- %OSP = percent of segment with on-street parking

- f_b = buffer area barrier coefficient (= 5.37 for trees spaced 20 feet on centre)

- W_b = buffer width (distance between edge of pavement and footpath, measured in feet)

- f_{sw} = footpath presence coefficient (= 6–0.3Ws)

- W_s = width of footpath (feet)

- Vol_{15} = average traffic during a 15-minute period

- L = total number of (through) lanes (for road or street)

- SPD^2 = average running speed of motor vehicle traffic (miles/hr).

The best model form and its terms, coefficients and T-statistics are shown in table 3.1. The model has a R^2 value of 0.85.

Table 3.1   Model coefficients and T-statistics

Model terms	Coefficients	T-statistics
Lateral separation elements: $\ln(LS)$	-1.2021	-10.072
Motor vehicle volume: $\ln(Vol_{15}/L)$	0.253	3.106
Speed and MV type: SPD^2	0.0005	2.763
Constant	5.3876	11.094
Model correlation (R^2)	0.85	

In table 3.2, the pedestrians' LOS scores resulting from the equation developed by Landis et al have been stratified into service categories A–F, reflecting the users' perceptions of the road segments' LOS for pedestrian travel.

Table 3.2   LOS categories (Landis et al)

Level of Service	Pedestrian LOS score
A	≤1.5
B	>1.5 and ≤2.5
C	>2.5 and ≤3.5
D	>3.5 and ≤4.5
E	>4.5 and ≤5.5
F	>5.5

3.2.1.2   Huang and Chiun – Modelling level of service on pedestrian environment (2007)

Huang and Chiun developed a pedestrian LOS prediction model based on 1075 participants and 263 street segments in Taiwan. The authors criticised the Landis et al model for using a potentially non-repeatable questionnaire methodology to determine the quality of the walking environment.

Huang and Chiun collected the following variables that they considered would affect the pedestrian LOS:

- the effective width of the footpath (W_s)

- the width of barriers (W_b)

- the flow volume of pedestrians in maximum 15-minute periods during the peak hour (N_p)

- the flow rate of pedestrians per minute per effective width of footpath (Q_p)

- the vehicle flow volume in the peak hour (F).

If W_s is fixed and N_p increases, then Q_p can indicate the level of congestion of a pedestrian walking environment.

The authors used the 'fuzzy weighting methodology' to develop a safety index and a comfort index for each of the street segments. Both the safety index (α_s) and comfort index (α_c) are functions of Q_p, W_s, W_b and F.

A step-wise regression analysis using 215 observations was undertaken.

Consequently, the following model was developed using α_s and α_c as the independent variables:

$$Pedestrian\ LOS = 0.782\alpha_s + 0.810\alpha_c - 3.535 \qquad \text{(Equation 3.2)}$$

The correlation coefficient (R^2) of the above model is 0.9983. Based on the model, the authors were able to develop a LOS grading A–L using Q_p, W_s, W_b and F, as shown in figure 3.1.

Figure 3.1   Pedestrian LOS grading system (Huang and Chiun 2007)

δ	1		2		3	
$level$	A	B	C	D	E	F
Q_p	0.1~0.5	0.5~0.8	0.9~1.3	1.4~1.5	1.6~2.1	2.1~2.5
$\bar{W}_s$	0~1	1.5	2	2.5	3	3.5
W_b	1~1.5	1.5	1.5~2	2~2.5	2.5~3	3~3.5
F	0~116	170~819	1897 ~1399	1404 ~1594	1612 ~1937	1939 ~2203

δ	4		5		6	
$level$	G	H	I	J	K	L
Q_p	2.6~3.8	3.9~4.1	4.2~5.6	5.7~6.4	6.5~9.8	10~14.4
$\bar{W}_s$	4	4.5	5	5.5	6	6.5
W_b	3.5~4	4	4	4.5~4.5	4.5~4.5	5
F	2207 ~2669	2681 ~2961	2969 ~3240	3246 ~3542	3565 ~3725	3784 ~4065

3.2.1.3   Gallin – Quantifying pedestrian friendliness (2001)

Gallin developed a very simplistic model to determine LOS for pedestrians for footpath segments. He identified the following three main categories that affect pedestrian LOS:

*   the physical characteristics

*   location factors

*   user factors.

The factors contained in each category are scored by using the system shown in table 3.3. Each factor is multiplied by its respective weight, and addition of these values results in a combined score that is used to assign the corresponding LOS grades, as shown in table 3.4.

Table 3.3   Assessment table to determine pedestrian LOS for footpath segments (Gallin 2001)

Category	Factor	Weight	0 points	1 point	2 points	3 points	4 points
Design Factors (Physical Characteristics)	Path Width	4	No pedestrian path	0-1m	1.1 - 1.5m	1.6 - 2.0m	more than 2m wide
	Surface Quality	5	unsealed and/or many cracks/bumps, ie very poor quality	poor quality	moderate quality, i.e. some cracks/bumps etc.	reasonable quality, ie acceptable standard	excellent quality (continuous surface with very few bumps/cracks etc)
	Obstructions	3	more that 21 obstructions per km	between 11 and 20 obstructions per km	between 5 and 10 obstructions per km	between 1 and 4 obstructions per km	no obstructions
	Crossing Opportunities	4	none provided, difficult to cross	some provided but poorly located	some provided and are reasonably well located but more are needed	adequate crossing facilities are provided and are reasonably well located OR none are provided as they are unnecessary	dedicated pedestrian crossing facilities are provided at adequate frequency
	Support Facilities	2	non existent	few provided and poorly located	few provided and reasonably well located	several provided and well located OR absent but unnecessary	many provided and well located
Location Factors	Connectivity	4	non existent	poor	reasonable	good	excellent
	Path Environment	2	unpleasant environment, close to vehicular traffic	poor environment, may be within 1m of kerb	acceptable environment, between 1 and 2m of kerb	reasonable environment, between 2 and 3m from kerb	pleasant environment, pedestrians more than 3m from kerb
	Potential for Vehicle Conflict	3	severe, more than 25 conflict points per kilometre	poor situation, between 16 and 25 conflict points per km	moderate, ie 10 to 15 potential vehicle conflict points per km	reasonable, 1 to 10 or less conflict points per km	no vehicle conflict opportunities
User Factors	Pedestrian Volume	3	More than 350 per day	226 to 350 per day	151 to 225 per day	81 to 150 per day	Less than 80 per day
	Mix of Path Users	4	majority of path users are non-pedestrians	approx 51% to 70% of path users are non-pedestrians	between 21% and 50% non-pedestrian path users	less than 20% non-pedestrians	pedestrians only
	Personal Security	4	unsafe	poor	reasonable	good	excellent security provided

Table 3.4   Pedestrian LOS grade scale (Gallin 2001)

Level of service	Pedestrian LOS score
A	132 or higher
B	101–131
C	69–100
D	37–68
E	36 or lower

3.2.2   Pedestrian LOS prediction model for urban signalised intersections

3.2.2.1   Petritsch et al – Level of service model for pedestrians at signalized intersections (2004)

Petritsch et al developed a pedestrian LOS prediction model for urban signalised intersections. They used the results from a pedestrian LOS perception survey that involved the collection of more than 500 observations from approximately 50 participants who walked on a particular metropolitan route in Florida. The survey used both volunteer and paid participants. Because the quality of the roadway segments between intersections had already been surveyed by Landis et al, the purpose of this survey was to evaluate the quality or LOS of just the intersections.

The route was approximately 5km in length and included 23 intersection crossings that all had different crossing distances and traffic volumes. The entire route had urban arterial facility sections with varying traffic, roadside features and roadway conditions. All the arterial sections had footpaths.

Participants were asked to score the LOS of the individual intersections between A–F, where level A was considered the most safe/comfortable (or least hazardous) and level F the least safe/comfortable (or most hazardous). The participants were instructed to consider only conditions within the intersections and their approach lanes. During the survey these were marked with 'Begin intersection' and 'End intersection' signs. Participants were also told not to consider any of the following factors:

- conditions of the road segment before the 'Begin intersection' sign or after the 'End intersection' sign

- the aesthetics, neighbourhood quality, or condition of adjacent properties

- anything outside the intersection itself or its adjacent footpaths.

The researchers used the participants' intersection scores to validate four hypotheses prior to the development of a pedestrian LOS model for signalised intersections. The results of the hypothesis testing are summarised in table 3.5, which shows that the LOS results supported Hypothesis 3, and suggest that a specific pedestrian LOS model for signalised intersections is required. The result for Hypothesis 4 suggests that volunteer participants, rather than paid members of the survey team, can be used for pedestrian LOS perception surveys, thereby reducing the data-collection costs for pedestrian model development projects.

Table 3.5   Hypotheses test results for signalised intersections

Hypothesis	Result
1 Participants would score the intersections differently according to their demographic characteristics.	Insignificant
2 Crossing pedestrians who were walking with the traffic (ie walking in the same direction as the traffic in the adjacent lanes parallel with the crosswalk) would score the intersections differently from crossing pedestrians who were walking against the traffic.	Insignificant
3 The pedestrian LOS model for roadway segments does not adequately predict how well intersections serve pedestrians.	Significant
4 Paid participants would score intersections differently from volunteer participants.	Insignificant

The researchers identified the following list of variables that could affect the preliminary structure and testing of the pedestrian LOS model:

• perceived conflicts:

– motorists turning right from the street parallel to the road crossing

– motorists turning right from side streets, on a red light

– through motorists on the street parallel to the road crossing

– motorists turning left from the street parallel to the road crossing

• perceived exposure:

– crossing distance

– presence of a crosswalk

– other traffic-control devices (eg no right turn on red signs, yield to pedestrians, etc)

– presence of kerb and/or sidewalk at waiting/landing areas

– median type (raised, painted, or none)

• delay – the researchers used equation 18-5 from the *Highway capacity manual* (TRB 2000) to calculate pedestrian delay at signalised intersections.

These variables were identified using the following processes:

• Identify which variables are relevant, using Pearson Correlations.

• Test for the best configuration of each variable that results in the best-fit regression model.

• Establish the coefficients for the variables that result in the best-fit regression model.

The researchers conducted step-wise regression analysis using over 500 real-time observations.

Consequently, the following model was developed:

Pedestrian LOS for Signalised Intersections = (RTOR+PermLefts) + (PerpTrafVol*PerpTrafSpeed) + (LanesCrossed0.514) + ln(PedDelay) + C (Equation 3.3)

where:

- RTOR+PermLefts = sum of the number of right-turn-on-red vehicles, and the number of motorists making a permitted left turn, in a 15-minute period

- PerpTrafVol*PerpTrafSpeed = product of the traffic in the outside through lane of the street being crossed, and the midblock 85th percentile speed of traffic on the street being crossed, in a 15-minute period

- LanesCrossed = number of lanes being crossed by the pedestrian

- PedDelay = average number of seconds the pedestrian is delayed before being able to cross the intersection

- C = constant.

The best model form and its terms' coefficients and T-statistics are presented in table 3.6. The model has a R^2 value of 0.77. This model has the same LOS grading system as the one shown earlier in table 3.2.

Table 3.6   Model coefficients and statistics

Model terms	Coefficients	T-statistics
SUMRTOR_PermLefts	5.689E-03	8.474
PRODPerpTrafVol_PerpTrafSpeed	1.274E-04	27.955
LanesCrossed$^{0.514}$	0.6810	17.579
Ln(PedDelay)	4.011E-02	7.527
Constant	0.5997	6.756
Model correlation (R^2)	0.77	

3.2.3 Pedestrian LOS prediction model for urban intersections

3.2.3.1 Muraleetharan et al – Method to determine pedestrian level-of-service for crosswalks at urban intersections (2005)

Muraleetharan et al selected 17 intersections in an urban area in Japan to develop a pedestrian LOS prediction model for urban intersections. The 17 intersections consisted of 12 signalised intersections and 5 unsignalised intersections. The researchers designed a questionnaire asking the selected participants to rate the LOS of the crossing, on a scale from 0 to 10, after they had crossed the road. A score of 10 meant 'very comfortable to cross' and a score of 0 meant 'extremely difficult to cross'. A total of 252 participants responded to the survey. Responses from people who were unfamiliar with the location and only used the intersection a few times per month or year were not taken into the analysis.

The researchers identified a list of factors that would affect the LOS of pedestrians at urban intersections by referring to research that they had undertaken in a previous project, *A study on evaluation of pedestrian level of service along sidewalks and at crosswalks using conjoint analysis* (Muraleetharan et al

2004). These factors included space at corners, crossing facilities, turning vehicles, delay at signals, and pedestrian–bicycle interactions – see figure 3.2.

Figure 3.2   Factors affecting pedestrian LOS at intersections (Muraleetharan et al 2004)
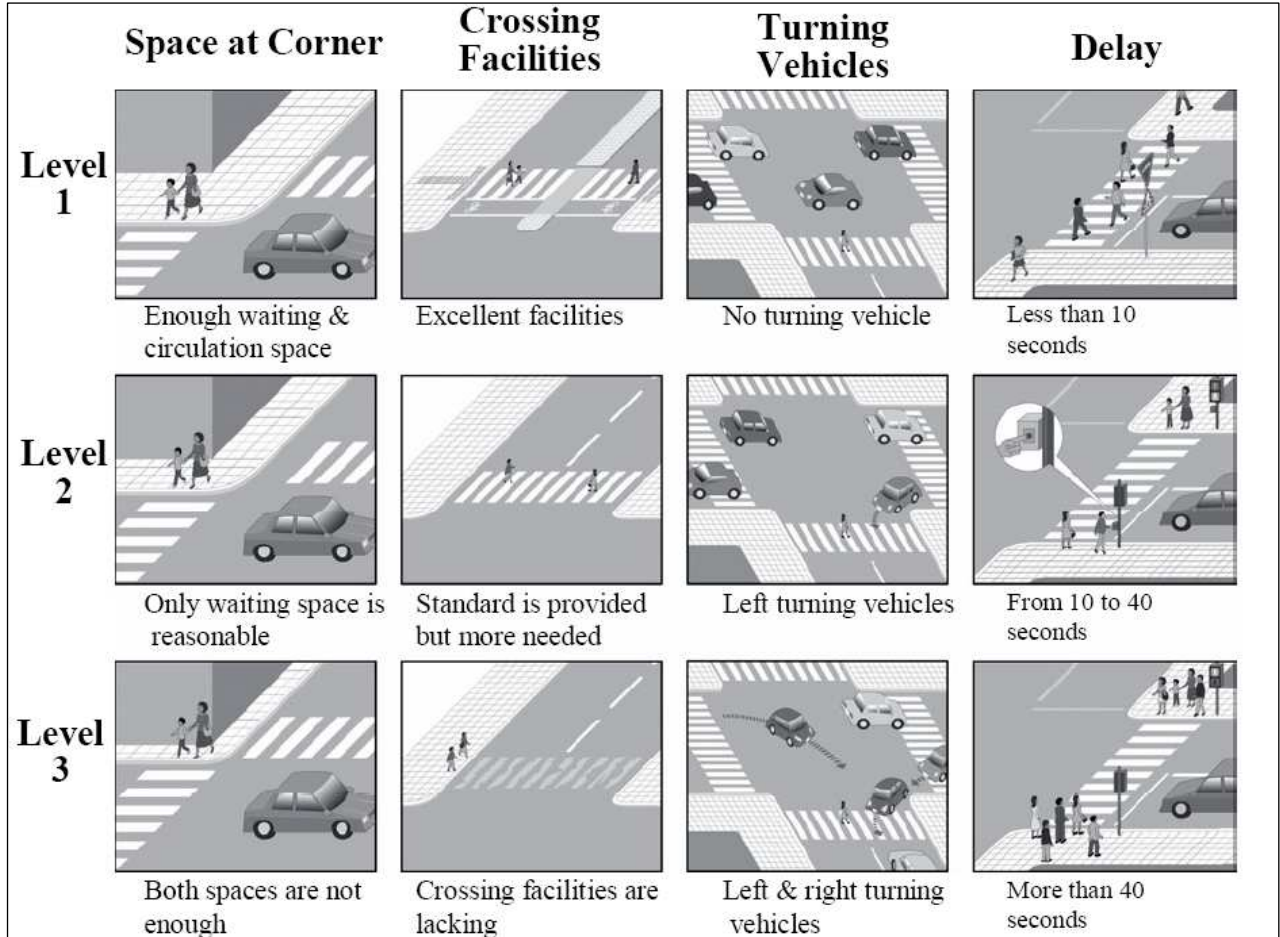
The factors identified in figure 3.2 were weighted by coefficients derived by step-wise regression modelling importance. Given that the factors shown in figure 3.2 are categorical variables, they were assigned a categorical score individually to be transformed into numerical variables.

A step-wise multivariable regression analysis was used to express the pedestrian LOS prediction model for intersections. Consequently, the following model was developed:

$$PedestrianLOS = 7.842 + \sum_{i=1}^{3} \sum_{j=1}^{3} D_{ij}\delta_{ij} - 0.037\,pd - 0.0031\,pb$$

(Equation 3.4)

where:

- D_{ij} = categorical score associated with j^{th} level of the ith attribute

- δ_{ij} = 1 if the jth level of the ith attribute is present

- pd = pedestrian delay in seconds

- pb = number of pedestrian–bicycle interactions.

3.2.4 Modelling the pedestrian LOS for urban arterials with footpaths

3.2.4.1 Petritsch et al – Pedestrian level of service model for urban arterial facilities with sidewalks (2006)

Petritsch et al developed a pedestrian LOS prediction model for urban arterials with footpaths, utilising the results from their pedestrian LOS perception survey that had collected more than 500 observations from approximately 50 participants walking on one route in Florida. The purpose of that survey had been to evaluate the pedestrian LOS of the urban arterial facility as a whole, not just the intersections or the roadway segments between intersections. It only addressed the through-movement of the pedestrians along the arterial route, not pedestrians crossing from one side of the arterial to the other.

The course was approximately 5km in length and included 11 urban arterial facility sections. The intersections had different crossing distances and traffic volumes. The entire route had urban arterial facility sections with varying traffic, roadside features and roadway conditions. All the arterial sections had footpaths provided.

Participants were asked to score the LOS of the individual intersections from A to F, where A was considered the most safe/comfortable (or least hazardous) and F the least safe/comfortable (or most hazardous). The participants were instructed to consider only the conditions within the intersections and their approach lanes, which were marked with 'Begin facility' and 'End facility' signs. Participants were also told not to consider any of the following:

- the conditions of the road section prior to the 'Begin facility' sign or 'End facility' sign

- the aesthetics, neighbourhood quality, or condition of adjacent properties.

The researchers used the participants' intersection scores to undertake testing of three hypotheses prior to the development of a pedestrian LOS model for signalised intersections. The results of the hypothesis testing are summarised in table 3.7.

Table 3.7   Hypotheses test results for urban arterials with footpaths

Hypothesis	Result
1 Participants would score the intersections differently according to their demographic characteristics.	Insignificant
2 The pedestrian LOS model for roadway segments does not adequately predict how well facilities serve pedestrians.	Significant
3 Paid participants would score intersections differently from volunteer participants.	Insignificant

The researchers identified the following list of variables that could affect the preliminary structure and testing of the pedestrian LOS model:

- proximity to the travel lanes

  – width of the outside travel lane

  – width of any additional cycle lane or paved shoulder

  – separation between the pavement and the footpath

  – width of the footpath

- perceived conflicts at intersections

    – motorists turning right from the street parallel to the crosswalk

    – motorists turning right from side streets, on a red light

    – through motorists on the street parallel to the crosswalk

    – motorists turning left from the street parallel to the crosswalk

- perceived exposure to threat when crossing roadways or driveways

    – crossing distance (across the street/driveway width plus a portion of the intersection radii)

    – presence of a crosswalk – possibly modified by various markings

    – other traffic-control devices (eg 'No right turn on red' signs, 'Yield to pedestrians' signs, etc

    – presence of kerb and/or sidewalk (at waiting/landing areas)

    – median type (raised, painted, or none)

- delay – the researchers used equation 18-5 from the *Highway capacity manual* (TRB 2000) to calculate pedestrian delays at signalised intersections.

The following processes were used to identify the above variables:

- Identify which variables are relevant, using Pearson Correlations.

- Test for the best configuration of each variable that results in the best-fit regression model.

- Establish the coefficients for the variables that result in the best-fit regression model.

The researchers conducted step-wise regression analysis using over 500 real-time observations. Consequently, the following model was developed:

$$\textit{Ped LOS for Arterials with Sidewalks} = a1(\textit{XingWidth/Mile}) + a2(\textit{Vol15}) + C \qquad \text{(Equation 3.5)}$$

where:

- XingWidth/Mile = total width of crossings at conflict locations (this term is the sum (per mile) of the crossing widths (in feet) of all driveways and intersections, signalised and unsignalised)

- Vol15 = average 15-minute volume on the adjacent roadway

- C = constant.

The best model form and its terms' coefficients and T-statistics are presented in table 3.8. The model has a R^2 value of 0.77. This model has the same LOS grading system as the one shown earlier in table 3.2.

Table 3.8   Model coefficients and statistics

Model terms	Coefficients	T-statistics
XingWidth/Mile	0.001 (a1)	2.314
Vol15	0.008 (a2)	2.923
Constant	1.43 (C)	3.373
Model correlation (R^2)	0.70	

3.3   Application of pedestrian LOS prediction models

Pedestrian LOS prediction models can evaluate walking routes according to the pedestrians' primary perception of safety or comfort.

In terms of a pedestrian LOS prediction model for the roadside environment between intersections, Landis et al (2001) stated that

> ... transportation practitioners can now establish a target pedestrian LOS and use the pedestrian LOS prediction model for roadside environment between intersections to test alternative roadway cross-section designs by iteratively changing the independent variables to find the best combination factors to achieve the desired LOS. The model thus provides roadway designers with solid guidance on how to better design pedestrian environments: how far footpaths should be placed from traffic; when, and what type of buffering or protective barriers are needed; how wide the footpath should be etc.

In terms of a pedestrian LOS prediction model for intersections, it is also possible to evaluate the level of accommodation that intersections provide to pedestrians. Intersections with a low pedestrian LOS can be improved by modifying the intersection design to reduce pedestrian delay and vehicle speed.

The pedestrian LOS model for arterials with footpaths can evaluate sections of arterial roads that include both intersections and road segments. Arterial roads with a low pedestrian LOS can be improved by reducing the vehicle traffic flow. The number of conflict points with pedestrians on the arterial roads can be controlled using access management techniques.

The Baltimore Metropolitan Council (BMC 2004) used Landis et al's 2001 pedestrian LOS prediction model to determine the pedestrian LOS of more than 1400 miles of roadside segments in the Baltimore Region and Baltimore City. Overall, it was found that the roadway network in the Baltimore region provided poor conditions for walking, with an average pedestrian LOS rating of D (model score = 3.79).

BMC also carried out a sensitivity analysis on how the variables within the model affected the model's predictability. Using the baseline averages of the model input variables, it was noted that the width of footpaths and traffic volumes influenced the pedestrian LOS values to the greatest degree, and the other variables were less of an influence.

BMC graded the LOS of the walking network in Baltimore City as shown in figure 3.3, which identifies the segments that required future improvements to increase the walkability of the whole of Baltimore City.

Figure 3.3   Pedestrian LOS grading of the walking network in Baltimore City (BMC 2004)
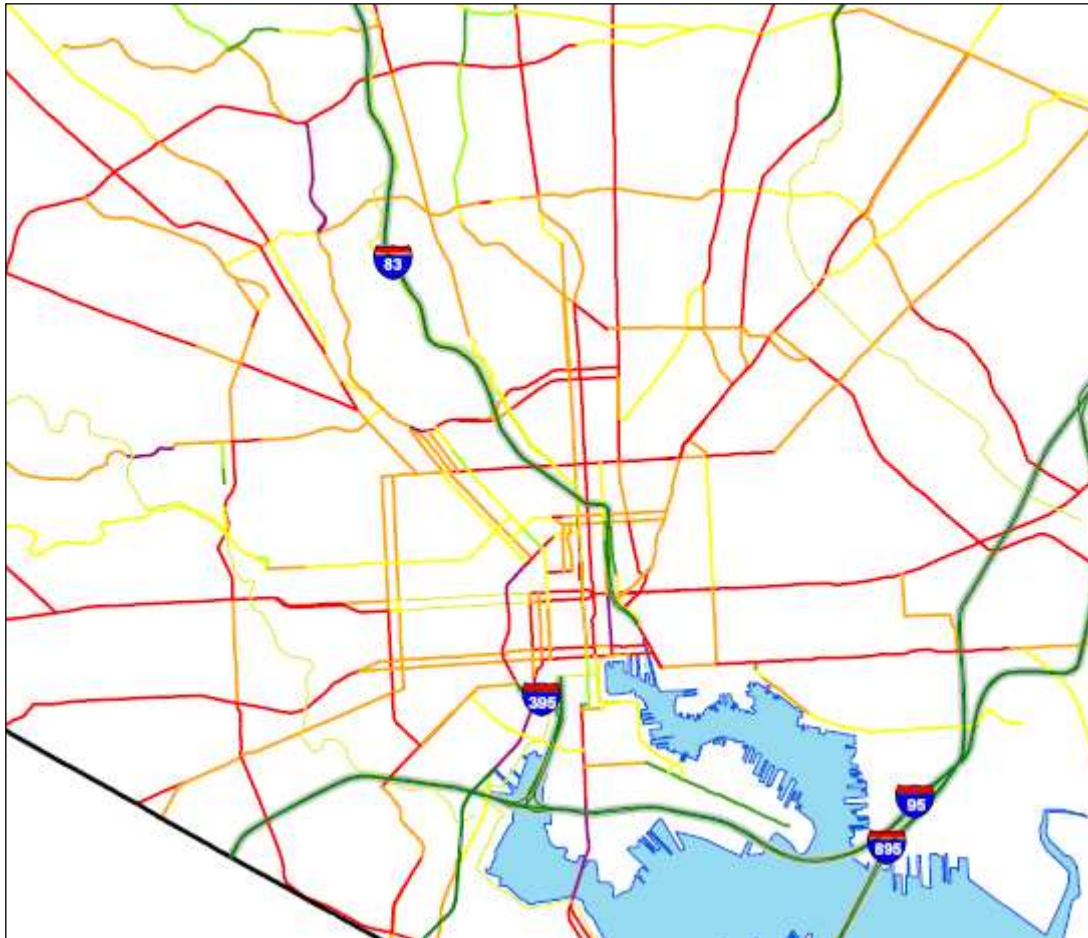
3.4   Summary

There are several overseas pedestrian LOS prediction models that can be used to assess the walking LOS within a city or region, to identify the roadway elements that require future improvement for pedestrians. The types of pedestrian LOS prediction models developed internationally, and the key variables identified for the individual models, are summarised in table 3.9.

Table 3.9   Pedestrian LOS prediction model types and key variables

Model type	Country	Key variables
Roadside segments between intersections	US	• lateral separation of pedestrians from motor vehicle traffic • presence of physical barriers and buffers • outside lane traffic volume • motor vehicle speed • vehicle mix
	Taiwan	• effective width of footpath • width of barriers • flow volume of pedestrians • vehicle flow volume in the peak hour

Model type	Country	Key variables
Urban signalised intersections	US	• turning vehicles • 85th percentile speed of traffic • number of lanes being crossed by pedestrians • pedestrian delay
Urban intersections	Japan	• space at intersection corner • intersection crossing facilities • intersection turning vehicles • pedestrian delay • number of pedestrian–bicycle interactions
Urban arterials with footpaths	US	• total width of crossings at conflict locations • average volume on the adjacent roadway

Consulting the international pedestrian LOS prediction modelling methodologies has ensured the New Zealand models that have been developed in this research are in line with those international methodologies, and extend the knowledge in this area.

4   Data collection methodology

4.1   Introduction

The survey methodology consisted of two data collection processes:

- the collection of physical and operational variables, using *Walkability tools – research variables collection methodology* (Abley 2006)

- the collection of perception survey data, using the CSR methodology (Abley 2010, NZTA 2010).

These methodology documents can be downloaded from www.levelofservice.com.

This data was collected between October 2009 and January 2010, and stored on a central database at www.levelofservice.com. The data was later extracted to develop the mathematical models.

Christchurch, Gisborne, Auckland and Wellington were selected as the locations for the four CSR surveys commissioned for this project. For each city, a group of at least 12 participants and a suitable survey route were selected – the processes for doing this are outlined in section 4.2. A number of control measures and variations to the general methodology were made and are summarised in section 4.3.

4.2   General methodology

4.2.1   Finding participants

A variety of methods can be used to find participants for a CSR. For this project, a minimum of 12 participants were considered necessary for each CSR. As the participants were required for a full day (8 hours), the CSR positions were paid, as an incentive to being involved. (However, Petritsch et al (2004) found that paid participants do not score sections differently from those who are volunteers, so this incentive could be revised for future projects.)

Local clubs and societies were a valuable source of survey participants, as these often have a members' email list that make it easy for them to distribute information. Student Job Search was also useful, but because most of the willing participants were from the same age group, not all of them were deemed suitable. The main source of participants for this project was the employment, career and recruitment website www.seek.co.nz. Because of this website's popularity with job seekers, there were more applicants for the CSR positions than were required.

Participants were selected to represent a cross-section of the population, using the 'participant criteria' outlined in the CSR methodology (NZTA 2010).

The job advertisement stipulated that applicants should:

- be able-bodied, with no physical and/or visual impairments

- provide details of their age and gender

- be available for the day immediately after the one scheduled for the CSR in case it had to be deferred because of issues such as inclement weather.

In order to select the most representative group of participants, a list of applicants' details was created in order to ensure a range of different ages and an equal gender spread. An extra three participants were selected, to ensure the CSRs would not be cancelled because of fewer than the minimum number of participants being available on the day. This brought the total number of participants to 15 for each trial – actual participant numbers for each survey can be found in section 4.4.

Once applicants had been selected, they were sent a set of instructions regarding their role and were required to confirm their availability for the survey via email or a telephone call to the CSR leader.

The time frame for finding enough suitable participants was proportional to the size of the city or town. In the large cities (ie Auckland, Wellington and Christchurch), approximately one week was sufficient; in Gisborne, approximately two weeks were required.

4.2.2 Route choice

It was important to choose the routes for the surveys carefully, to maximise the use of the participants' time as well as to incorporate a diverse range of sections in the route to enable the measurement of the influence of different variables.

In an attempt to increase the range of variables and LOS variability, a mix of routes, based on the area types shown in table 4.1, was chosen. However, it turned out that the majority of the links and crossings were of 'normal' quality.

Table 4.1   Area types chosen to increase the variability of key data variables surveyed

Area type	Characteristics
Older industrial area with some derelict areas	• poor footpath conditions • close to roadway (and truck traffic) • smell could be an issue • rubbish/litter and detritus • little greenery • including section(s) along multilane and noisy roads
Residential, in lower socio-economic area	• litter • vandalism and graffiti • limited greenery and open space • poor-quality footpaths • ideally including zebra crossings • including sections next to high-volume roads

Area type	Characteristics
High-quality central-city environment	- redevelopment with new paving and/or cobbles - high-activity area - high-quality comfort features - high pedestrian volumes and wider footpaths - traffic-signal crossings - verandas – partial and complete coverage - good-quality crossing aids - some multilane crossings - with and without kerbside parking
New suburb with plenty of park land	- plenty of parks and open spaces along route - footpaths with wider separation from traffic - high-quality crossing aids

Although the area types described in the above table were incorporated into the four survey locations (Auckland, Christchurch, Gisborne and Wellington), they were not all represented at each location. Focusing on one or two of the area types for each survey location allowed for a less restricted route choice.

Choosing the specific path lengths and suitable crossings was a difficult task, and it was best to consult with staff members of the local councils for their in-depth knowledge of the local streets and of which areas would be the most appropriate for the CSR surveys. Once the specific areas were chosen, they were linked together by a series of path lengths and road crossings to form a complete pedestrian route.

Photos from Google Street View were cross referenced in order to check the road and pedestrian environments. The final route choices were checked again with staff members of the local councils, in case the road layout or pedestrian environment had changed significantly in the interim – if this was the case, a more appropriate location was selected.

Once the route had been approved by all interested stakeholders, a final map of the CSR route was created (see appendix A). Each path length and road crossing was labelled with a unique ID and if appropriate, the path length or road crossing was colour coded to show if that part of the route would be surveyed in the morning or afternoon.

Although it would have been more efficient to have a route that started and ended in the same location, it was sometimes necessary to travel to another location for part of the route, in order to maintain levels of variability in the pedestrian environment. It was important that this travel time had to be considered during the planning of the route, in case some route sections might need to be removed either before the survey began, or during the survey day, if time ran short.

The Christchurch CSR map (shown in appendix A) shows approximately 40 sections distributed equally between the morning and afternoon of the survey day. This number of sections was calculated based on previous CSRs that found it took approximately 3 hours to survey 40 sections that were made up of road crossings and path lengths in approximately equal numbers. This was found to be the practicable maximum number of sections for a full day of surveying.

It is important to note that in the Gisborne and Auckland CSRs, some additional questions were included, thus increasing the time taken per section. These additional questions are described in section 4.3.3.

4.3   Survey specifics

4.3.1   Programme and timing

The dates of the CSR surveys, and the operational and physical variables that were collected, are shown in table 4.2. Because of the amount of measuring involved, the process of collecting physical variables required multiple days of surveying. Operational measurements were collected during the actual CSRs.

Table 4.2   Data collection dates

Location / Data type	Christchurch	Gisborne	Auckland	Wellington
CSR and collection of operational variables	3/11/2009	19/11/2009	1/12/2009	19/01/2010
Collection of physical variables	23/10/2009 2/11/2009 14/12/2009	18/11/2009 20/11/2009	30/11/2009 2/12/2009	18/01/2010 20/01/2010

The weather was carefully monitored throughout the duration of the surveys, in order to ensure consistent results. In the event of bad weather, the CSR was postponed because it was thought the weather could adversely affect the way participants scored different sections.

All the surveys were undertaken on a weekday (Monday–Friday). This ensured all the footpaths would be evaluated under their normal weekday conditions.

4.3.2   Control

It was considered that participants in different cities might score similar footpaths differently. To measure the extent of this, a control was applied in the form of a participant who scored all of the routes. This provided a 'normal' measure against which the other participants could be compared.

The control participants for Gisborne and Auckland filled out the CSR road-crossing and path-length forms concurrently, and in effect, became another participant in the survey, thus increasing the data to a minimum of 13 participant responses. The control participant also took part in the Wellington CSR.

It should be noted that the Christchurch control participant's responses were gathered after the CSR was completed. Therefore the experiences of the control participant in Christchurch were not consistent with the operational data collected.

4.3.3   Additional survey questions

Following the Christchurch CSR, four extra questions were added to the CSR path-length forms to elicit information about the physical elements that had contributed most significantly to the participants' overall perceived levels of path-length walkability.

The physical elements considered were:

- the actual footpath, including the density of its usage

- the road, including the level of traffic on the road

- the degree of separation between the footpath and the road

- the larger environment beyond the footpath and road – ie all aspects not already covered above that made the environment feel more or less comfortable to be in.

The extra questions are described in more detail in appendix B. Gisborne and Auckland participants answered these questions immediately after the usual CSR questions for each path length. During the participant briefing, extra time was taken to explain what each of the questions meant.

4.4   Summary

Surveying was undertaken in four locations in New Zealand – Auckland, Gisborne, Wellington and Christchurch. Individual perceptions of the walking environment were collected using the CSR methodology, and physical and operational variables were collected using the 'Walkability tools research variables collection' methodology (Abley 2006).

Overall, 52 people of various ages, with an approximately even split of males and females, reviewed 165 path lengths and 137 road crossings. Table 4.3 shows the mix between path lengths and road crossings, as well as a breakdown of the types of participants.

Table 4.3   Survey summary table

Location / Variable		Christchurch	Gisborne	Auckland	Wellington	*Total*
Total length (m)		5800	6100	7800	6900	*26,600*
Path lengths (number)		40	40	31	54	*165*
Road crossings (number)		41	39	34	23	*137*
Gender	Males	8	5	5	2	*20*
	Females	5	8	8	11	*32*
Age	18–29	7	5	3	7	*22*
	30–39	4	2	5	2	*13*
	>40	2	6	5	4	*17*

5 Model development methodology

5.1 Background

This section describes the modelling methodology that was adopted for the purpose of developing models for predicting the walkability of path-length and road-crossing sections, and identifies the preferred models for each section type and for different age groups. In addition, the results of an assessment of the variability of CSR walkability scores by participant gender and age are provided.

5.2 Selection of predictor variables

5.2.1 Introduction

The CSRs involved collecting data on a large number of variables for both path lengths and road crossings. For the purpose of developing a model for predicting walkability, it was not considered feasible for all variables to be included as predictor variables during the model development stage.

The full variables collection methodology report (Abley 2006) provides a description of each of the physical and operation variables that have been used in model development, and also includes the process for collecting the variables. The variables themselves are listed in appendix C along with the variable 'string name' – ie the shorthand name of the variable that was used in the statistical modelling software package. The modelling package that was used to undertake the analysis was Minitab version 16.

This section describes the detailed methodology adopted for narrowing down the number of variables that were eventually used for developing the walkability prediction model.

5.2.2 Grouped variable sets

The exhaustive set of physical and operational variables for which data was collected during the CSR surveys was assessed to identify the variables that were most likely to have a strong relationship with walkability. This was achieved by analysing the correlations between variables, and classifying them into several categories (or 'groups') based on the expected type of influence of the respective variables on walkability.

Correlations of all variables within each group (and between different groups) were analysed to exclude variables that were highly correlated, and to determine the initial set of variables for input into the models. The full correlation matrices for path-length and road-crossing variables are provided in appendix C.

The sets of grouped variables for path lengths were as follows:

- gradient
  - average longitudinal gradient (%)

- crossfall
  - average crossfall (%)

- separation from road
  - distance from moving vehicles (m)

- accessways
  - number of vehicle accessways
  - visibility to vehicle accessways
  - use of accessways

- footpath width
  - average effective footpath width
  - minimum effective width along path
  - maximum effective width along path

- hazards
  - surface type – concrete or asphalt
  - average stumbling hazards (mm)
  - average trip hazards
  - average obstacle effective width
  - deviation around obstacles
  - footpath condition

- urban design
  - how many utilities
  - quantity of greenery
  - land-use class
  - how many comfort features
  - average step height
  - design comfort

- traffic
  - number of adjacent vehicles (road width)
  - vehicle speed
  - number of heavy vehicles
  - noise in decibels

- pedestrian volume
  - people flow
  - people density

- environment and personal security
  - litter
  - detritus
  - vandalism
  - number of hiding places

- weather
  - survey weather
  - weather, rain
  - weather, cloudy
  - weather, windy
  - temperature

- parking
  - use of on-street parking

- presence of others
  - shared path.

The sets of grouped variables for crossings were as follows:

- entry from roadway and exit to roadway
  - kerb/kerb cutdown present
  - average trip hazard – average kerb gradient (both sides), average road gradient (both sides)

- crossing distance
  - crossing length, distance (m)
  - possible crossing width distance
  - median/refuge island present

- traffic
  - traffic volume at crossing
  - noise in decibels
  - time taken to cross
  - delay (calculated)

- pedestrian flow
  - people density
  - people flow

- speed
  - vehicle speed
  - posted speed limit

- road pavement condition
  - road condition
  - average trip hazards
  - average stumbling hazards (mm)

- central island
  - presence of a central island
  - average island effective width

- footpath condition

- presence of cycle lanes
  - number of cycle lanes to cross

- crossing type
  - type of crossing – zebra/signalised/uncontrolled

- urban design
  - how many comfort features

- visibility to traffic

- weather
  - survey weather
  - weather, rain
  - weather, cloudy
  - weather, windy

- tactiles
  - presence of tactile aids

- deviation from desire lines

- personal security
  - litter
  - detritus
  - vandalism.

These variables represent the initial set of variables that formed the sample set for model development. However, all other physical and operational variables that were excluded at this stage were later tested during the model development process, to identify any other important variables that may have been overlooked.

5.2.3   Continuous and discrete variables

Variables for which data was collected in the CSR surveys can be broadly classified into two categories – continuous variables and discrete variables.

5.2.3.1   Continuous variables

These are variables that can assume any value within the limits of the variable range. For example, road width is classified as a continuous variable.

5.2.3.2   Discrete variables

Discrete variables are those that can only take on values that have been predefined as part of the variable's definition. For example, the walkability of a site, as collected during the CSR surveys, is a discrete variable, since this can only assume integer values between 1 and 7 (inclusive). Similarly, 'Weather, windy' is classified as a discrete variable since it can only assume two values, ie either 'Yes' or 'No'.

Discrete variables can be further subdivided into:

- ordinal variables, which include those variables that have been rated on a predefined scale (eg the walkability rating and 'yes/no' variables)

- categorical variables, which have two or more categories without any ranking between categories (eg land use).

Many of the variables for which data was collected during the CSR surveys were in the category of 'discrete variables'.

5.2.4 Short-listed variables

This section lists the variables within each of the variable groups in section 5.2.2. These variables were selected for further analysis and formed the sample set used for modelling.

5.2.4.1 Path-length variables

Table 5.1 lists the variables that were included in the sample set for path lengths, along with the variable type – ie whether continuous or discrete.

Table 5.1 **Path-length variables selected for modelling**

Category	Variable name	S. no.	Variable description	Type
Gradient	Avg longgrad	1	Average longitudinal gradient (%)	Continuous
Crossfall	Avg cfall	2	Average crossfall (%)	Continuous
Separation from road	Disveh	3	Distance from moving vehicles (m)	Continuous
Accessways	Vaways	4	Number of vehicle accessways	Discrete
	Visacc	5	Visibility to vehicle accessways	Discrete
	Useacc	6	Use of accessways	Discrete
Footpath width	Avg ewidth	7	Average effective width of the path	Continuous
	Min ewidth	8	Minimum effective width of the path	Continuous
	Max ewidth	9	Maximum effective width of the path	Continuous
Hazards	Surface	8	Surface (concrete, asphalt or other)	Discrete
	Avg stum	9	Average stumbling hazards (mm)	Continuous
	Avg trip	10	Average trip hazards	Continuous
	Avg obs ewidth	11	Average effective width of path at the location of an obstacle	Continuous
	Devi	12	Deviation around obstacles	Discrete
	Footcon	13	Footpath condition	Discrete
Urban design	Manyutil	14	How many utilities	Discrete
	Green	15	Quantity of greenery	Discrete
	Manycom	16	How many comfort features	Discrete
	Avg stepav	17	Height of steps along route	Continuous
	Luclass	18	Land-use class	Discrete
Traffic	Numveh	19	Number of adjacent vehicles (per hour)	Continuous

Category	Variable name	S. no.	Variable description	Type
Traffic	Roadwid	20	Road width (m)	Continuous
	Vspeed	21	Vehicle speed	Continuous
	Numhveh	22	Number of heavy vehicles (per hour)	Continuous
	Dbnoise	23	Noise in decibels	Continuous
Ped. volume	Peoplenum	24	People flow (per hour)	Continuous
	Density	25	People density	Continuous
Environment and personal security	Litter	26	Litter	Discrete
	Deti	27	Detritus	Discrete
	Vanda	28	Vandalism	Discrete
	Numhide	29	Number of hiding places	Discrete
Weather	Weather	30	Survey weather	Discrete
	Rain	31	Weather, rain	Discrete
	Cloud	32	Weather, cloudy	Discrete
	Wind	33	Weather, windy	Discrete
	Temp.	34	Temperature	Continuous
Parking	Useosp	35	Use of on-street parking	Discrete
Shared path	Shared	36	Shared path	Discrete

5.2.4.2   Correlations between path-length variables

Table 5.2 lists some of the significant correlations between the selected path-length predictor variables and all variables for which data was collected during the CSR surveys.

Table 5.2   Path-length variable correlations

Variable 1	Variable 2	Correlation
Survey weather	Weather, windy	0.784
Average effective width of path	Average effective width of permanent non-regular obstacles	0.765
How many utilities	How many comfort features	0.722
Average effective width of path	Average effective width (m) of regular obstacles	0.667
People flow per hour	People density	0.645
Average effective width of path	Average obstacle effective width	0.577
Average obstacle effective width	Average effective width (m) of regular obstacles	0.573
How many utilities	Street activity	0.567
How many utilities	People flow per hour	0.556
People flow per hour	Street activity	0.536
Average obstacle effective width	Average effective width of permanent non-regular obstacles	0.522
Weather, cloudy	Humidity	0.521
How many comfort features	Design effort	0.519
Temperature	Humidity	-0.501
How many utilities	Average number of regular obstacles	0.475

Variable 1	Variable 2	Correlation
Average effective width of path	How many utilities	0.470
Average effective width of path	Street activity	0.468
Average obstacle effective width	Average number of regular obstacles	0.466
Average obstacle effective width	Building veranda	0.463
Number of adjacent vehicles per hour	Road width (m)	0.447
How many comfort features	People flow per hour	0.447
Average obstacle effective width	How many utilities	0.447
Average stumbling hazards (mm)	Average trip hazards	0.447
How many utilities	Design effort	0.443
How many utilities	Building veranda	0.437
Average obstacle effective width	Cane-detectable regular obstacles	0.435
Vandalism	Average number of steps	0.432
Average effective width of path	Road width (m)	0.429
Average effective width of path	Building veranda	0.419
Average obstacle effective width	People flow per hour	0.416
Distance from moving vehicles (m)	Road width (m)	0.415
Use of on-street parking	Weather, cloudy	0.413
Average effective width of path	Design effort	0.412
Quantity of greenery	Building veranda	-0.401
Survey weather	Number of adjacent vehicles per hour	0.394
Litter	Detritus	0.389
Average effective width of path	Average number of regular obstacles	0.389
Survey weather	Temperature	-0.385
Average effective width of path	How many comfort features	0.372
Temperature	Number of adjacent vehicles per hour	-0.362
Vandalism	Litter	0.361
Number of adjacent vehicles per hour	Noise in decibels	0.344
Average trip hazards	Number of vehicle accessways	0.339
Vehicle speed	Street activity	-0.331
Distance from moving vehicles (m)	On-street parking available	0.329
Shared path	Quantity of greenery	0.318
Number of adjacent vehicles per hour	Number of heavy vehicles per hour	0.309

The following are some of the key observations from table 5.2:

- The high correlation coefficient (0.722) between the number of utilities and comfort features suggests that paths that have more utilities such as bus stops, ATM machines and telephone booths are also better provided with comfort features such as seating and drinking fountains.

- Paths with more utilities and comfort features are associated with higher pedestrian usage.

- The presence of utilities and comfort features contributes towards increasing the number of obstacles on a path.

- The effective width of permanent regular and non-regular obstacles is found to be highly correlated with the effective width of the path (0.765 and 0.667 for non-regular and regular obstacles respectively). This suggests that paths that have a larger number of regular or non-regular obstacles are usually wider than those that have fewer obstacles.

- Roads with a high traffic volume are seen to be wider than those with a low traffic flow.

- The correlation between effective path width and road width (0.429) suggests that paths adjacent to major roads are usually wider than those adjacent to narrower roads.

- A moderate correlation (0.415) is seen between distance from moving vehicles and road width. This, along with the correlation between road width and traffic volume, indicates that paths adjacent to busy roads are usually further away from the road than those adjacent to roads with lower traffic volumes.

- The number of stumbling hazards and trip hazards are correlated (0.447).

- Paths next to roads with high traffic volumes usually had a higher amount of noise (coefficient of correlation of 0.34).

5.2.4.3   Variables for road crossings

Variables included in the modelling for road crossings are provided in table 5.3:

Table 5.3   Road-crossing variables selected for modelling

Category	Variable name	S. no.	Variable description	Value type
Entry and exit to road	Ekerbd, exitd	1	Entry or exit kerb dropped	Discrete
	Ekerbf, ekerbr	2	Entry kerb: footpath and road gradient	Continuous
	Exitf, exitr	3	Exit kerb: footpath and road gradient	Continuous
	Avgf	4	Average footpath gradient (entry and exit kerb)	Continuous
	Avgr	5	Average road gradient (entry and exit kerb)	Continuous
Crossing distance	Crosdi	6	Crossing-length distance (m)	Continuous
	Rist	7	Refuge island	Discrete
Traffic	Dbnoise	8	Noise in decibels	Continuous
	Traffic volume	9	Volume of traffic at crossing	Continuous
	Timetak	10	Time taken to cross	Continuous
Pedestrian volume	Peoplenum	11	People flow	Continuous
	Density	12	People density	Continuous
Speed of traffic	Vspeed	13	Vehicle speed	Continuous
	Pospeed	14	Posted speed limit	Continuous
Road pavement condition	Rdcon	15	Road condition	Discrete
	Avg stum	16	Average stumbling hazards (mm)	Continuous
	Avg trip	17	Average trip hazards	Continuous
Central island	Iswid	18	Island start: effective width	Continuous
	Imwid	19	Island middle: effective width	Continuous

Category	Variable name	S. no.	Variable description	Value type
Central island	Ifwid	20	Island finish: effective width	Continuous
	Avgiwid	21	Average island effective width	Continuous
Footpath	Footcon	22	Footpath condition	Discrete
Cycle lanes	Croscyc	23	Number of cycle lanes to cross	Discrete
Urban design	Manucom	25	How many comfort features	Discrete
Visibility	Vistra	26	Visibility to traffic	Discrete
Weather	Weather	27	Survey weather	Discrete
	Rain	28	Weather, rain	Discrete
	Cloud	29	Weather, cloudy	Discrete
	Wind	30	Weather, windy	Discrete
Tactile aids	Tpva	31	Tactile paving or visual aids	Discrete
Deviation from desire line	Ddl	32	Deviation from desire line	Continuous
Environment and personal security	Litter	33	Litter	Discrete
	Deti	34	Detritus	Discrete
	Vanda	35	Vandalism	Discrete
Delay	Delay	36	Crossing delay[a]	Continuous

a) Delay was calculated from the time taken to cross (timetak) by using the crossing distance and assuming an average walking speed of 1.5m/s.

5.2.4.4 Correlations between road-crossing variables

Table 5.4 lists the significant correlations between road-crossing predictor variables and all variables for which data was collected.

Table 5.4 Road-crossing variable correlations

Variable 1	Variable 2	Correlation
People flow (during crossing time)	People density	0.790
Survey weather	Weather, windy	0.785
Crossing control type	Number of traffic lanes to cross	-0.701
Weather, cloudy	Humidity	0.505
People density	Design effort	0.439
Volume of traffic (per hour)	Comfort features	0.435
Entry kerb: footpath gradient	Exit kerb: footpath gradient	0.424
People flow (during crossing time)	Kerb: effective width	0.418
Noise in decibels	Volume of traffic	0.402
Crossing-length distance (m)	Number of traffic lanes to cross	0.338
Crossing-length distance (m)	Number of cycle lanes to cross	0.328
Noise in decibels	Crossing control type	-0.315
Tactile paving or visual aids	Protection from permanent hazards	0.307
Road condition	Footpath condition	0.306
Deviation from desire line	Refuge island	0.301

The key observations from table 5.4 are as follows:

- The large negative correlation (-0.701) between crossing type and number of traffic lanes shows that the number of traffic lanes to be crossed by pedestrians decreases from signalised crossings to uncontrolled crossings.

- The correlation of 0.435 between hourly traffic volume and comfort features suggests that more comfort features are provided on road crossings with a higher volume of traffic.

- As in the case of path lengths, volume of traffic is found to be correlated (0.402) to the level of noise at a road crossing. The correlation between noise and crossing type also leads to the expected conclusion that signalised crossings are noisier than zebra and uncontrolled crossings because of higher traffic volumes.

- Footpath gradients on entry and exit kerbs are also found to be correlated (0.424).

5.3   Data manipulation

5.3.1   Introduction

This section describes data-adjustment and manipulation procedures that were required to convert the raw CSR data into a form suitable for use during the model development process.

5.3.2   Adjustment of raw walkability ratings

Because of human and behavioural differences, it was expected that there would be an inherent variability in the raw walkability scores among various participants surveying the same section or site. An initial analysis was conducted to assess the magnitude of this variation by comparing the raw walkability ratings for each participant on a given site. Figure 5.1 illustrates the results of this analysis for Site 16 (Park Tce/Rolleston Ave/Salisbury St), located in Christchurch.

Figure 5.1   Variability in raw walkability rating (Site 16, Christchurch)
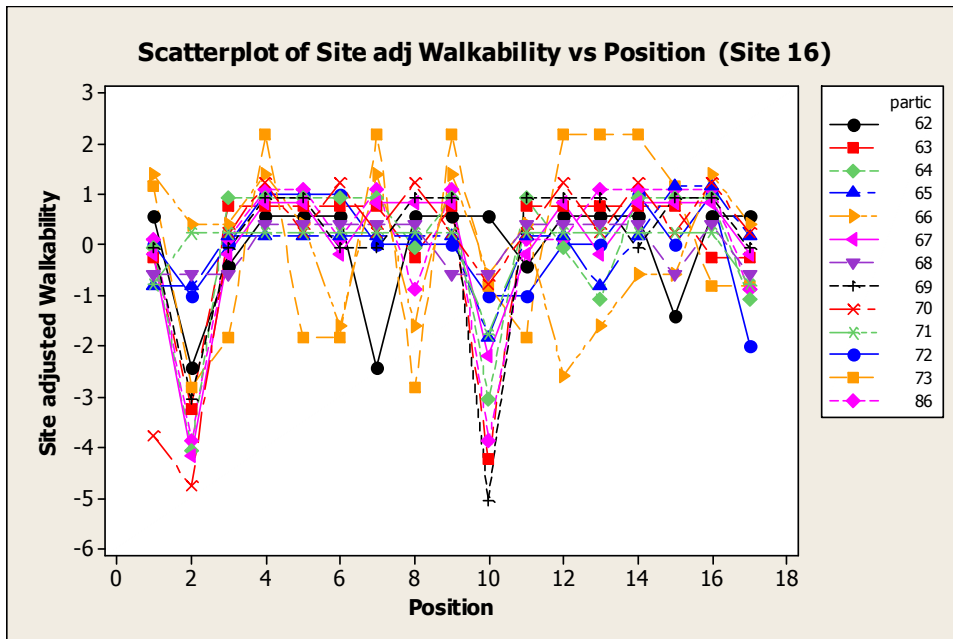
Figure 5.1 shows a large variation in the walkability rating from different participants for the same section (path length/road crossing). Similar plots were generated for sites within each city, and similar levels of variation were observed in those examples as well. This variation highlighted the need for adjustment of the raw walkability ratings, to minimise the amount of variation and provide a suitable response variable for use in the model development stage.

This was achieved by using the walkability scores from the common participant across all the surveyed sites. As a result of the need for this adjustment, 14 path-length and 10 road-crossing sites that had not been surveyed by the common participant were excluded from the sample set used for the model development.

The following two-step process was adopted for adjusting the raw walkability scores from each participant:

- **Step 1 - Adjustment of participant mean ratings:** Participants' walkability ratings for each site were adjusted so that each participant at that site had the same mean rating. This was done so that deviations of a participant from their own mean of zero could be recorded. This would enable more agreement in the absolute scores from one participant to another, but no change to the order of scoring. Figure 5.2 illustrates the change in participant walkability ratings for Site 16 as a result of this step of the adjustment.

Figure 5.2   Walkability adjustment step 1: mean participant rating of zero (Site 16, Christchurch)

Scatterplot of Site adj Walkability vs Position (Site 16)
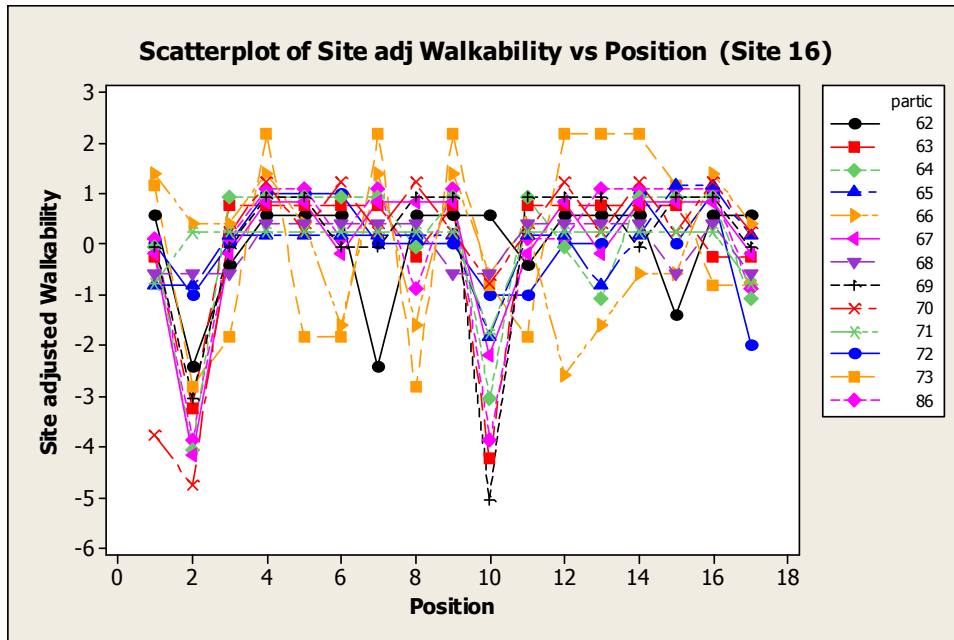
- **Step 2 - Addition of mean common participant rating:** The scores for each participant within each site were then adjusted by the mean rating of the common participant. This was done by calculating the average walkability score of the common participant for the given site, and adding the average walkability score of the common participant to the values obtained from Step 1. This resulted in the following adjusted walkability rating plot for Site 16.

Figure 5.3   Walkability adjustment step 2: adding mean rating for common participant (Site 16, Christchurch)

Scatterplot of P86 adjusted Walkability vs Position (Site 16)
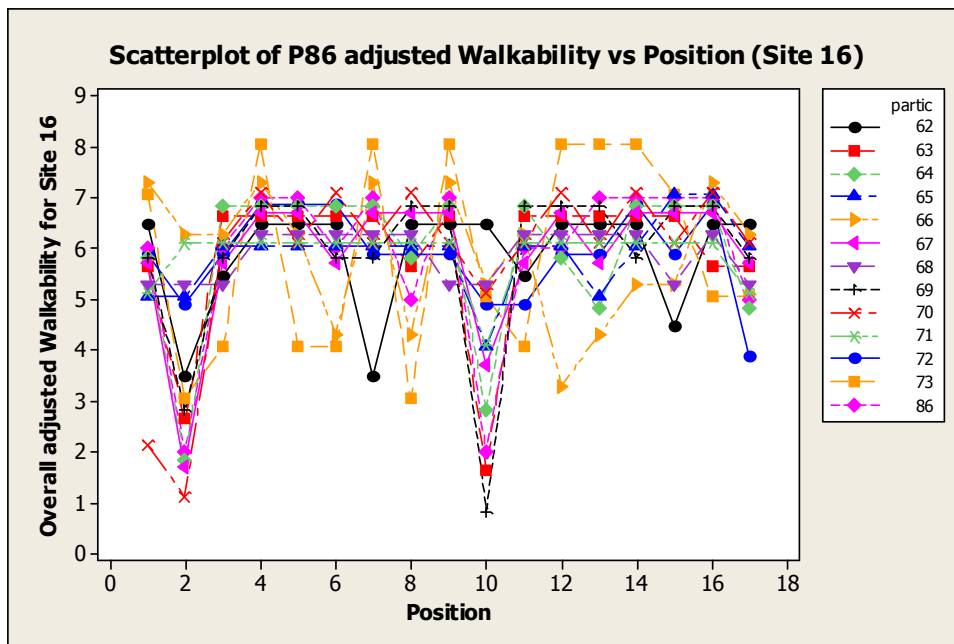
Walkability ratings from participants at all other sites were adjusted in a similar manner. The adjusted walkability rating was calculated using the following formula:

Adjusted walkability = (Raw walkability) – (Average walkability for a given participant for a given site) + (Average walkability of the common participant for that site)   (Equation 5.1)

The Minitab macro that was used for adjusting the walkability ratings is provided in appendix E.

Tables 5.5 and 5.6 illustrate the effect of this adjustment across the path lengths and road crossings respectively for sites that were surveyed by the common participant. Tables 5.7 and 5.8 show the respective mean percentage differences between the adjusted and raw walkability ratings in each of the cities, and for all sites collectively.

Table 5.5   Adjusted walkability vs raw walkability: path lengths

| Site	Site name	City	All participants excl. common participant: Avg walkability rating (1)	All participants excl. common participant: Avg adjusted walkability rating (2)	Common participant walkability rating (3)	Trend (1 - 2 - 3)	Walkability rating for common participant vs. all other participants at site
29	Karangahape Road/Mayoral Drive/Vincent Street	Auckland	5.010	5.875	5.875		17%
30	Park Road/Carlton Gore Road/Davis Crescent	Auckland	5.107	5.429	5.429		6%
31	Tamaki Drive/Khyber Pass Road	Auckland	5.656	6.000	6.000		6%
32	Long Drive/Tarawera Terrace/Tamaki Drive	Auckland	6.083	6.625	6.625		9%
16	Park Terrace/Rolleston Ave/Salisbury Street	Christchurch	6.417	6.714	6.714		5%
18	Worcester Street/Armagh Street/Oxford terace	Christchurch	5.685	6.111	6.111		7%
19	Victoria Street/Salisbury Street/Durham Street North	Christchurch	5.548	5.429	5.429		-2%
21	Manchester Street/Gloucester Street/	Christchurch	5.281	4.375	4.375		-17%
22	Kilmore Street/Barbadoes Street/Durham Street North	Christchurch	5.224	4.388	4.333		-17%
23	Gladstone Road/Peel Street/Fitzherbert Street	Gisborne	5.771	6.250	6.250		8%
24	Carnarvon Street/Gladstone Road/Kahutia Street	Gisborne	5.021	5.500	5.500		10%
25	Kahutia Street/Customhouse Street/Ormond Road	Gisborne	4.806	4.000	4.000		-17%
26	Wainui Road/Hirini Street/Rutene Road	Gisborne	5.362	5.778	5.778		8%
28	Rutene Road/De Lautour Road/Craig Road	Gisborne	5.486	5.833	5.833		6%
34	Glenmore Street (Lower)	Wellington	6.385	6.250	6.250		-2%
35	Glenmore Street (Centre)	Wellington	5.917	6.000	6.000		1%
38	Governor Road	Wellington	4.750	5.000	5.000		5%
39	Northland Road	Wellington	5.967	5.592	5.400		-9%
41	Upland Road (Upper)	Wellington	6.167	6.000	6.000		-3%
45	Upland Road (Centre)	Wellington	6.167	5.052	5.048		-18%
47	Seaview Terrace	Wellington	4.708	5.833	5.833		24%
48	Upland Road (Lower)	Wellington	6.208	6.000	6.000		-3%
49	Salamanca Road (Southern)/Oriely Avenue	Wellington	5.667	5.800	5.800		2%
50	Salamanca Road (Northern)	Wellington	5.306	6.083	6.083		15%

The comparison of the walkability rating from the common participant and from all other participants, shown in the next table (5.6), leads to some interesting observations. Overall, the common participant rated sections in Auckland slightly higher than the rest of participants there, whereas it was the opposite case in Christchurch. The figures in other cities were mixed, with the walkability rating from the common participant being both higher and lower than the average of the other participants, depending on the individual site.

Table 5.6   Percentage difference (adjusted walkability vs raw walkability): path lengths

City	% difference (adjusted walkability vs raw walkability)
Auckland	10%
Christchurch	-5%
Gisborne	3%
Wellington	2%
All sites	**2%**

A similar trend as that observed for path lengths is also observed in the case of road crossings, as shown in table 5.7. Table 5.8 shows that the common participant rated slightly higher in Auckland and slightly lower in Christchurch, when compared with all other participants.

Table 5.7   Adjusted walkability vs raw walkability: road crossings

Site	Site name	City	All participants excl. common participant: Avg walkability rating (1)	All participants excl. common participant: Avg adjusted walkability rating (2)	Common participant walkability rating (3)	Trend (1 - 2 - 3)	Walkability rating for common participant vs. all other participants at site
29	Karangahape Road/Mayoral Drive/Vincent Street	Auckland	4.861	6.444	6.444		33%
30	Park Road/Carlton Gore Road/Davis Crescent	Auckland	4.635	5.250	5.250		13%
31	Tamaki Drive/Khyber Pass Road	Auckland	5.102	5.778	5.778		13%
32	Long Drive/Tarawera Terrace/Tamaki Drive	Auckland	5.281	4.625	4.625		-12%
16	Park Terrace/Rolleston Ave/Salisbury Street	Christchurch	5.608	5.300	5.300		-5%
18	Worcester Street/Armagh Street/Oxford terace	Christchurch	5.677	6.625	6.625		17%
19	Victoria Street/Salisbury Street/Durham Street North	Christchurch	5.767	5.700	5.700		-1%
21	Manchester Street/Gloucester Street/	Christchurch	5.131	4.143	4.143		-19%
22	Kilmore Street/Barbadoes Street/Durham Street North	Christchurch	5.833	6.167	6.167		6%
23	Gladstone Road/Peel Street/Fitzherbert Street	Gisborne	5.287	5.889	5.889		11%
24	Carnarvon Street/Gladstone Road/Kahutia Street	Gisborne	4.593	3.889	3.889		-15%
25	Kahutia Street/Customhouse Street/Ormond Road	Gisborne	5.115	4.125	4.125		-19%
26	Wainui Road/Hirini Street/Rutene Road	Gisborne	5.250	5.143	5.143		-2%
28	Rutene Road/De Lautour Road/Craig Road	Gisborne	4.819	5.000	5.000		4%
34	Glenmore Street (Lower)	Wellington	6.000	6.000	6.000		0%
38	Governor Road	Wellington	5.083	5.667	5.667		11%
39	Northland Road	Wellington	5.083	6.167	6.000		18%
41	Upland Road (Upper)	Wellington	4.750	4.000	4.000		-16%
47	Seaview Terrace	Wellington	4.500	4.000	4.000		-11%
48	Upland Road (Lower)	Wellington	5.417	5.500	5.500		2%
49	Salamanca Road (Southern)/Oriely Avenue	Wellington	5.833	6.600	6.600		13%
50	Salamanca Road (Northern)	Wellington	4.383	5.200	5.200		19%

Table 5.8   Percentage difference (adjusted walkability vs raw walkability): road crossings

City	% difference (adjusted walkability vs raw walkability)
Auckland	12%
Christchurch	-1%
Gisborne	-4%
Wellington	5%
All sites	**3%**

The adjusted walkability ratings for both path lengths and road crossings formed the basis of the walkability measures used during the development of the prediction models.

5.3.3   Manipulation of variables

Discrete variables (ie variables that can only take fixed pre-defined values) constitute a significant proportion of the variables for which data was collected during the CSR surveys. The range of values of these variables was manipulated to make the data suitable for modelling. This manipulation was carried out in two stages.

- **Stage 1:** In the case of 'Yes/No' variables, 'Yes' was given a value of 1 while 'No' was given a value of 0.

- **Stage 2:** Certain discrete variables (eg quantity of greenery, litter, vandalism, etc) were rated on a scale of 1–5, with 1 being the lowest and 5 being the highest. Some of these variables also had a 0 rating representing N/A – eg a 0 rating was given to 'visibility of vehicle accessways' in cases where no vehicle accessways were present. These were modified as shown in table 5.9.

Table 5.9   Manipulation of discrete variables

Original value	Manipulated value
0	(Replaced with a blank value)
1	-1
2	-1
3	0
4	+1
5	+1

The overall rating was thus changed from a scale of 1–5 to a scale of -1 to +1.

5.3.4   Additional data manipulation and exclusions

- 'Weather, rain' was removed from the sample set of both path lengths and road crossings, since its value was found to be equal to 'No' in all cases.

- The posted speed limit of almost all sites and sections in the sample set was 50kph. 'Posted speed limit' was thus excluded from the list of variables to be analysed because of the lack of variation afforded in the data for this variable.

- Values of certain variables were recorded multiple times. For example, in the case of path lengths, 'effective footpath width' was measured at multiple locations along a path. In such cases, a gross average of all available measurements was taken as the final value.

- Data on land use collected during the CSR surveys was used to set up three separate land-use category variables, each of which assume 'Yes/No' (+1/0) values as described earlier. These were:

  - parkland/residential (pa+res)

  - suburban shopping/commercial retail (ss+cr)

  - commercial industrial/industrial (ci+i).

- Certain other variables, such as crossing type and vehicle speed, were manipulated to enable them to assume numerical values.

Table 5.10   Manipulation of land-use and crossing-type variables

Variable	Values
Crossing control type	Traffic light = 1 Zebra crossing = 2 Uncontrolled = 3
Vehicle speed	Below speed limit = -1 At speed limit = 0 Above speed limit = +1

Further details on data collection procedures for each of the variables can be found in the *Variables collection methodology* report (Abley 2006).

5.4   Analysis of predictor variables

5.4.1   Sample size

As mentioned earlier, only those path-length and road-crossing sections that had been surveyed by the common participant during the CSR surveys were selected for use in the final sample set for modelling.

Table 5.11 provides the number of sections (path lengths and road crossings) that were included in the sample set, by city.

Table 5.11   Sample size for path lengths and road crossings

City	Number of sections	
	Path lengths	Road crossings
Auckland	31	34
Christchurch	40	41
Gisborne	40	39
Wellington	52	23
Total	**163**	**137**

5.4.2   Path-length variables

5.4.2.1   Introduction

Figures 5.4–5.8 show scatter plots of the various path-length predictor variables against the average adjusted walkability rating from all participants on a path-length section. Table 5.1 provides descriptions of the variable names used in the figures.

5.4.2.2   Gradient, crossfall, separation from road

Figure 5.4 shows plots of average longitudinal gradient and crossfall along the path, and separation from the road.

Figure 5.4   Gradient, crossfall, separation from road vs adjusted walkability
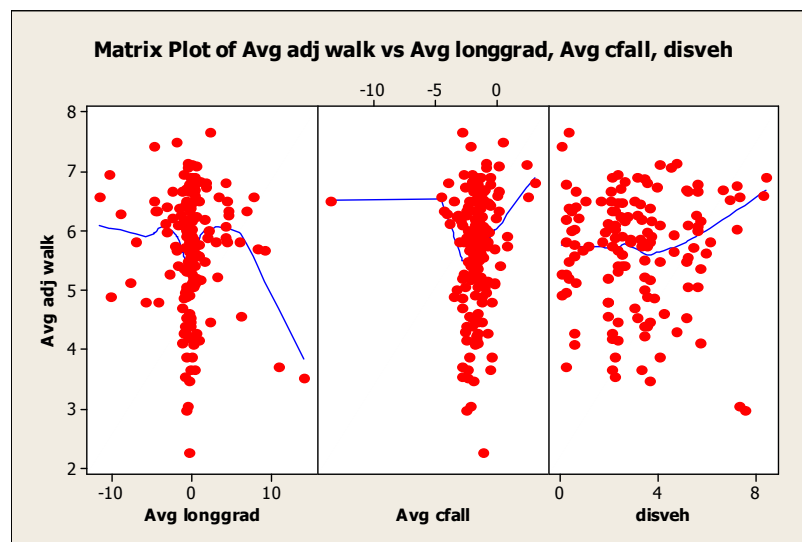
Although the plot for crossfall does not show a clear relationship with walkability, the plot for separation from the road (disveh) indicates that a greater separation between road and footpath had a positive effect on walkability. The range of distances of separation of paths included in the sample set for this study was 0–8.4m.

The plot for gradient shows that downhill paths, which have a negative gradient, (not unsurprisingly) were considered to be more walkable than those that go uphill.

5.4.2.3   Vehicle accesses

Figure 5.5 suggests that increased visibility of vehicles from accessways (visacc) had a positive effect on walkability, while higher use of vehicle accesses (useacc) tended to result in a drop in overall walkability.

Figure 5.5   Number, visibility and use of vehicle accessways vs adjusted walkability
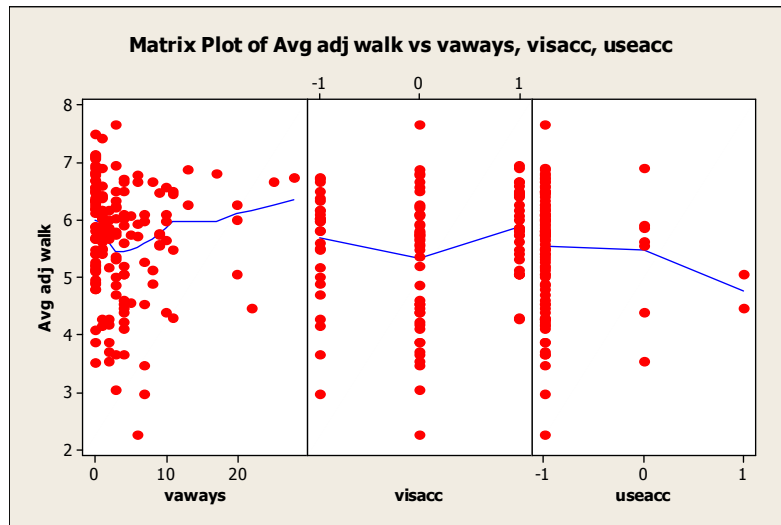
5.4.2.4   Footpath width

Figure 5.6 shows a plot of average, minimum and maximum effective footpath widths against adjusted walkability. Excluding the outlier observed to the right of each plot, the trend lines show that paths that provided more walking space were favoured by pedestrians.

Figure 5.6   Effective footpath width vs adjusted walkability
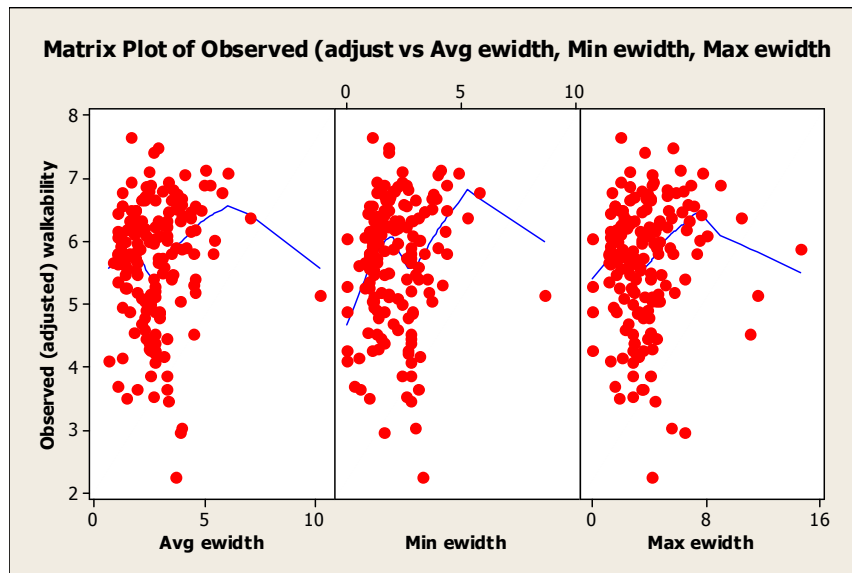
5.4.2.5   Surface, hazards and footpath condition

The scatter plots in figure 5.7 suggest that a better footpath (footcon) had a significant effect on the overall walkability of a path. The plots for stumbling (avg stum) and tripping (avg trip) hazards also indicate that paths with few or no hazards were more walkable.

Figure 5.7   Surface, hazards and footpath condition vs adjusted walkability
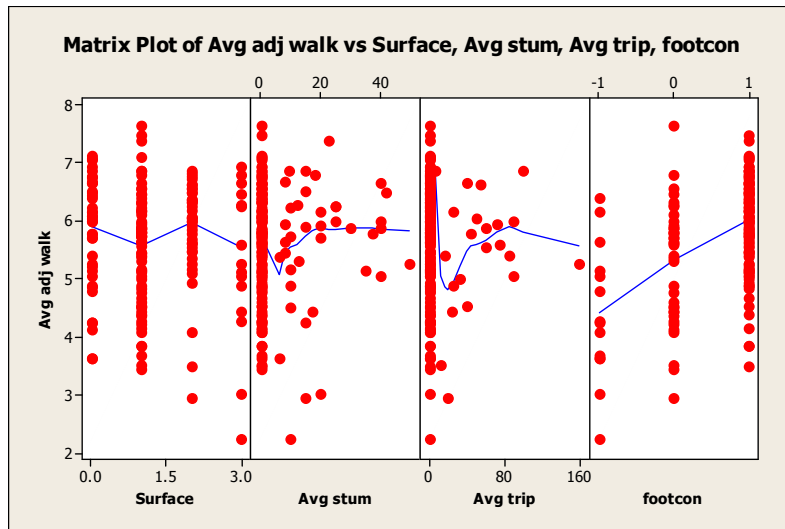
5.4.2.6   Urban design and land use

The number of utilities (manyutil), comfort features (manycom) and the quantity of greenery (green) all had positive effects on walkability. Path lengths located in parkland and residential land-use zones had higher walkability ratings, while those in suburban shopping, commercial and industrial-type land zones had lower ratings.

Figure 5.8   Number of utilities, number of comfort features, greenery and land-use types vs adjusted walkability
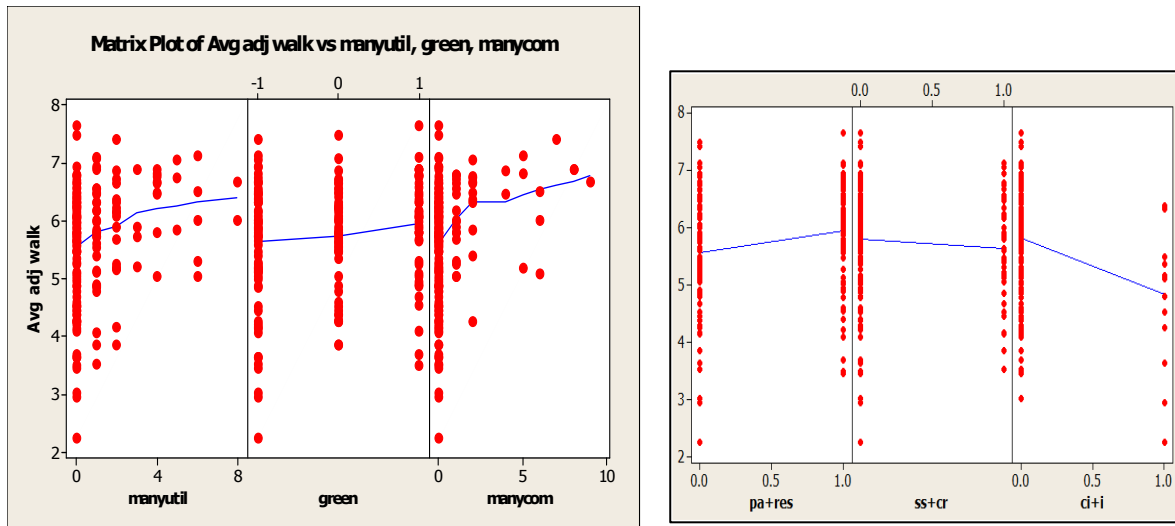
5.4.2.7   Traffic

Figure 5.9 does not indicate a clear trend between road width (roadwid) and walkability. However, the plot shows that a few paths that had a very wide road adjacent to them were associated with lower-than-average walkability (adjusted) ratings.

Path lengths where adjacent traffic was travelling below the speed limit of the area had higher walkability ratings. Note that only path lengths where vehicles were travelling at or below the speed limit of the area were surveyed. Also, all surveyed path lengths were located in 50kph speed limit zones.

Noise (dbnoise) had a significant effect on walkability, with noisier sites having lower walkability (adjusted) ratings.

Figure 5.9   Number of vehicles, road width, vehicle speed, number of heavy vehicles and noise vs adjusted walkability
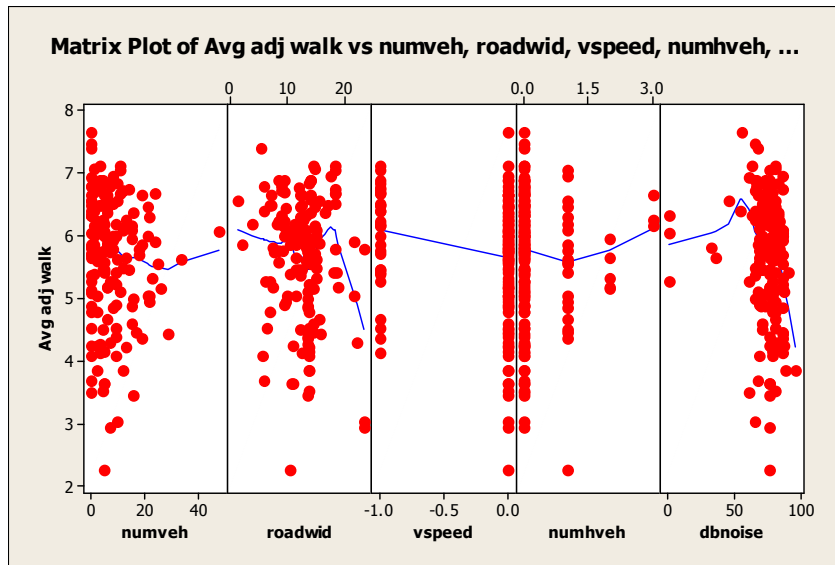
5.4.2.8   Pedestrian volume

Figure 5.10 shows that higher pedestrian numbers (peoplenum) and density resulted in slight increases to overall walkability, and there may have been an optimum pedestrian density where walkability was maximised.

Figure 5.10   Number of people and people density vs adjusted walkability
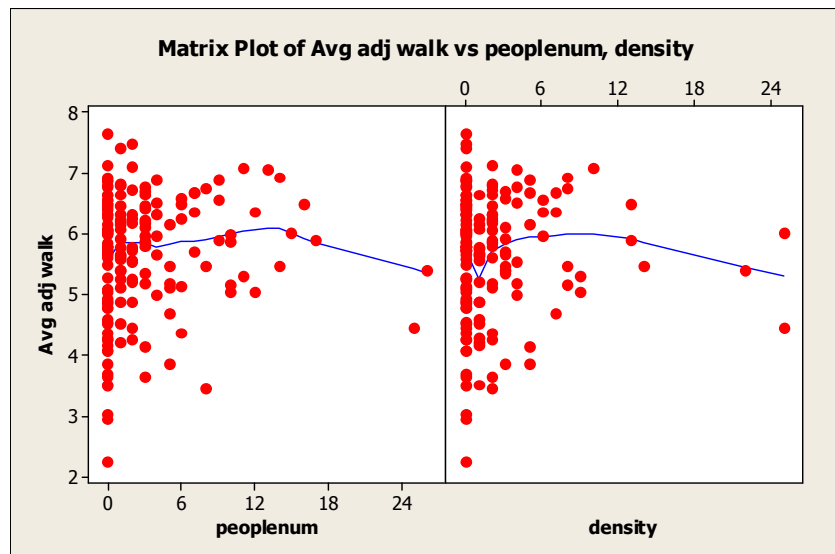
5.4.2.9 Environment and personal security

Sites with larger quantities of litter, detritus (deti) and vandalism (vanda) were found to be less walkable than sites where these factors were not present.

Figure 5.11   Litter, detritus and vandalism vs adjusted walkability
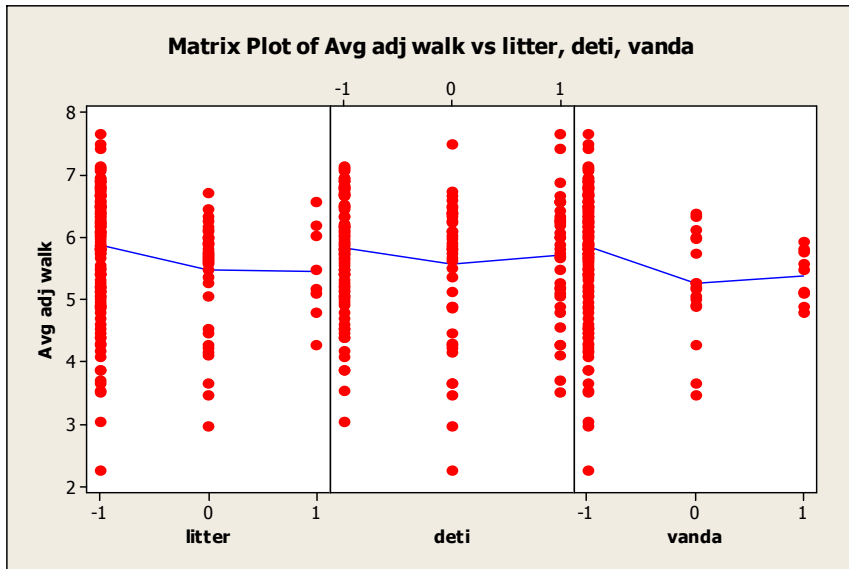
5.4.2.10 Weather

The effect of most weather variables, except wind, is not clearly understandable, as shown in figure 5.12. Windy conditions resulted in a lowering of the walkability (adjusted) rating. No data was available on rain.

Figure 5.12   Weather vs adjusted walkability
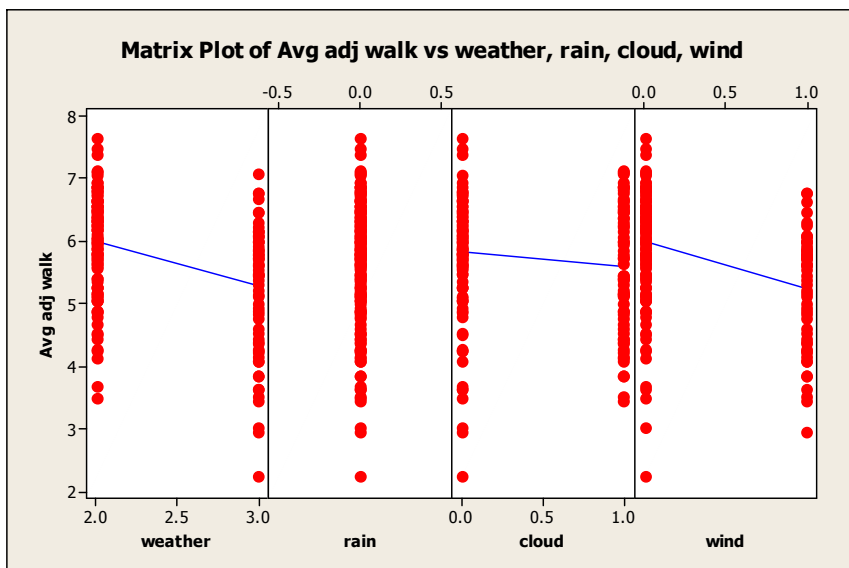
5.4.2.11 On-street parking and shared paths

Figure 5.13 suggests that paths that were shared between multiple user types (eg cyclists and pedestrians) were favourable for walking when conflicts with cyclist are low. The graph for use of on-street parking (useosp) indicates a slight decrease in walkability at higher levels of parking.

Figure 5.13   On-street parking and shared path vs adjusted walkability
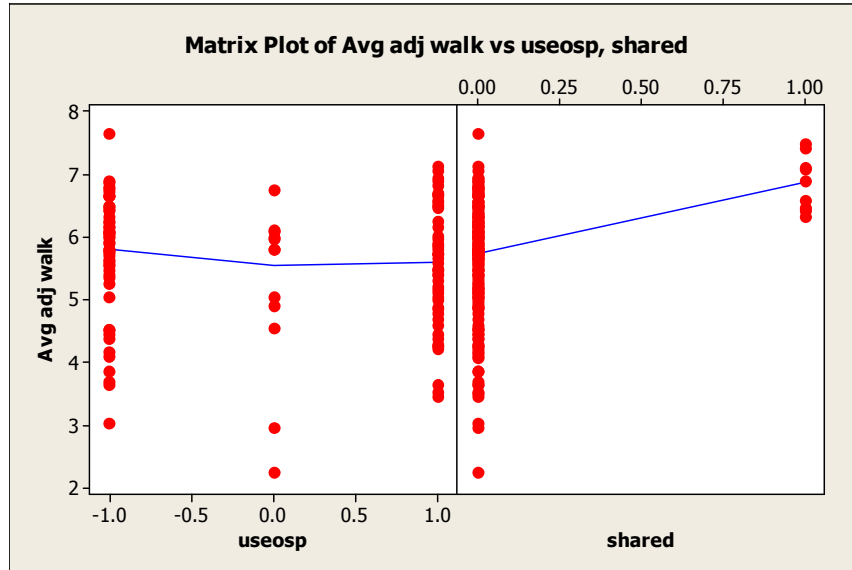
5.4.3   Road-crossing variables

This section provides a breakdown of crossings, by type, in the sample set, along with scatter plots of the road-crossing predictor variables against the average adjusted walkability rating for all participants on a road-crossing section. Descriptions of variables used in the figures were provided earlier in table 5.3.

5.4.3.1   Crossing types

Out of the 137 road crossings that were included in the sample set, 86 were uncontrolled and 38 were signalised. Only 13 of the 137 crossings were zebra crossings (see figure 5.14).

Figure 5.14   Number of crossings, by type
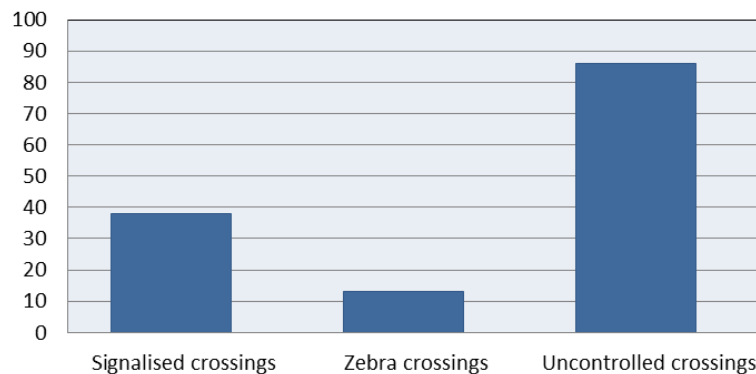
5.4.3.2   Entry and exit kerb, footpath and road gradient

Figure 5.15 shows that the presence of kerb cutdowns on entry and exit kerbs of a crossing (kerb cutdown) resulted in making the crossing more walkable for pedestrians. The plots for average entry and exit road (avgr) and footpath gradients (avgf) show a large degree of scatter, although steep road gradients generally appear to be unfavourable.

Figure 5.15 –Entry and exit kerb, footpath and road gradient vs adjusted walkability
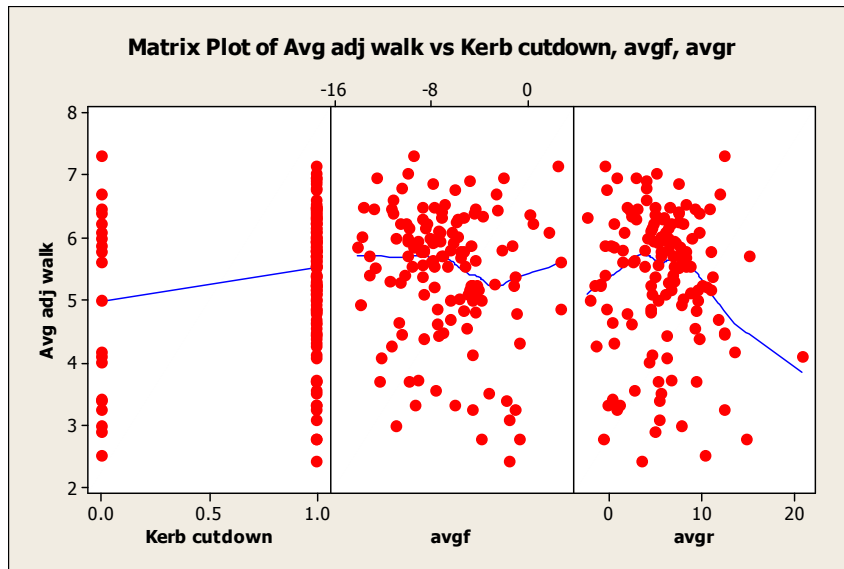
5.4.3.3   Crossing distance and central islands

No clear conclusions can be drawn from the plots of crossing distance (crosdi) and presence of central island (rist), as shown in figure 5.16. The plot for crossing distance shows a high degree of scatter and indicates a general positive relationship between walkability and crossing distance. Wider central islands (avgiwid) were found to be more walkable.

Figure 5.16   Crossing distance and presence of central islands vs adjusted walkability
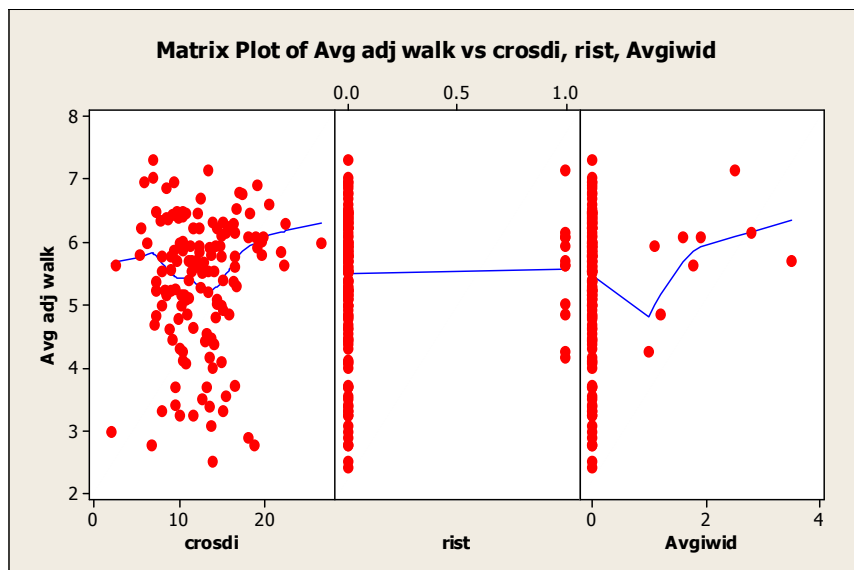
5.4.3.4   Traffic

Limited traffic-volume data (traffic) was available for the road crossings in the sample set. Figure 5.17 indicates that noisy crossings with higher traffic volumes were, in general, less walkable. The walkability of a crossing increased in environments where vehicle speeds were low. High visibility to oncoming traffic (vis tra) also resulted in making the crossing safer, thus increasing walkability. The graphs for time taken to cross, and delay, show mixed trends, with walkability initially decreasing with an increase in crossing time, and showing little variation at intersections with higher crossing times.

Figure 5.17   Traffic volume, noise, vehicle speed, visibility to traffic, time taken to cross and delay vs adjusted walkability
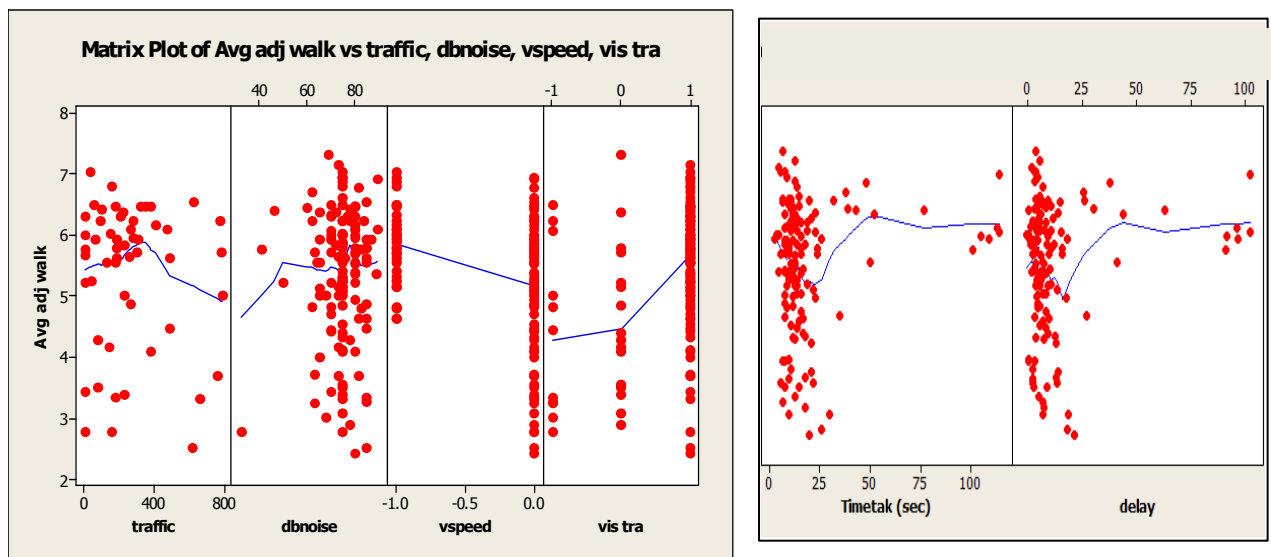
5.4.3.5   Pedestrian volume

Figure 5.18 indicates that walkability generally increased as the number of crossing pedestrians (peoplenum) increased.

Figure 5.18   Pedestrian volume and people density vs adjusted walkability
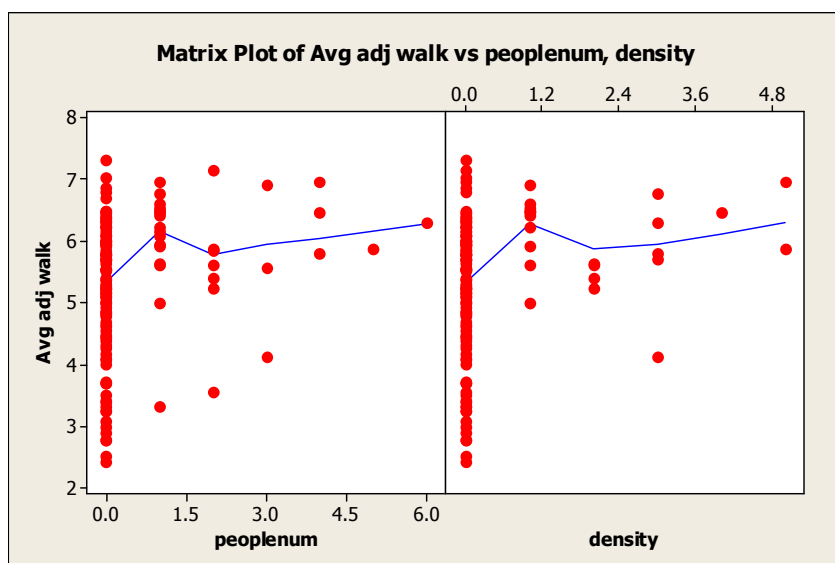
5.4.3.6   Crossing type

Figure 5.19 shows that uncontrolled crossings were generally rated to be less walkable than zebra crossings and signalised crossings.

Figure 5.19 – Crossing type vs adjusted walkability
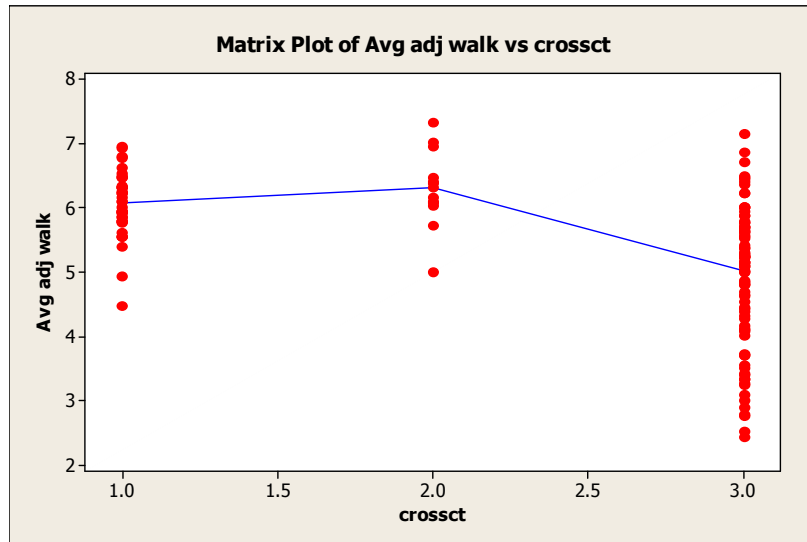
5.4.3.7   Road condition, hazards and footpath condition

Figure 5.20 shows that improvements in road condition (rdcon) and footpath condition (footcon) led to marked increases in walkability. Higher numbers of stumbling and tripping hazards were, in general, seen to reduce the quality of the road crossing.

Figure 5.20   Road condition, stumbling hazards, tripping hazards and footpath condition vs adjusted walkability
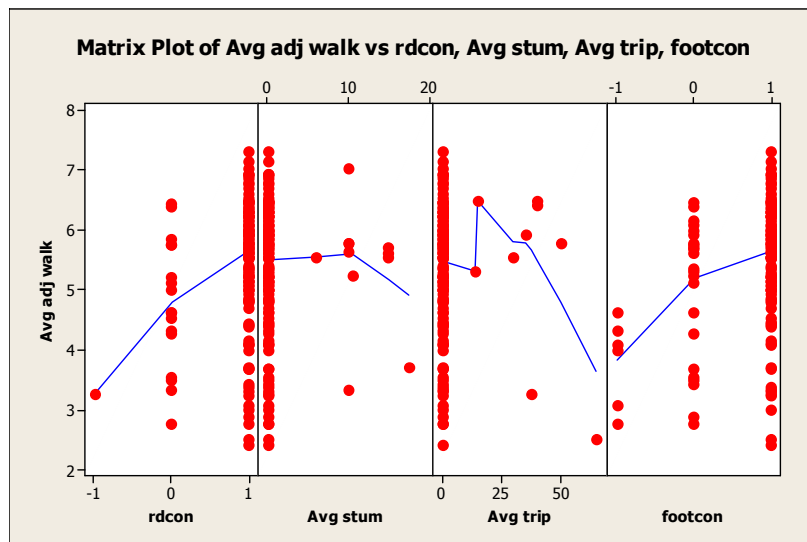
5.4.3.8   Number of cycle lanes to cross

No clear conclusion can be drawn from figure 5.21. Crossings where pedestrians were required to cross one or more cycle lanes appeared to have similar walkability (adjusted) ratings.

Figure 5.21   Number of cycle lanes to cross vs adjusted walkability
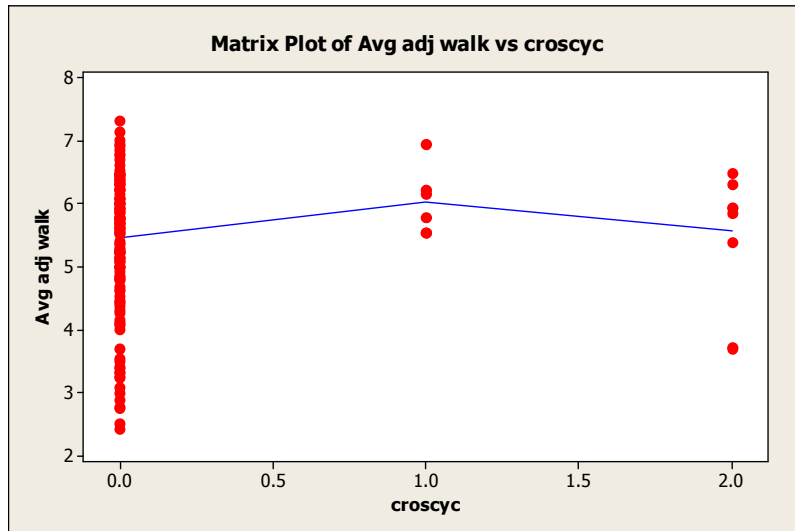
5.4.3.9   Comfort features, tactile aids and deviation

Most crossings had neither comfort features (manucom) installed nor required any deviation (ddl) from the direct crossing paths of pedestrians. Tactile aids (tpva), when present, were generally found to result in a higher walkability score.

Figure 5.22   Comfort features, tactile aids and deviation vs adjusted walkability
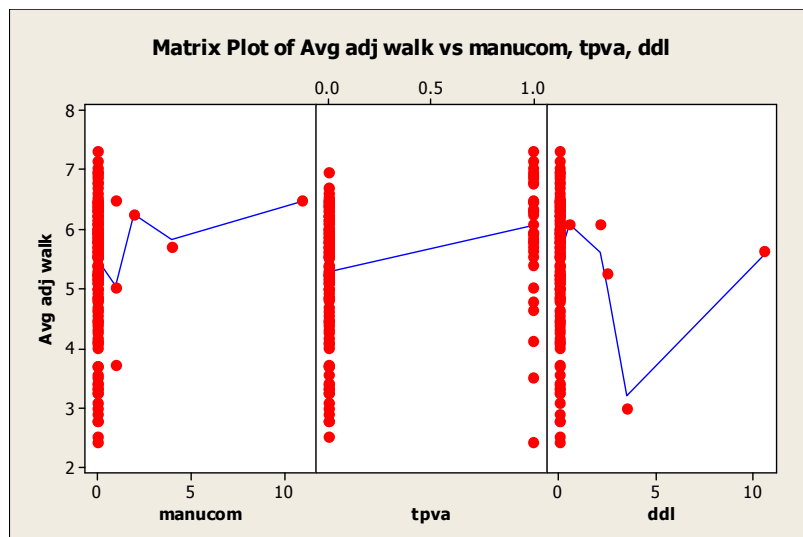
5.4.3.10 Weather

Figure 5.23 shows that weather did not have a significant effect on the level of walkability of road crossings.

Figure 5.23   Weather vs adjusted walkability
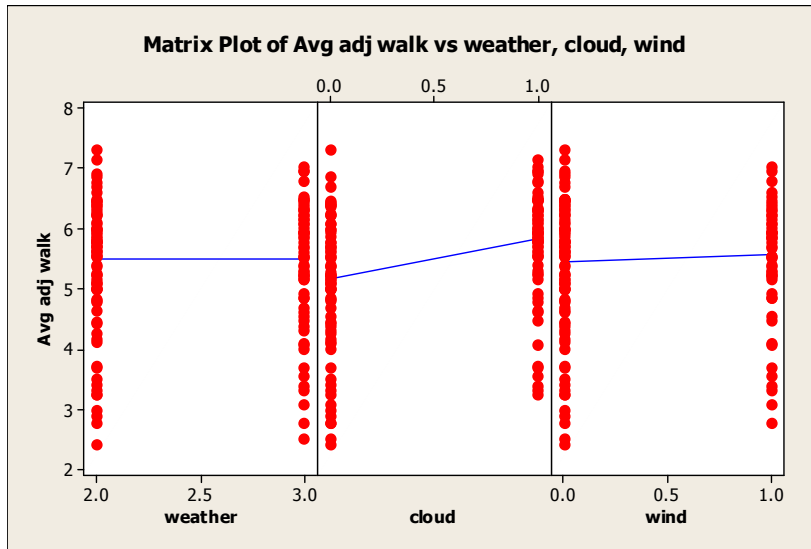
5.4.3.11 Environment and personal security

Figure 5.24 indicates that higher quantities of litter had a detrimental effect on the walkability of road crossings. Detritus (deti) and vandalism (vanda) do not appear to have had a significant effect on the walkability (adjusted) values.

Figure 5.24   Litter, detritus and vandalism vs adjusted walkability
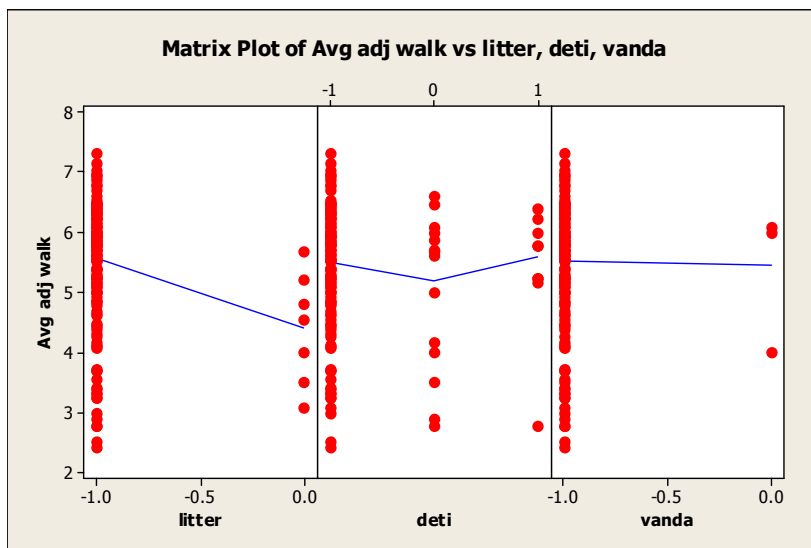
5.5   Analysis of walkability, by gender and age

The CSR participants who rated the walkability of path lengths and road crossings were of both genders and a variety of ages. This section examines the influence of gender and age on the raw walkability scores (unadjusted) for path lengths and road crossings.

For this analysis, the participants were divided into two gender groups (male and female) and two age groups (18–59, and 60 or older). It should be noted that the sample set for the different age and gender groups analysed within each city may not be representative of the whole city.

5.5.1   Walkability of path lengths, by gender

Table 5.12 shows the average raw walkability rating from male and female CSR participants for path-length sections in each site, along with the percentage difference between the male and female walkability ratings. For reference, the average raw path-length walkability rating for all participants at a particular site is also shown.

Table 5.12   Average male and female raw walkability ratings

Site	Site name	City	Average walkablity: All participants	Walkability: Males	Walkability: Females	% Difference Females vs. Males
29	Karangahape Road/Mayoral Drive/Vincent Street	Auckland	5.077	5.150	5.031	-2%
30	Park Road/Carlton Gore Road/Davis Crescent	Auckland	5.132	5.257	5.054	-4%
31	Tamaki Drive/Khyber Pass Road	Auckland	5.683	5.875	5.563	-5%
32	Long Drive/Tarawera Terrace/Tamaki Drive	Auckland	6.125	6.400	5.953	-7%
16	Park Terrace/Rolleston Ave/Salisbury Street	Christchurch	6.440	6.571	6.229	-5%
18	Worcester Street/Armagh Street/Oxford terace	Christchurch	5.718	5.639	5.844	4%
19	Victoria Street/Salisbury Street/Durham Street North	Christchurch	5.538	5.393	5.771	7%
21	Manchester Street/Gloucester Street/	Christchurch	5.212	5.172	5.275	2%
22	Kilmore Street/Barbadoes Street/Durham Street North	Christchurch	5.155	5.042	5.344	6%
23	Gladstone Road/Peel Street/Fitzherbert Street	Gisborne	5.808	5.896	5.732	-3%
24	Carnarvon Street/Gladstone Road/Kahutia Street	Gisborne	5.058	5.292	4.857	-8%
25	Kahutia Street/Customhouse Street/Ormond Road	Gisborne	4.744	4.907	4.603	-6%
26	Wainui Road/Hirini Street/Rutene Road	Gisborne	5.376	5.611	5.175	-8%
28	Rutene Road/De Lautour Road/Craig Road	Gisborne	5.513	5.611	5.429	-3%
34	Glenmore Street (Lower)	Wellington	6.375	6.375	6.375	0%
35	Glenmore Street (Centre)	Wellington	5.923	5.000	6.091	22%
38	Governor Road	Wellington	4.769	4.875	4.750	-3%
39	Northland Road	Wellington	5.923	5.300	6.036	14%
41	Upland Road (Upper)	Wellington	6.154	5.833	6.212	6%
45	Upland Road (Centre)	Wellington	6.077	5.500	6.182	12%
47	Seaview Terrace	Wellington	4.795	4.917	4.773	-3%
48	Upland Road (Lower)	Wellington	6.192	6.750	6.091	-10%
49	Salamanca Road (Southern)/Oriely Avenue	Wellington	5.677	4.700	5.855	25%
50	Salamanca Road (Northern)	Wellington	5.365	4.792	5.470	14%

Although the difference between the average male and female ratings for the Auckland, Gisborne and Christchurch sites is less than 10%, a large proportion of the Wellington sites display a considerable difference between the male and female ratings, with female CSR participants generally perceiving the paths to be more walkable than their male counterparts.

Figure 5.25 shows the average male and female raw walkability ratings for path lengths, by city, and compares them with the mean walkability of path lengths in that city.

Figure 5.25   Mean raw walkability of path lengths, by gender, for each city

	Auckland	Christchurch	Gisborne	Wellington
■ Average walkablity: All participants	5.504	5.613	5.300	5.725
■ Walkability: Males	5.671	5.563	5.463	5.404
⊔ Walkability: Females	5.400	5.693	5.159	5.783
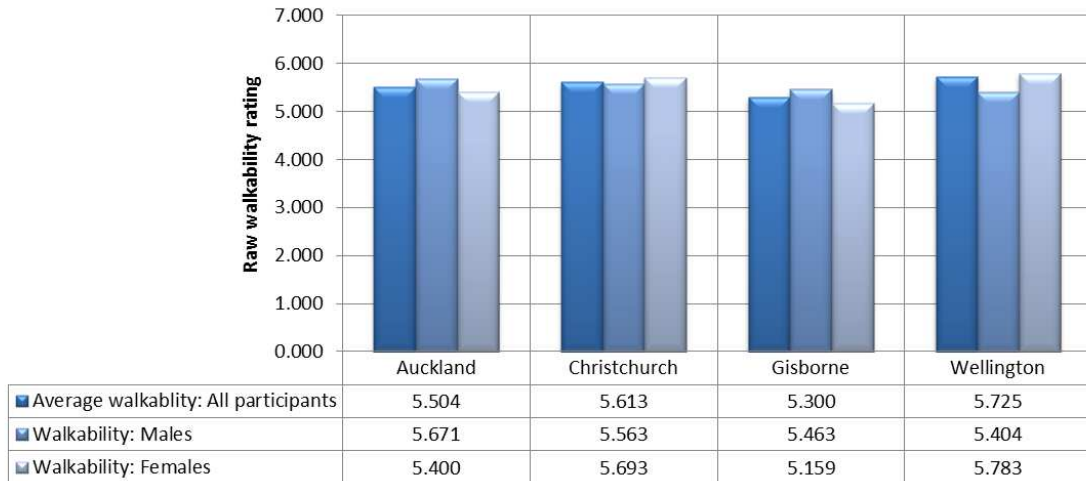
Overall, Wellington had the highest mean walkability score for path lengths, followed by Christchurch and Auckland. However, the average male walkability rating for the Wellington paths was the lowest out of all four cities, while the average female rating was the highest. This may represent an outlier response from a specific individual, and is not conclusive.

5.5.2   Walkability of path lengths, by age group

Table 5.13 shows the average raw walkability rating from CSR participants at each site, based on their age group.

Table 5.13   Average raw walkability ratings, by age group

Site	Site name	City	Average walkablity: All participants (1)	Walkability: Ages 18-59 (2)	Walkability: Ages 60 and above (3)	Trend (1-2-3)
29	Karangahape Road/Mayoral Drive/Vincent Street	Auckland	5.077	5.182	4.500	
30	Park Road/Carlton Gore Road/Davis Crescent	Auckland	5.132	5.273	4.357	
31	Tamaki Drive/Khyber Pass Road	Auckland	5.683	5.716	5.500	
32	Long Drive/Tarawera Terrace/Tamaki Drive	Auckland	6.125	6.045	6.563	
16	Park Terrace/Rolleston Ave/Salisbury Street	Christchurch	6.440	6.440	6.429	
18	Worcester Street/Armagh Street/Oxford terace	Christchurch	5.718	5.722	5.667	
19	Victoria Street/Salisbury Street/Durham Street North	Christchurch	5.538	5.548	5.429	
21	Manchester Street/Gloucester Street/	Christchurch	5.212	5.271	4.500	
22	Kilmore Street/Barbadoes Street/Durham Street North	Christchurch	5.155	5.174	5.000	
23	Gladstone Road/Peel Street/Fitzherbert Street	Gisborne	5.808	5.975	5.250	
24	Carnarvon Street/Gladstone Road/Kahutia Street	Gisborne	5.058	5.188	4.625	
25	Kahutia Street/Customhouse Street/Ormond Road	Gisborne	4.744	4.878	4.296	
26	Wainui Road/Hirini Street/Rutene Road	Gisborne	5.376	5.433	5.185	
28	Rutene Road/De Lautour Road/Craig Road	Gisborne	5.513	5.667	5.000	
34	Glenmore Street (Lower)	Wellington	6.375	6.375	6.375	
35	Glenmore Street (Centre)	Wellington	5.923	5.875	6.000	
38	Governor Road	Wellington	4.769	5.094	4.250	
39	Northland Road	Wellington	5.923	6.025	5.760	
41	Upland Road (Upper)	Wellington	6.154	6.375	5.800	
45	Upland Road (Centre)	Wellington	6.077	6.375	5.250	
47	Seaview Terrace	Wellington	4.795	5.063	4.367	
48	Upland Road (Lower)	Wellington	6.192	6.250	6.100	
49	Salamanca Road (Southern)/Oriely Avenue	Wellington	5.677	5.944	5.075	
50	Salamanca Road (Northern)	Wellington	5.365	5.594	5.000	

The data indicates that the average walkability ratings from participants in the 18–59 age group were at, or above, the mean for the site. The average walkability ratings for participants aged 60 or above were close to, or below, the mean value for the site, in the majority of cases.

Figure 5.26 shows average raw walkability ratings for each of the two age groups, by city, and compares them with the mean walkability of path lengths in that city.

Figure 5.26   Mean raw walkability of path lengths, by age group, for each city

	Auckland	Christchurch	Gisborne	Wellington
■ Average walkablity: All participants	5.504	5.613	5.300	5.725
■ Walkability: Ages 18–59	5.554	5.631	5.428	5.897
▨ Walkability: Ages 60 and above	5.230	5.405	4.871	5.398
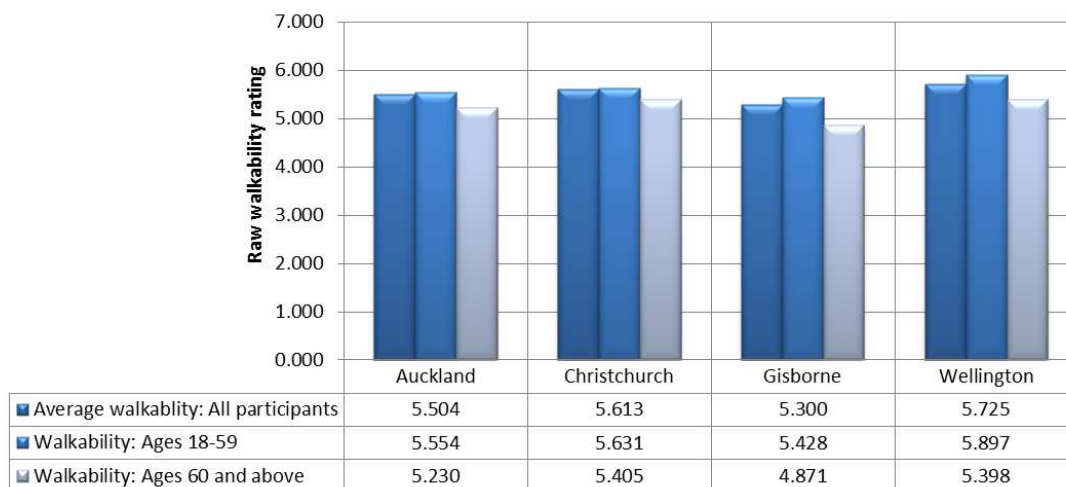
Wellington, at 5.897, had the highest average rating among 18–59 year olds. Christchurch had the best average rating for people above the age of 60, while Gisborne had the worst rating from this age group.

Table 5.14   Average male and female raw walkability ratings

Site	Site name	City	Average walkablity: All participants	Walkability: Males	Walkability: Females	% Difference Females vs. Males	
29	Karangahape Road/Mayoral Drive/Vincent Street	Auckland	4.983	4.889	5.042		3%
30	Park Road/Carlton Gore Road/Davis Crescent	Auckland	4.683	4.850	4.578		-6%
31	Tamaki Drive/Khyber Pass Road	Auckland	5.154	5.267	5.083		-3%
32	Long Drive/Tarawera Terrace/Tamaki Drive	Auckland	5.231	5.825	4.859		-17%
16	Park Terrace/Rolleston Ave/Salisbury Street	Christchurch	5.585	5.688	5.420		-5%
18	Worcester Street/Armagh Street/Oxford terace	Christchurch	5.750	5.594	6.000		7%
19	Victoria Street/Salisbury Street/Durham Street North	Christchurch	5.762	5.663	5.920		5%
21	Manchester Street/Gloucester Street/	Christchurch	5.055	5.054	5.057		0%
22	Kilmore Street/Barbadoes Street/Durham Street North	Christchurch	5.859	5.604	6.267		12%
23	Gladstone Road/Peel Street/Fitzherbert Street	Gisborne	5.333	5.519	5.175		-6%
24	Carnarvon Street/Gladstone Road/Kahutia Street	Gisborne	4.538	4.944	4.190		-15%
25	Kahutia Street/Customhouse Street/Ormond Road	Gisborne	5.038	5.021	5.054		1%
26	Wainui Road/Hirini Street/Rutene Road	Gisborne	5.239	5.476	5.020		-8%
28	Rutene Road/De Lautour Road/Craig Road	Gisborne	4.833	5.111	4.595		-10%
34	Glenmore Street (Lower)	Wellington	6.000	5.625	6.068		8%
38	Governor Road	Wellington	5.128	4.667	5.212		12%
39	Northland Road	Wellington	5.154	3.750	5.409		44%
41	Upland Road (Upper)	Wellington	4.692	4.250	4.773		12%
47	Seaview Terrace	Wellington	4.462	4.000	4.545		14%
48	Upland Road (Lower)	Wellington	5.423	5.000	5.500		10%
49	Salamanca Road (Southern)/Oriely Avenue	Wellington	5.892	5.750	6.068		6%
50	Salamanca Road (Northern)	Wellington	4.446	4.625	4.500		-3%

The results for path lengths were similar, with Auckland, Gisborne and Christchurch showing relatively little variation between male and female scores for the majority of sites, while Wellington still had a higher rating from female participants than from males.

Figure 5.27 shows a comparison of the walkability scores, by city.

Figure 5.27   Mean raw walkability of road crossings, by gender, for each city

	Auckland	Christchurch	Gisborne	Wellington
Average walkablity: All participants	5.013	5.602	4.997	5.150
Walkability: Males	5.208	5.520	5.214	4.708
Walkability: Females	4.891	5.733	4.807	5.259

Christchurch had the highest overall average rating, and the best ratings from both males and females. Gisborne had the lowest average rating from females, while Wellington had the lowest average rating from males.

5.5.3   Walkability of road crossings, by age group

Table 5.15 shows the average raw walkability rating for different age bands of CSR participants at each site.

Table 5.15   Average raw walkability ratings, by age group

Site	Site name	City	Average walkablity: All participants (1)	Walkability: Ages 18-59 (2)	Walkability: Ages 60 and above (3)	Trend (1-2-3)
29	Karangahape Road/Mayoral Drive/Vincent Street	Auckland	4.983	5.202	3.778	
30	Park Road/Carlton Gore Road/Davis Crescent	Auckland	4.683	4.852	3.750	
31	Tamaki Drive/Khyber Pass Road	Auckland	5.154	5.293	4.389	
32	Long Drive/Tarawera Terrace/Tamaki Drive	Auckland	5.231	5.205	5.375	
16	Park Terrace/Rolleston Ave/Salisbury Street	Christchurch	5.585	5.742	3.700	
18	Worcester Street/Armagh Street/Oxford terace	Christchurch	5.750	5.906	3.875	
19	Victoria Street/Salisbury Street/Durham Street North	Christchurch	5.762	5.775	5.600	
21	Manchester Street/Gloucester Street/	Christchurch	5.055	5.036	5.286	
22	Kilmore Street/Barbadoes Street/Durham Street North	Christchurch	5.859	5.875	5.667	
23	Gladstone Road/Peel Street/Fitzherbert Street	Gisborne	5.333	5.444	4.963	
24	Carnarvon Street/Gladstone Road/Kahutia Street	Gisborne	4.538	4.811	3.630	
25	Kahutia Street/Customhouse Street/Ormond Road	Gisborne	5.038	5.225	4.417	
26	Wainui Road/Hirini Street/Rutene Road	Gisborne	5.239	5.457	4.476	
28	Rutene Road/De Lautour Road/Craig Road	Gisborne	4.833	5.200	3.611	
34	Glenmore Street (Lower)	Wellington	6.000	6.344	5.450	
38	Governor Road	Wellington	5.128	5.417	4.667	
39	Northland Road	Wellington	5.154	5.438	4.700	
41	Upland Road (Upper)	Wellington	4.692	4.688	4.700	
47	Seaview Terrace	Wellington	4.462	4.625	4.200	
48	Upland Road (Lower)	Wellington	5.423	5.813	4.800	
49	Salamanca Road (Southern)/Oriely Avenue	Wellington	5.892	5.889	6.313	
50	Salamanca Road (Northern)	Wellington	4.446	4.500	4.550	

The results shown in the table above indicate that most CSR participants in the 18–59 age bracket gave walkability ratings at, or above, the mean walkability of the road crossing. The average walkability rating from participants aged 60 or above was lower than the mean for the site, in most cases.

Figure 5.28 shows average raw walkability ratings for each of the three age groups, by city.

Figure 5.28   Mean raw walkability of road crossings, by age group, for each city

	Auckland	Christchurch	Gisborne	Wellington
■ Average walkablity: All participants	5.013	5.602	4.997	5.150
■ Walkability: Ages 18-59	5.138	5.667	5.228	5.339
▣ Walkability: Ages 60 and above	4.323	4.825	4.219	4.922

Out of the four cities examined, road crossings in Christchurch received the highest ratings from people aged 18–59, and also had the highest overall walkability rating. Auckland had the lowest average rating from people aged 18–59, and Wellington had the highest rating from participants aged 60 or over.

6 Prediction models

6.1 Mathematical approach

Minitab was used to conduct linear regression modelling using a stepwise forward and backward substitution approach. The average adjusted walkability for each section (ie path length or road crossing) for each site was chosen as the response variable, and all other selected variables were added as predictor variables while conducting the modelling exercise. The alpha (α) value for addition and elimination of variables was set to 0.05, to enable only those variables that had a reasonable 'fit' to be included in the model. The stepped results of the forward and backwards approach are shown in appendix E.

6.1.1 Predictor variables

The predictor variables for path lengths and road crossings that were identified in section 5 formed the basis for the testing of variables during the model development process. Initial analysis resulted in a set of best-performing variables that were subsequently shortlisted for further testing.

All possible variables for which data was collected, and which were not included in the original list of variables identified in tables 6.1 and 6.2 (following), were tested at this stage to determine any variables that could have a significant influence on walkability but had been overlooked earlier.

6.1.2 Models developed

The following categories of models were developed for path lengths and road crossings:

- **Overall models** – These are the main models that take into account the full sample set of sites and variables available for both path lengths and crossings, and describe the best variables for predicting the walkability of each. These models are recommended for practitioner use.

- **Age-group models** – Models for predicting the walkability of path lengths and road crossings were also built for CSR survey participants belonging to different age groups. Survey participants were classified into the groups 'Young adult and mature adults (aged 18–59)' and 'Elderly (aged 60+)'. Additional testing was undertaken by further dividing the 'young and mature adults' group into those aged 18–29 and 30–59. However, the results from these subgroups did not show significant variation between the model coefficients, so the grouping reverted to the 18–59 age bracket.

- **Environment-variable models** – CSR participants were asked to rate certain environment variables (see table 6.1) in addition to the overall walkability of a section. These variables were separately adjusted on the basis of the rating of the common participant, and used as response variables after being averaged across each section and site to develop prediction models for the respective environment variable.

Table 6.1   Environment-variable models

Path lengths	Road crossings
• Safe from falling	• Safe from traffic
• Pleasant	• Lower waiting time

Figure 6.1 provides a summary illustration of the various model types for path lengths and road crossings.

In addition to the model categories described earlier, models for the different genders of CSR participants were also built. However, because there was no significant variability between the coefficients of the male and female participant models, these were not included in the final set of published models.

Figure 6.1   Walkability models
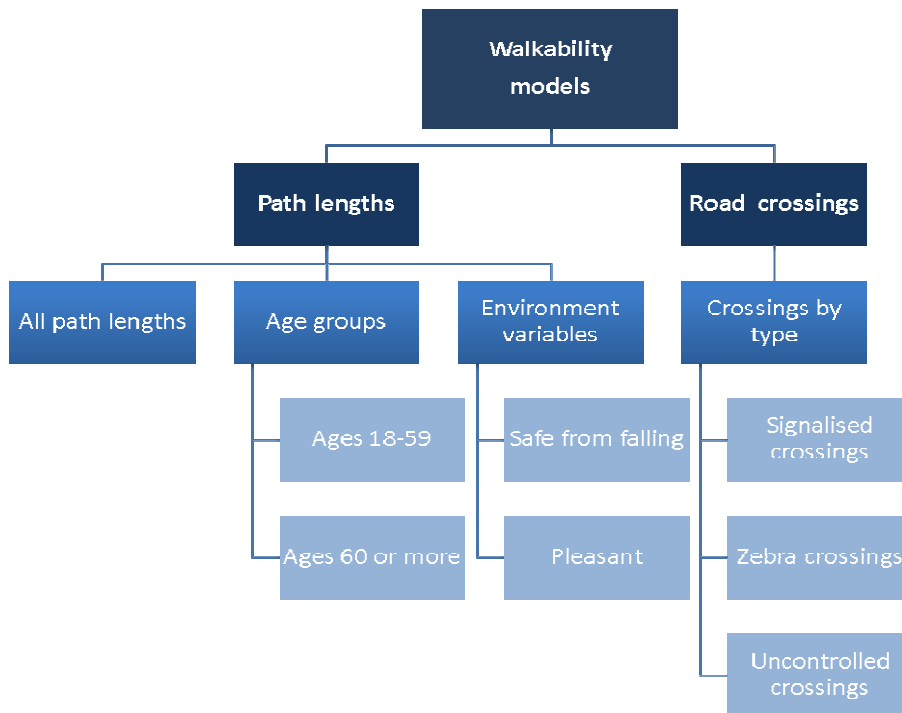
6.2   Path-length models

The final set of selected variables identified in section 5.4.2 was utilised for generating the final model for predicting the walkability of path lengths. The analysis resulted in the following overall preferred mathematical model.

Walkability$_{PL}$ = 4.426 + 0.561 footcon + 0.300 green - 0.378 vspeed + 0.294 comfort - 0.464 devi + 0.415 pa+res + 0.170 min ewidth - 0.186 numhide - 0.0034 Avg stepav + 0.201 dese   (Equation 6.1)

Note: The above equation has been normalised to an ambient temperature of 22°C and non-windy conditions. Windy conditions are found to reduce the walkability rating by 0.54, while an increase or decrease of temperature of 1°C leads to a positive and negative change in the walkability rating of 0.065 respectively.

The descriptions and possible values of the variables in the model are shown in table 6.2.

Table 6.2   Path length model variable descriptions

Variable	Description	Possible values
footcon	Footpath condition	Poor footpath condition = -1 Average footpath condition = 0 Good footpath condition = +1
green	Quantity of greenery	Little or no greenery = -1 Moderate greenery = 0 Significant greenery = +1
comfort	Presence of comfort features	Comfort features not present = 0 Comfort features present = 1
devi	Deviation around obstacles	Little or no deviation = -1 Small amount of deviation = 0 Significant deviation = +1
min ewidth	Minimum path effective width	In metres
vspeed	Vehicle speed	Below speed limit = -1 At speed limit = 0 Above speed limit = +1
avg stepav	Average step height	In millimetres
dese	Design effort	Not designed/very low design effort = -1 Low to medium design effort = 0 High to very high design effort = +1
numhide	Number of hiding places	Number of hiding places along the path
pa+res	Parkland or residential land use	Parkland or residential = 1 Other land use = 0

The R^2 value of the path lengths model was found to be 0.59. Figure 6.2 depicts a scatter plot of the observed values of walkability (adjusted for variation on the basis of the common survey participant) against the modelled values as predicted by the model.

Figure 6.2   Scatter plot of observed vs modelled walkability
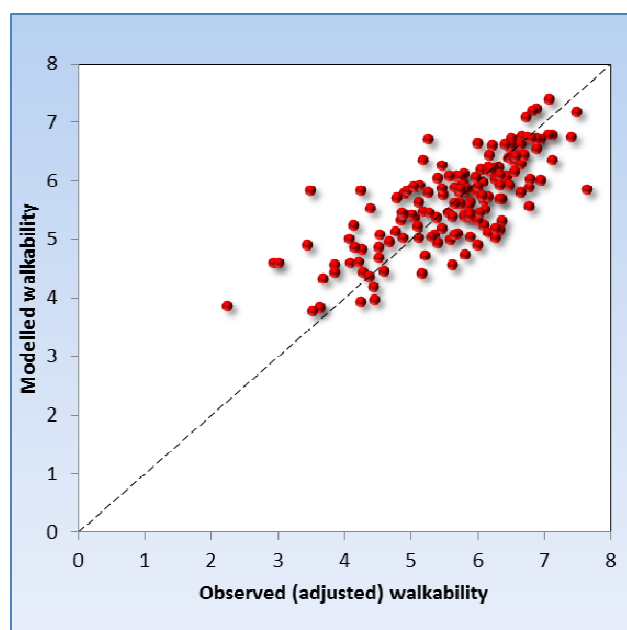
Figure 6.3 shows residual plots for the path-length model.

Figure 6.3   Residual plots: path-length model
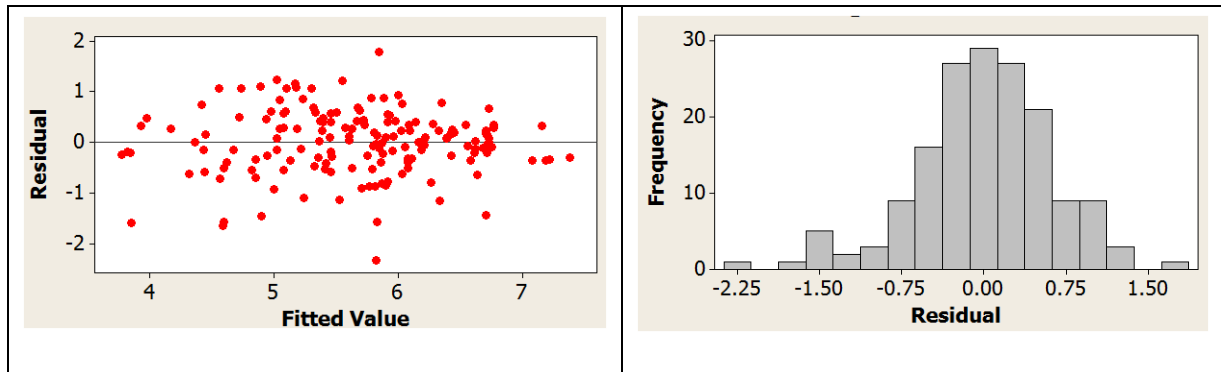
The model shows that footpath condition, quantity of greenery, presence of comfort features, vehicle speed, land use (parkland or residential) and deviation around obstacles are the major factors that affect the walkability of a path. Improvements in the condition of the footpath and the presence of more trees and comfort features are likely to have a significant positive effect on the walkability of a path. A higher speed of vehicles on the adjacent road segment, and presence of obstacles (leading to greater deviation in the travelled path), is likely to significantly reduce its walkability.

Land use is another factor identified in the model. The coefficient of 0.415 for parkland/residential land use suggests that paths in parkland or residential areas are more walkable than those in industrial areas.

Because of the perceived personal security risks associated with the number of hiding places and amount of detritus on the path, these factors also affect its walkability, although not to the same degree as deviation around obstacles and vehicle speed.

The minimum effective width along the path has a positive relationship with walkability, as seen in the coefficient of 0.17. This suggests that wider paths are, in general, rated to be more walkable, but the walkability rating of a path is affected more by the presence of obstacles leading to the path being narrow, rather than by the average or maximum widths of the path.

Higher design effort – ie the presence of functional streetscaping items and the absence of steps along the path – also improve its walkability rating.

Table 6.3 shows model results for the two age-group models, for path lengths.

Table 6.3   Age-group model coefficients

Variable	Coefficient age 18–59	Coefficient age >60
constant	4.429	4.757
footcon	0.531	0.7
green	0.29	
comfort	0.29	0.76
devi	-0.41	-0.51
min ewidth	0.173	
vspeed	-0.42	
avg stepav		-0.0047
dese	0.222	
numhide	-0.159	-0.32
pa+res	0.39	0.67
R-Sq	**0.57**	**0.40**

Note: The above table has been normalised to an ambient temperature of 22°C and non-windy conditions. Windy conditions reduced the walkability rating from people aged 18–59 by 0.47, and from people aged 60+ by 0.89.

Figure 6.4 depicts the scatter plots of observed vs predicted walkability for the two age-group models.

Figure 6.4   Scatter plot of observed vs modelled walkability
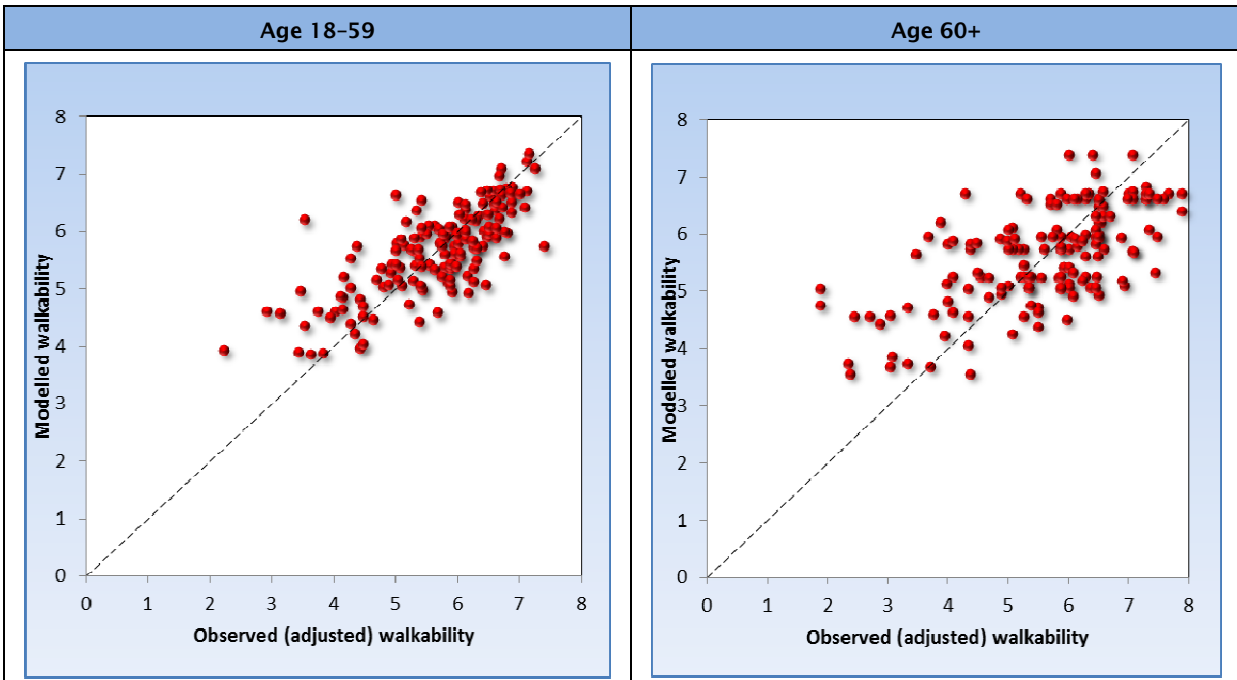
Figure 6.5 shows residual plots for the two age-group models. The skew towards the negative is evident from these plots, although it seems to vary more than the positive residuals shown in the bottom graphs. This indicates that the respondents tended to vary in how poorly they rated sections that were less walkable.

Figure 6.5   Residual plots – age-group models
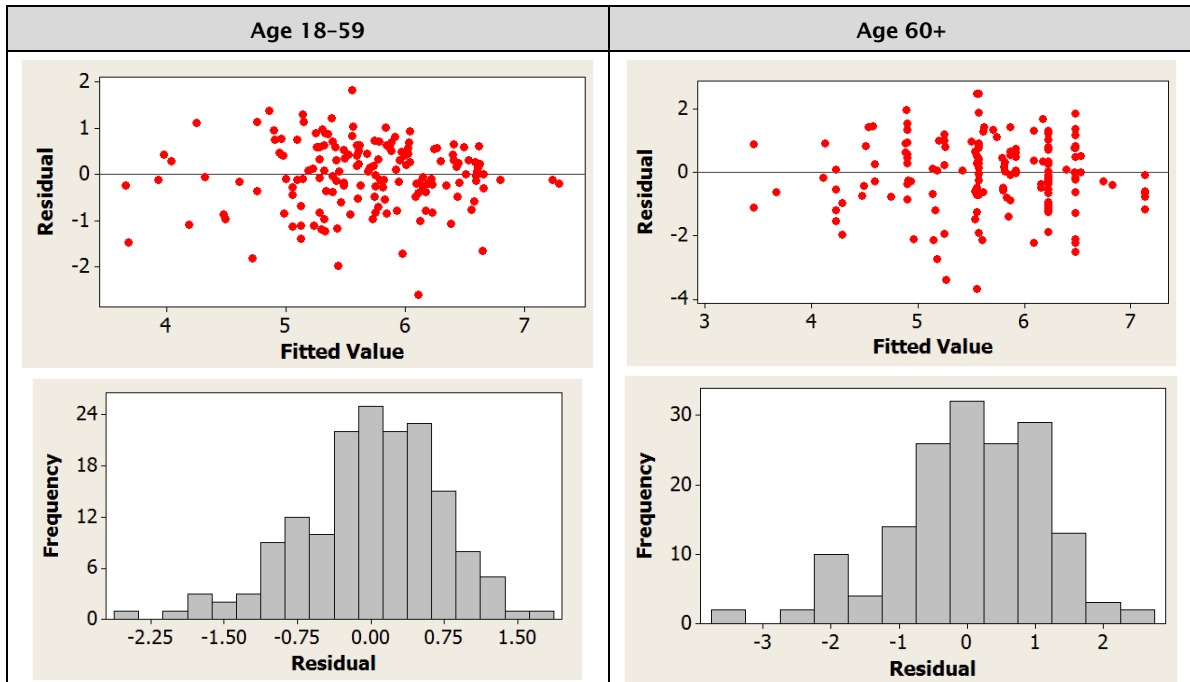
The R^2 value of the model for people aged 30–59 was 0.57, which indicates a well-fitting model. The R^2 value for people aged 60+ was 0.40, which represents an average level of fit between predicted and actual values of walkability.

Once again, the importance of footpath condition, presence of comfort features, land use (parkland/residential), number of hiding places, and level of deviation, stands out. The age-group models also indicate that greenery, vehicle speed, design effort and minimum effective width along the path had an influence on the walkability rating from young and mature adults, but not that from elderly participants. However, the walkability ratings from the elderly participants were influenced by the average combined height of steps along the path.

6.3   Environment-variable models

Models were developed for predicting the 'safe from falling' and 'pleasant' nature of path lengths. Table 6.4 lists the coefficients for the environment-variable models.

Table 6.4   Environment-variable model coefficients

Variable	Safe from falling	Pleasant
constant	5.761	2.775
footcon	0.537	0.47
green		0.547
comfort		0.46
devi	-0.23	-0.41
min ewidth		0.248
vspeed		-0.66
avg stepav	-0.005	
dese	0.27	0.38
numhide	-0.174	
pa+res		
R-Sq	**0.36**	**0.54**

Note: The above table has been normalised to an ambient temperature of 22°C and non-windy conditions. Windy conditions reduced the 'pleasant' rating by 0.57, while wind did not have an effect on the 'safe from falling' rating.

Figure 6.6 shows plots of observed vs predicted walkability for the categories 'safe from falling' and 'pleasant'.

Figure 6.6   Scatter plot of observed vs modelled walkability
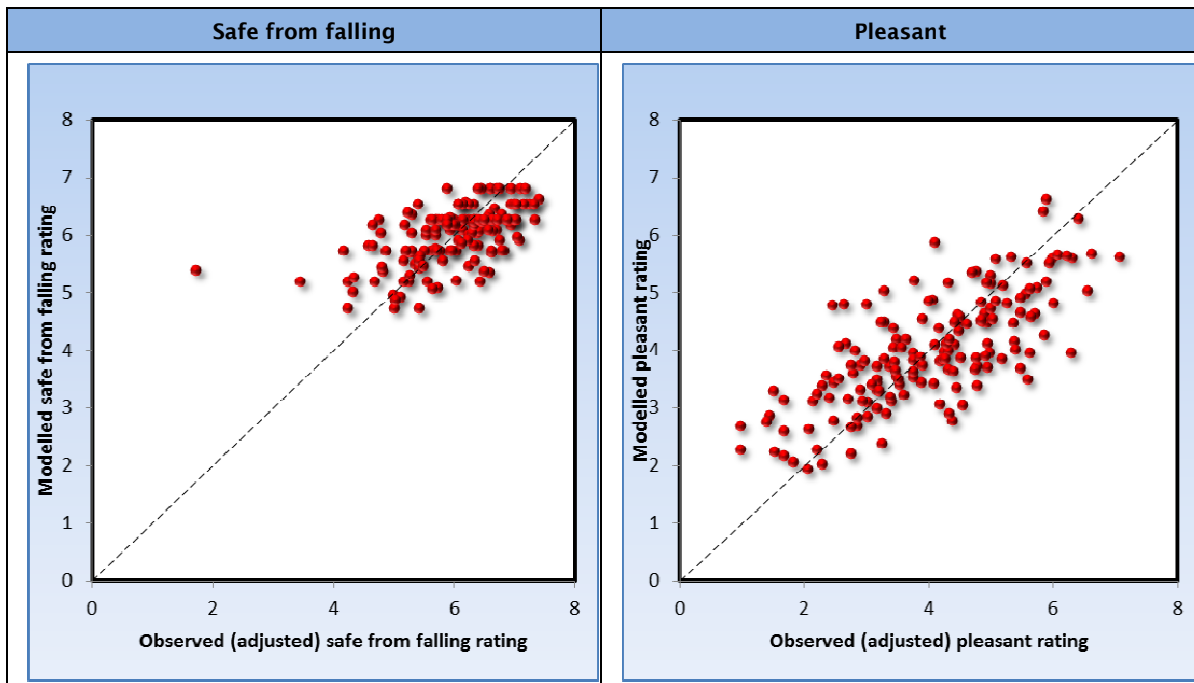
Figure 6.7 shows residual plots for environment-variable models. A large amount of variation is seen in the residual plot for 'pleasant', indicating that respondents tended to differ in their perceptions of the pleasantness of a given section.

Figure 6.7   Residual plots – environment-variable models
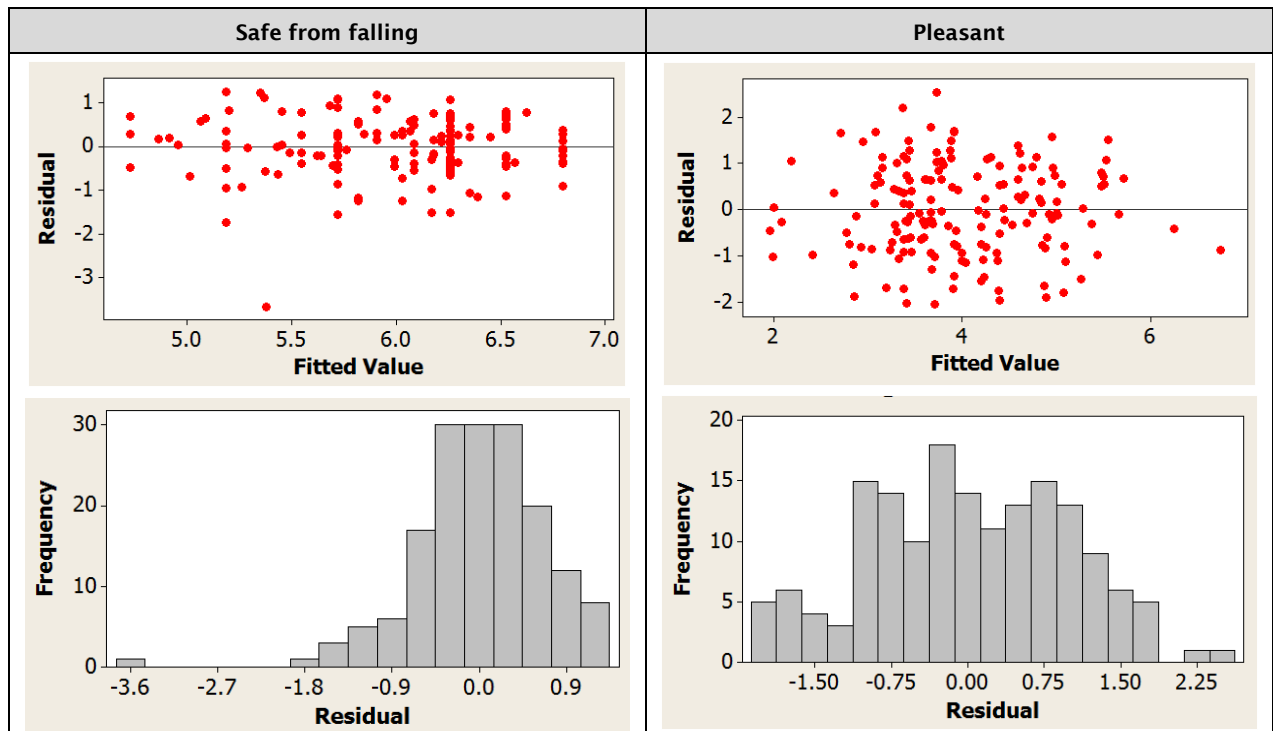
The model for 'pleasant' displays a moderate R^2 value of 0.54. However, the R^2 value of the 'safe from falling' model is quite low at 0.36.

The models for pleasantness of environment show that a well-maintained footpath, abundance of trees and comfort facilities, reduced deviation of path, wider path, and low speed of vehicles on the adjacent section of road all result in making a path more pleasant for pedestrians. Land-use classification, step height and number of hiding places were not found to be significant influences in this model.

Although it is hard to draw conclusions from the 'safe from falling model' because of the low R^2 value, the model does suggest that footpath condition is one of the most important factors affecting the risk of falling on a path. The amount of deviation, step height along the path and number of hiding places negatively affected the 'safe from falling' rating.

6.3.1   Summary: path-length models

Table 6.5 lists the various models developed for path lengths, along with variable coefficients and model R^2 values.

Table 6.5   Models for path lengths

Variable	Walkability – all ages	Walkability by age group		Environment	
		Age 18–59	Age >60	Safe from falling	Pleasant
Number of path length sections included in sample set: 163					
constant	4.426	4.429	4.757	5.761	2.775
footcon	0.561	0.531	0.7	0.537	0.47
green	0.3	0.29			0.547
comfort	0.294	0.29	0.76		0.46
devi	-0.464	-0.41	-0.51	-0.23	-0.41
min ewidth	0.17	0.173			0.248
vspeed	-0.378	-0.42			-0.66
avg stepav	0.0034		-0.0047	-0.005	
dese	0.201	0.222		0.27	0.38
numhide	-0.186	-0.159	-0.32	-0.174	
pa+res	0.415	0.39	0.67		
R-Sq	**0.59**	**0.57**	**0.40**	**0.36**	**0.54**

The significance values of various variables in the main path-lengths model are shown in table 6.6. Different scenarios have been assessed in order to provide an indication of the contribution of each variable towards the overall walkability rating. A comprehensive set of significance values of variables in the age-group and environment-variable models is provided in appendix F.

Table 6.6   Contributions to overall walkability score, by variable: path-length model

Variable	Well-designed path		No comfort features on path		Paths in commercial/ industrial zones, little or no greenery		Narrow paths in poor condition and with hiding spaces		Poorly designed path	
	Variable values	*Walkability: significance value*	*Variable values*	*Walkability: significance value*	*Variable values*	*Walkability: significance value*	*Variable values*	*Walkability: significance value*	*Variable values*	*Walkability: significance value*
constant		4.426		4.426		4.426		4.426		4.426
footcon	1	0.561	1	0.561	1	0.561	-1	-0.561	-1	-0.561
green	1	0.3	1	0.3	0	0	1	0.3	-1	-0.3
comfort	1	0.294	0	0	1	0.294	1	0.294	-1	-0.294
devi	-1	0.464	-1	0.464	-1	0.464	-1	0.464	1	-0.464
min ewidth	3	0.51	3	0.51	3	0.51	1.5	0.255	1.5	0.255
vspeed	-1	0.378	-1	0.378	-1	0.378	-1	0.378	0	0
avg stepav	150	0.51	150	0.51	150	0.51	150	0.51	165	0.561
dese	1	0.201	-1	-0.201	1	0.201	1	0.201	-1	-0.201
numhide	0	0	0	0	0	0	1	-0.186	2	-0.372
pa+res	1	0.415	1	0.415	0	0	1	0.415	0	0

Variable	Well-designed path		No comfort features on path		Paths in commercial/ industrial zones, little or no greenery		Narrow paths in poor condition and with hiding spaces		Poorly designed path	
	Variable values	*Walkability: significance value*	*Variable values*	*Walkability: significance value*	*Variable values*	*Walkability: significance value*	*Variablevalues*	*Walkability: significance value*	*Variablevalues*	*Walkability: significance value*
Predicted walkability rating	8.059		7.363		7.344		6.496		3.050	

The variable significance values shown in table 6.6 reaffirm the importance of the factors 'footpath condition', 'deviation', 'minimum path effective width', 'greenery', 'comfort' and 'land use' on the walkability of path lengths.

6.4   Road-crossing models

Separate models were built for predicting the walkability of each of the crossing types included in the sample set: signalised crossings, zebra crossings and uncontrolled crossings. Forward and backward substitution of the final set of variables selected for inclusion in the road-crossings model resulted in the models described below.

6.4.1   Models, by crossing type

6.4.1.1   Signalised crossings

Data available for the 38 signalised crossings in the sample set did not produce a significant model.

6.4.1.2   Zebra crossings

The number of zebra crossings in the sample set was relatively low, at 13. Forward and backward substitution in Minitab resulted in the following preferred model form:

$$Walkability_{zebra\ crossings} = 5.51 + 1.40\ rdcon + 0.477\ tpva - 0.052\ crosdi - 0.01\ delay \qquad \text{(Equation 6.2)}$$

The descriptions and range of possible values of the variables in the model are given in table 6.7 and the observed vs modelled walkability are shown in figure 6.8.

Table 6.7   Zebra crossings model variable descriptions

Variable	Description	Possible values
delay	Crossing delay	In seconds
crosdi	Crossing distance	Distance in metres.
rdcon	Road condition	Poor road condition = -1 Average road condition = 0 Good road condition = +1

Variable	Description	Possible values
tpva	Presence of tactile aids at crossing	Tactile aids present = 1 Tactile aids absent = 0

Figure 6.8   Scatter plot of observed vs modelled walkability
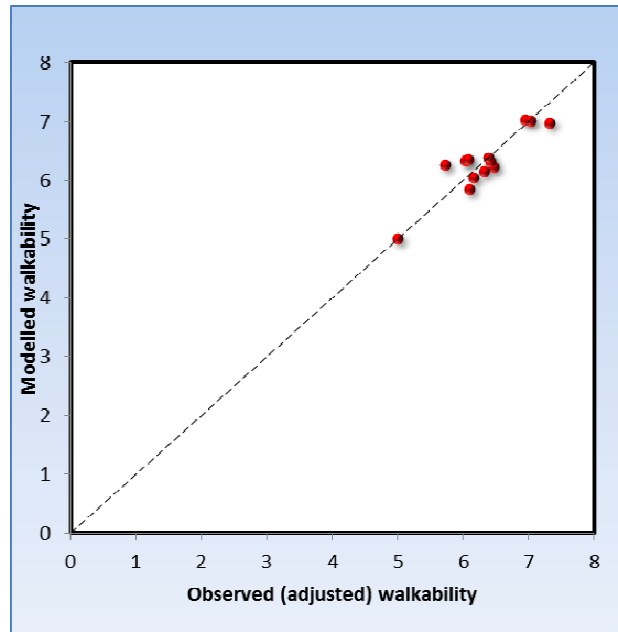
Figure 6.9 shows residual plots for the zebra crossings model.

Figure 6.9   Residual plots: zebra crossings model
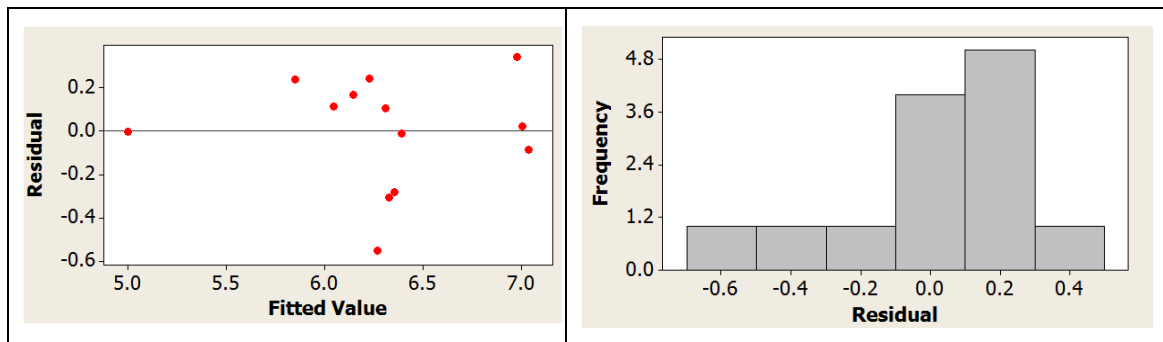
The R^2 of the model was quite high, at 0.82, although this was probably because of the low number of zebra crossings in the sample set.

The model shows that the walkability of zebra crossings increases as the condition of the road improves, and decreases as the distance to be crossed increases. The presence of tactile aids also leads to higher walkability scores, while higher crossing delays result in lower walkability ratings.

6.4.1.3   Uncontrolled crossings

Data from 86 uncontrolled crossings was available in the sample set.

Forward and backward substitution in Minitab resulted in the following preferred model form:

$$Walkability_{uncontrolled\ crossings} = 5.06 - 0.819\ vspeed + 0.640\ vis\ tra - 0.091\ delay + 0.377\ footcon + 0.706\ rist - 0.05\ crosdi$$

<div align="right">(Equation 6.3)</div>

The descriptions and range of possible values of the variables in the model are tabulated in table 6.8.

Table 6.8   Uncontrolled crossings model variable descriptions

Variable	Description	Possible values
vspeed	Vehicle speed	Below speed limit = -1 At speed limit = 0 Above speed limit = +1
vis tra	Visibility to traffic	Poor visibility = -1 Medium visibility = 0 Good visibility = +1
footcon	Footpath condition	Poor footpath condition = -1 Average footpath condition = 0 Good footpath condition = +1
delay	Crossing delay	In seconds
crosdi	Crossing distance	Distance in metres
rist	Presence of central island	Tactile aids present = 1 Tactile aids absent = 0

The walkability model for uncontrolled crossings had an R^2 value of 0.48, representing a reasonable fit. Figure 6.10 shows the observed values of walkability against the values predicted by the walkability model for uncontrolled crossings.

Figure 6.10   Scatter plot of observed vs modelled walkability
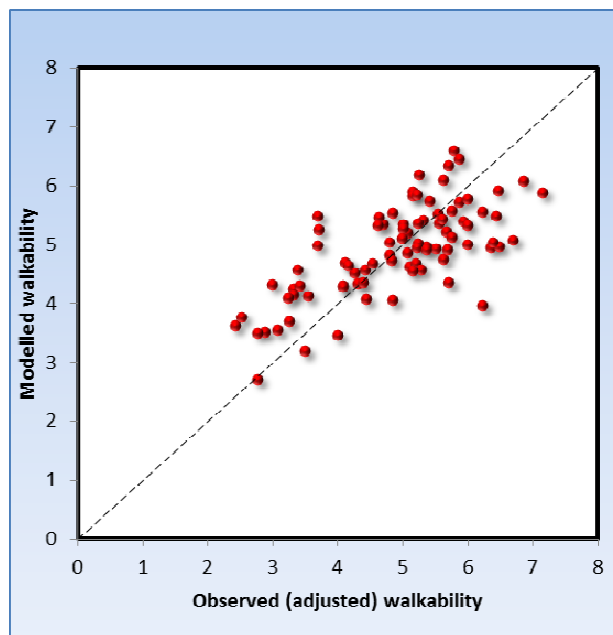
Figure 6.11 shows residual plots for the uncontrolled crossings model.

Figure 6.11   Residual plots: uncontrolled crossings model
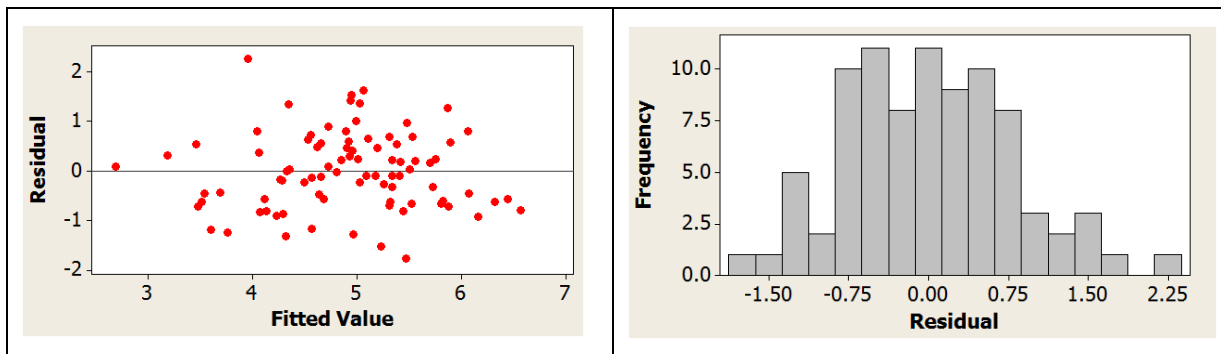
The model shows that vehicle speed, visibility to traffic, footpath condition and presence of a central island are the most important factors influencing the walkability of uncontrolled crossings. Large delays experienced while crossing, and wider crossings with larger crossing distances, have a negative effect on the path length's walkability.

6.4.2   Summary: road-crossing models

Table 6.9 lists the various models developed for road crossings, along with the coefficients of various variables and model R² values.

Table 6.9   Models for road crossings

Walkability, by crossing type			
	Signalised	**Zebra**	**Uncontrolled**
Sample set (sections)	*38*	*13*	*86*
constant		5.51	5.06
vspeed			-0.819
vis tra			0.64
footcon	No significantly converging model		0.377
delay		-0.01	-0.091
crosdi		-0.052	-0.05
rdcon		1.4	
tpva		0.477	
rist			0.706
R-Sq		0.82	0.48

The significance values of various variables in the zebra crossing and uncontrolled crossing models are shown in table 6.10. Different scenarios were assessed to provide an indication of the contribution of each variable towards the overall walkability rating. A comprehensive set of significance values of variables in the age-group and environment-variable models is provided in appendix F.

Table 6.10   Contributions to overall walkability score, by variable: zebra crossing and uncontrolled crossing models

Variable	Zebra crossing: generic		Larger zebra crossing with increased delay[a]		Zebra crossing on poorly maintained road with no tactiles		Uncontrolled crossing: with refuge		Larger uncontrolled crossing with higher vehicle speeds & increased delay		Uncontrolled crossing with poorly maintained footpath & no central island	
	Variable values	*Walkability: significance value*	*Variable values*	*Walkability: significance value*	*Variable values*	*Walkability: significance value*	*Variable values*	*Walkability: significance value*	*Variable values*	*Walkability: significance value*	*Variable values*	*Walkability: significance value*
constant		5.510		5.510		5.510		5.060		5.060		5.060
vspeed							-1	0.819	0	0	-1	0.819
vis tra							1	0.64	1	0.64	1	0.64
footcon							1	0.377	1	0.377	-1	-0.377
delay	5	-0.05	10	-0.1	5	-0.05	20	-1.82	30	-2.73	20	-1.82
crosdi	10	-0.52	15	-0.78	10	-0.52	10	-0.5	15	-0.75	10	-0.5
rdcon	1	1.4	1	1.4	-1	-1.4						
tpva	1	0.477	1	0.477	0	0						
rist							1	0.706	1	0.706	0	0
Predicted walkability rating	6.667		6.307		3.390		5.282		3.303		3.822	

a)   Note: Zebra crossings with high traffic flows can subject pedestrians to large delays as pedestrians confirm motorists will yield and allow them to cross. In these situations a zebra crossing may not be the most appropriate crossing facility.

The variable significance values shown in the above table reaffirm the importance of the factors 'road condition', 'delay', 'crossing distance', 'central island', and 'presence of tactiles' on the walkability of road crossings.

7   Discussion

While every journey, no matter how big or small, starts and ends with a single step, walking is often the forgotten mode of transport. Other modes, especially the private motor vehicle, have a high degree of measurability because they have already had significant study. This research fills some of the knowledge gap regarding walking, and provides practitioners with a technique for quantifying the quality of the pedestrian environment in a similar way to that which already exists for other modes of travel.

This research project combined the methodology for collecting people's perceptions of the walking environment that is outlined in the NZTA's *Guide to undertaking community street reviews* (2010), with the method for systematically collecting physical and operational variables that is outlined in *Walkability research tools – variables collection methodology* (Abley 2006). These publications and other background material can be found at www.levelofservice.com.

A number of surveys of the physical and operational characteristics of the street environment around New Zealand were undertaken, and those measurements were correlated with how people felt about those environments in terms of safety, pleasantness and other variables. The research then derived a number of predictive mathematical formulas that enabled the qualitative perception of the quality of the street environment to be calculated using quantitative measurements.

7.1   Use of the prediction models

Linear regression models for predicting walkability were developed for path lengths and road crossings. Separate models were also built for young/middle-aged and elderly participants, and for predicting environment variables for path lengths such as 'safe from falling' and 'pleasant'.

7.1.1   Understanding the modelled walkability rating

Figure 7.1 depicts the rating scale used in the NZTA publication to rate the walkability of a site in the CSR (2010), along with the implied LOS categories.

Figure 7.1   Community street review – level of service (NZTA 2010)

Opinion	Score	Pass/fail	Numerical grade	Level of service	Represented by colour
☺ Very good	7	Pass	>=6	A	Green
Good	6	Pass	>=5 and <6	B	Green
Slightly good	5	Pass	>4 and <5	C	Green
☺ Neutral	4		=4	N	White
Slightly bad	3	Fail	>=3 and <4	D	Yellow
Bad	2	Fail	>=2 and <3	E	Blue
☹ Very bad	1	Fail	<2	F	Red

Figure 7.1 provides a general guide to assessing the walkability ratings predicted by the various models. A predicted walkability rating of 4 is considered to be 'neutral', with scores higher and lower than 4 representing 'good' and 'bad' levels of walkability (respectively) of a particular site. It must be noted that in certain cases, the walkability rating predicted by the model may exceed 7 – this merely implies that the walkability is considered to be at a level comparable to 'very good'. It is also important to note that the prediction models were derived from data on sites that were predominantly at LOS A, B and C – thus they will provide valid results when used for sites within this range and can also be used to infer results outside this range.

7.1.2   Participant rating vs predicted rating

Prior to their introduction as the response variable during model development, the CSR participants' raw walkability ratings were adjusted according to the rating of the common participant. The prediction given by the walkability models is therefore also an adjusted walkability rating, and differs slightly in magnitude from the raw ratings. This aspect must be considered while evaluating model predictions.

Table 7.1 shows the magnitude of difference between raw and adjusted walkability measurements.

Table 7.1   Difference between raw and adjusted walkability ratings

City	% difference (adjusted walkability vs raw walkability)	
	Path lengths	**Road crossings**
Auckland	10%	12%
Christchurch	-5%	-1%
Gisborne	3%	-4%
Wellington	2%	5%
All sites	**2%**	**3%**

7.2   Model for path lengths

The preferred walkability model for path lengths is given by:

$Walkability_{PL}$ = 4.426 + 0.561 footcon + 0.300 green - 0.378 vspeed + 0.294 comfort - 0.464 devi + 0.415 pa+res + 0.170 min ewidth - 0.186 numhide - 0.0034 Avg stepav + 0.201 dese   (Equation 7.1)

Descriptions and possible values of the predictor variables are listed in table 7.2. The various models for path lengths, and coefficients of predictor variables for each, are tabulated below.

Table 7.2   Models for path lengths

Variable	Walkability: all ages	Walkability, by age group		Environment	
		Age: 18–59	Age: >60	Safe from falling	Pleasant
Number of path-length sections included in sample set: 163					
constant	4.426	4.429	4.757	5.761	2.775
footcon	0.561	0.531	0.7	0.537	0.47
green	0.3	0.29			0.547
comfort	0.294	0.29	0.76		0.46
devi	-0.464	-0.41	-0.51	-0.23	-0.41
min ewidth	0.17	0.173			0.248
vspeed	-0.378	-0.42			-0.66
avg stepav	0.0034		-0.0047	-0.005	
dese	0.201	0.222		0.27	0.38
numhide	-0.186	-0.159	-0.32	-0.174	
pa+res	0.415	0.39	0.67		
R-Sq	**0.59**	**0.57**	**0.40**	**0.36**	**0.54**

The most important factors that had a strong effect on the walkability of a path were 'footpath condition', 'quantity of greenery', 'presence of comfort features', 'deviation in path' and 'adjacent vehicle speed'. These variables featured in all path-length models except for the one for participants aged 60 or older (which excluded 'vehicle speed'), and the one for 'safe from falling', (which excluded 'vehicle speed' and 'greenery').

The factors 'obstacle effective width', 'temperature', 'setback of adjacent buildings', 'quantity of detritus', 'number of hiding places' and 'land use' also featured in most of the models.

The models also suggest that windy weather conditions can result in a decrease in the walkability of a path from between 0.39 and 0.76, depending on the specific model. Wind was highly correlated with the location of the survey.

The environment variable models suggest that 'footpath condition' and 'presence of comfort features' are the two most significant factors in reducing the perception of risk of falling on a path, while the factors 'greenery', 'footpath condition', 'weather (wind)' and 'presence of comfort features' significantly affect a path's perceived pleasantness.

7.3   Models for road crossings

The preferred walkability models for zebra crossings and uncontrolled crossings is given by:

$Walkability_{zebra\ crossings} = 5.51 + 1.40\ rdcon + 0.477\ tpva - 0.052\ crosdi - 0.01\ delay$ (Equation 7.2)

$Walkability_{uncontrolled\ crossings} = 5.06 - 0.819\ vspeed + 0.640\ vis\ tra - 0.091\ delay + 0.377\ footcon + 0.706\ rist - 0.05\ crosdi$ (Equation 7.3)

Descriptions and possible values of the predictor variables are given in table 7.3. The various models for road crossings, and coefficients of predictor variables for each, are tabulated.

Table 7.3   Models for road crossings

Variable	Walkability by crossing type		
	Signalised	Zebra	Uncontrolled
constant	*No significantly converging model*	5.51	5.06
vspeed			-0.819
vis tra			0.64
footcon			0.377
delay		-0.01	-0.091
crosdi		-0.052	-0.05
rdcon		1.4	
tpva		0.477	
rist			0.706
R-Sq		**0.82**	**0.48**

The most important factors affecting the walkability of road crossings were 'crossing type', 'vehicle speed', 'visibility to traffic' and 'footpath condition', and these feature in all models except those for zebra crossings and delay. The presence of a central island was also shown to positively affect the walkability of a crossing.

No statistically significant model could be developed for signalised crossings. The model for zebra crossings was based on a sample set of 13 crossings, and suggests that road condition and crossing distance are important factors. The time taken to cross was also found to be a factor in the case of uncontrolled crossings.

7.4   Comparison with the Landis walkability model

The linear regression approach to modelling walkability used in this study has previously been adopted in several other walkability studies and notably in the study by Landis (2001). The pedestrian LOS model developed by Landis is:

$$Ped\ LOS = -1.2021\ ln\ (W_{ol} + W_l + f_p x\ \%OSP + f_b\ x\ W_b + f_{sw}\ x\ W_s) + 0.253\ ln\ (Vol_{15}/L) + 0.0005\ SPD^2 + 5.3876$$

(Equation 7.4)

Where:

- W_{ol} = width of outside lane (feet)

- W_l = width of shoulder or bike lane (feet)

- f_p = on-street parking effect coefficient (= 0.20)

- %OSP = percent of segment with on-street parking

- f_b = buffer area barrier coefficient (= 5.37 for trees spaced 20 feet on centre)

- W_b = buffer width (distance between edge of pavement and footpath, measured in feet)

- f_{sw} = footpath presence coefficient (= $6-0.3W_s$)

- W_s = width of footpath (feet)

- Vol_{15} = average traffic during a 15-minute period

- L = total number of (through) lanes (for road or street)

- SPD^2 = average running speed of motor vehicle traffic (miles/hr).

The Landis model focused on the effects on pedestrian experience of traffic – participants were specifically instructed to ignore aesthetic aspects.

The key difference between the Landis model and the models developed as part of this study lies in the number of physical and operational characteristics that were assessed. Because of the significant amount of CSR survey data available on path-length and road-crossing sections, a much broader range of variables were analysed for their effects on walkability. However, the effect of some key traffic variables, such as traffic volume, speed and number of heavy vehicles, could not be adequately assessed as part of this study because they were only assessed subjectively, and were not measured as operational variables.

Both the Landis model and the models reported on in this study share some common findings, such as the effects on perceived walkability of factors such as footpath width, vehicle speed, and provision for on-street parking. This study builds upon the set of variables used in the Landis study, and includes consideration of factors such as environment, personal security, urban design, presence of hazards and comfort features, age and weather, in addition to road and footpath geometry. This consideration of a broad cross-section of factors is expected to lead to a more holistic assessment of walkability through the identification of key design and operational features that improve the quality of the walking environment.

The surveys in this study were conducted at quiet times of day and included fewer sites that had a poor rating from users – this decreased the range of footpath conditions for the study.

8   Recommendations

The following recommendations arise from this research:

- **Preferred overall models:** A number of mathematical models were created as part of this research. It is recommended that in terms of practical use, only the overall main models that predict walkability for path lengths, zebra road crossings and uncontrolled road crossings should be used by practitioners.

- **Data collection for sites at LOS D, E and F:** The sample set used in this study did not include a sufficient number of sites at LOS D, E and F to enable closer assessment and prediction of walkability scores for such sites. Future studies should focus on data collection from a broader range of sites, including an adequate number of sites with low pedestrian LOS ratings.

- **Data collection for road crossings:** The limited availability of relevant data meant that a sufficiently converging model for signalised road crossings could not be built as part of this study. In addition, the sample set included data from only 13 zebra crossing sites. Further research is needed to carefully examine the pedestrian walkability of these crossing types by utilising data from additional sites.

- **Collection of traffic-volume data:** Because of the limited availability of data on traffic volumes at path lengths and road crossings, traffic flow could not be included in the final walkability models. Efforts to use the logarithmic relationship between noise and traffic volume to develop a surrogate variable for traffic flow resulted in numerical complications during the modelling process. It is recommended that traffic flow data should be utilised in future analyses of the walkability of path lengths and road crossings.

- **Walkability at different times of day:** The data utilised for developing the walkability prediction models was obtained from CSR surveys that were held at various times during the day. Future studies could look at examining the walkability of sections at specific times of the day, especially in busy CBD areas where the walking environment can differ markedly between peak and non-peak times, and between daytime and the hours of darkness.

- **Model validation:** A comprehensive model validation exercise has not been undertaken as part of this study, and could be the focus of follow-on research.

- **Walkability for impaired pedestrians:** Further research is also recommended on analysis of the differences in walkability ratings between able-bodied pedestrians and those with physical and/or visual impairments.

9 References

Abley, S (2005) Walkability scoping paper. 62pp. Accessed 5 July 2011. *www.levelofservice.com/walkability-research.pdf*

Abley, S (2006) Walkability research tools – variables collection methodology. Christchurch: Land Transport NZ and Abley Transportation Consultants Ltd. 65pp.

Abley, S (2008) Walkability research tools – summary report. *NZ Transport Agency research report 356*. 16pp.

Abley, S (2010) *Community street review how to guide* – parts 1–3. NZ Transport Agency, Living Streets Aotearoa and Abley Transportation Consultants Ltd.

Baltimore Metropolitan Council (BMC) (2004) Bicycle level of service evaluation update & pedestrian level of service evaluation. Baltimore, Maryland: Baltimore Metropolitan Council. 33pp.

Boulter, R and R Rutherford (2004) Walking audit methodology. Auckland.

Centres for Disease Control and Prevention (CDC) (2000) Walkability Audit Tool. Accessed 25 August 2011. *www.cdc.gov/nccdphp/dnpao/hwi/downloads/walkability_audit_tool.pdf*

Fruin, JJ (1971) *Pedestrian planning and design*. New York: Metropolitan Association of Urban Designers and Environmental Planners. 206pp.

Gallin, N (2001) Quantifying pedestrian friendliness – guidelines for assessing pedestrian level of service. *Transport Research Laboratory Road and Transport research 10*, no.1: 47–55.

Huang, TH and C Chiun (2007) Modelling level of service on pedestrian environment. *Journal of the Eastern Asia Society for Transportation Studies 7*: 1774–1780.

Landis, BW, VR Vattikitti, RM Ottenberg, DS McLeod and M Guttenplan (2001) Modeling the roadside walking environment: pedestrian level of service. *Transportation Research Record 1773*, no.1: 82–88.

Living Streets (2002) DIY community street audits. UK: Living Streets. 41pp.

Muraleetharan, T, T Adachi, T Hagiwara and S Kagaya (2005) Method to determine pedestrian level-of-service for crosswalks at urban intersections. *Journal of the Eastern Asia Society for Transportation Studies 5*: 127–136.

Muraleetharan, T, T Adachi, K Uchida, T Hagiwara and S Kagaya (2004) A study on evaluation of pedestrian level of service along sidewalks and at crosswalks using conjoint analysis. *Journal of Infrastructure Planning, Japan Society of Civil Engineers 21*, no.3: 727–735.

NZ Transport Agency (2007) *Pedestrian planning and design guide*. Wellington: NZ Transport Agency. 188pp.

NZ Transport Agency (2010) Guide to undertaking community street reviews. Accessed 6 July 2011. *www.nzta.govt.nz/resources/community-street-reviews/docs/csr-guide.pdf*

Petritsch, TA, BW Landis, PS McLeod, HF Huang, S Challa and M Guttenplan (2004) Level-of-service model for pedestrians at signalized intersections. *Transportation Research Record 1939*: 55–62.

Petritsch, TA, BW Landis, PS McLeod, HF Huang, S Challa, CL Skaggs, M Guttenplan and V Vattikuti (2006) Pedestrian level-of-service model for urban arterial facilities with sidewalks. *Transportation Research Record 1982*: 84–89.

Transportation Research Board (TRB) (2000) *Highway capacity manual*. Washington DC: Transportation Research Board.

# Appendix A   CSR maps

Figure A1   Christchurch CSR map
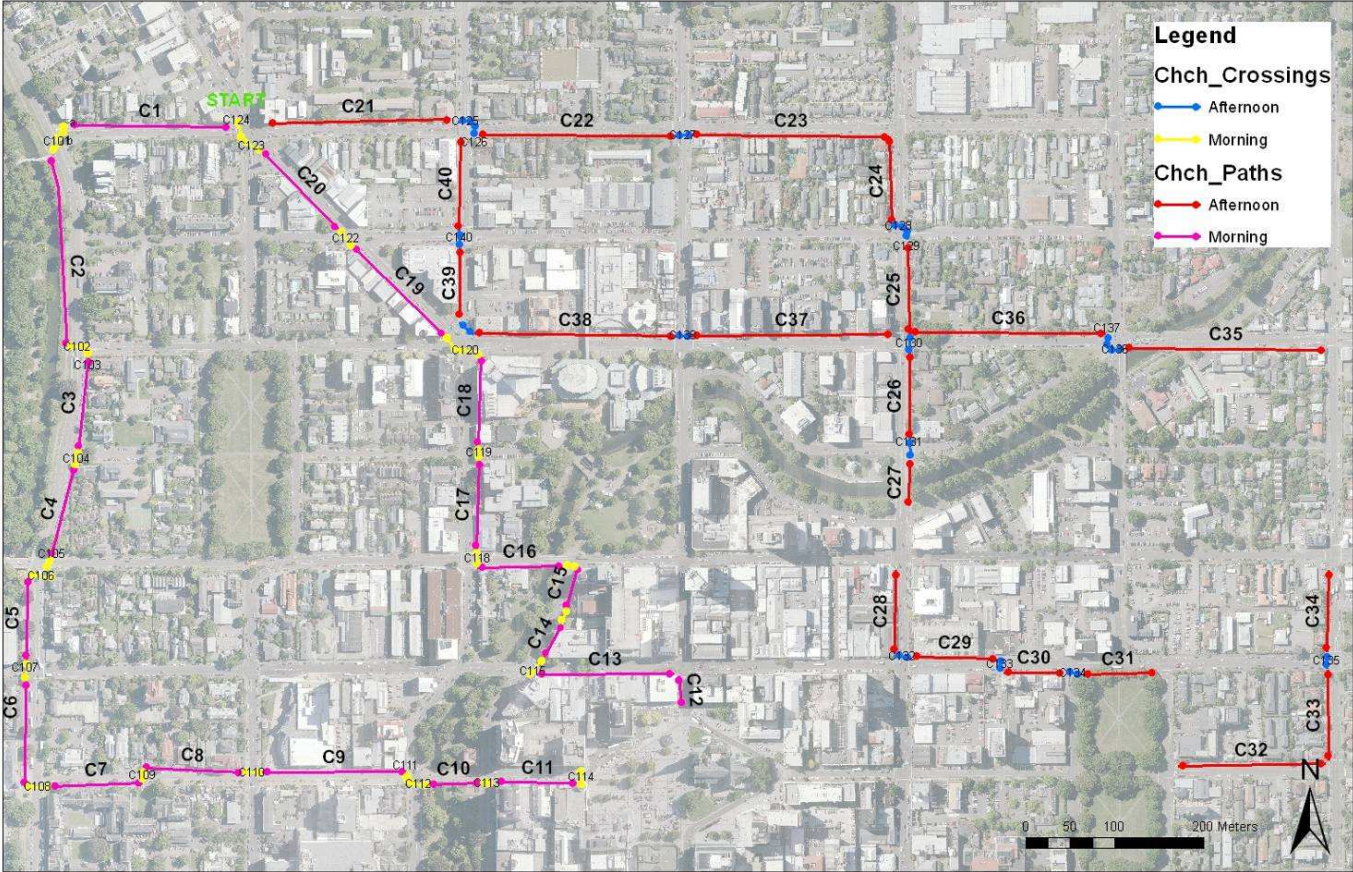
**Figure A2   Gisborne CSR map**

Figure A3   Auckland CSR map (morning)
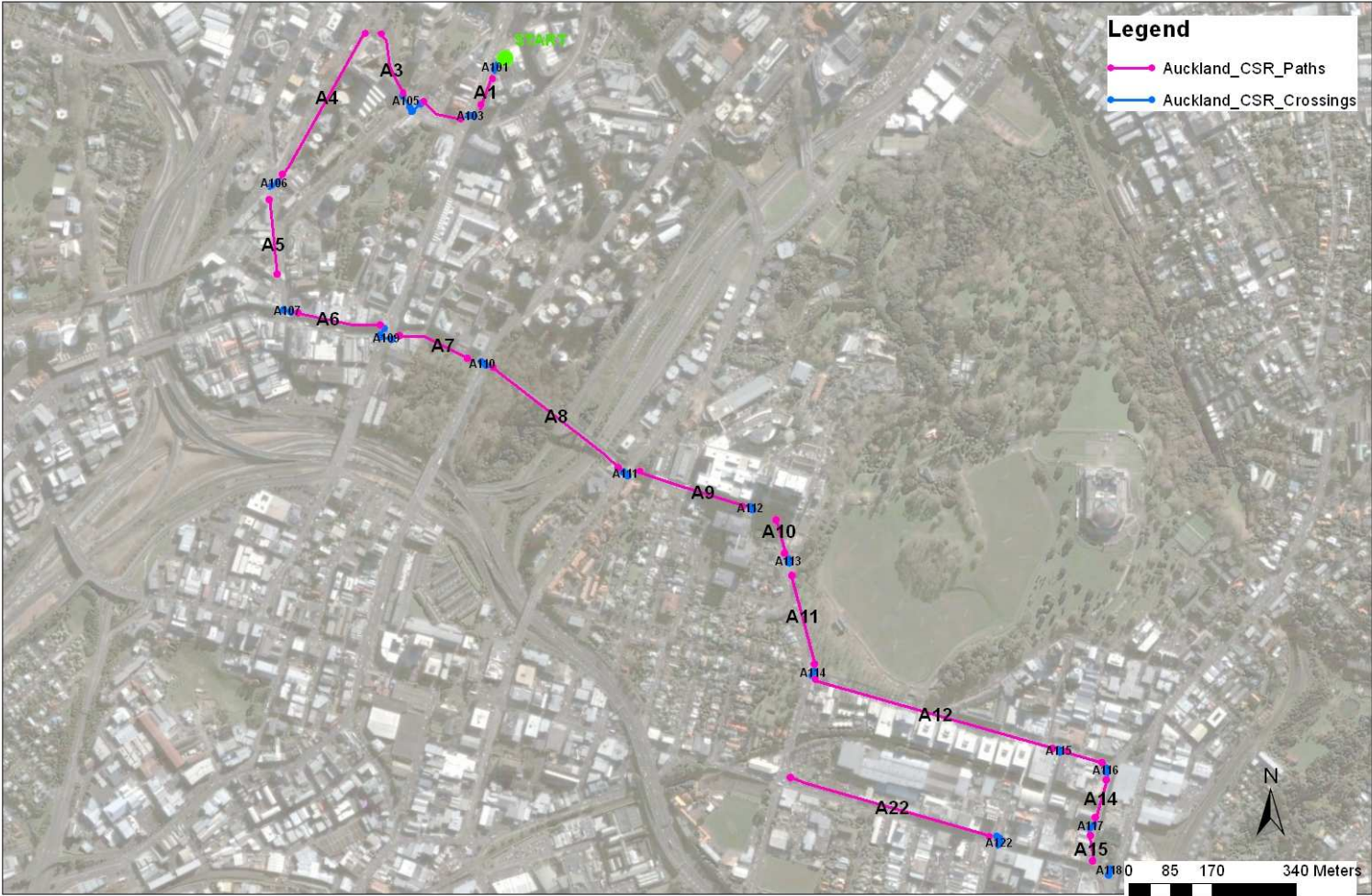
Figure A4   Auckland CSR map (afternoon)
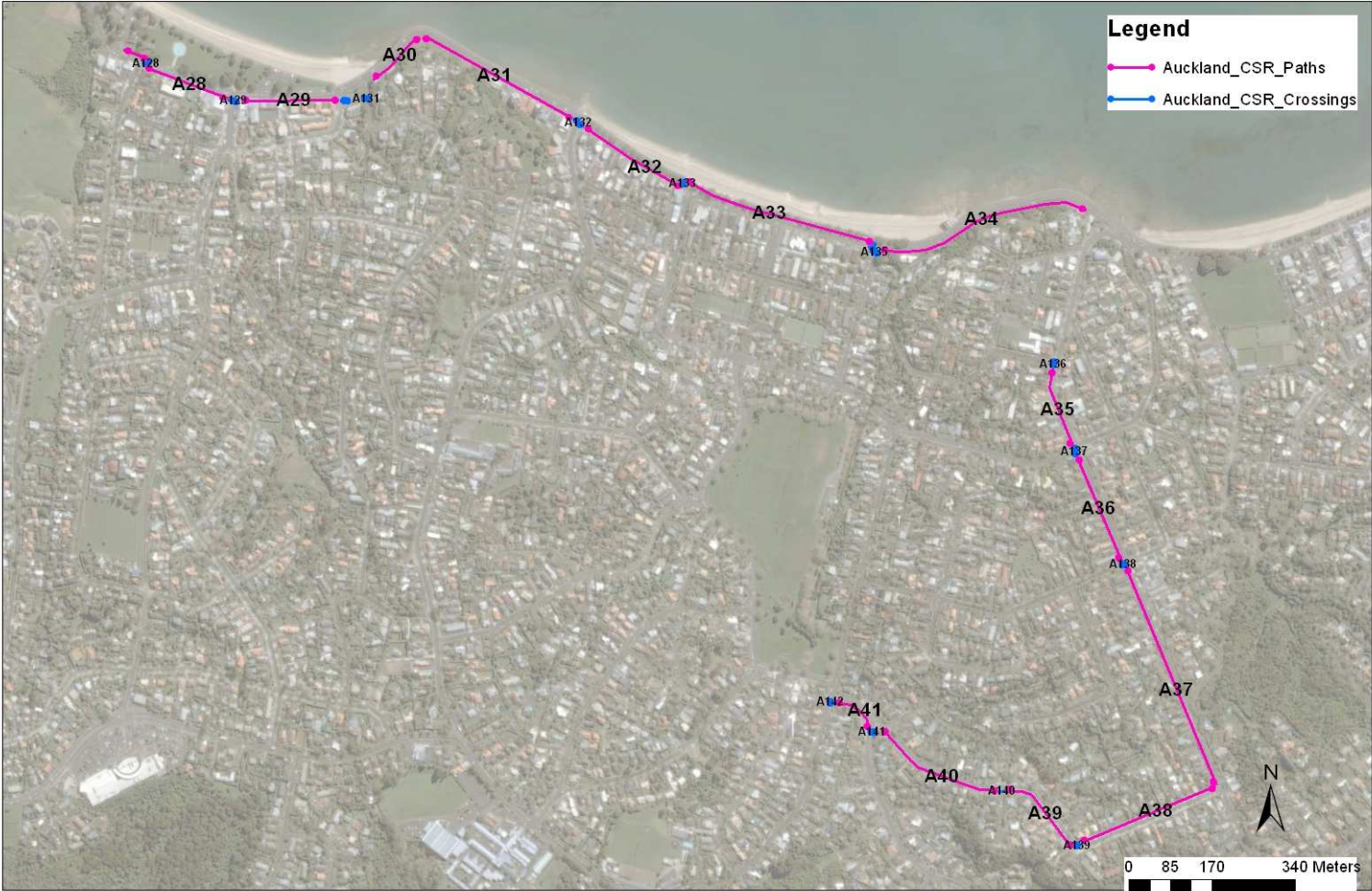
Figure A5   Wellington CSR map

Appendix B   Additional questionnaire

Rating aspect	Very low	Low	Just below neutral	Neutral	Just above neutral	High	Very high
	1	2	3	4	5	6	7
Footpath (circle)							
'I rate the contribution of the footpath alone to walkability.'	My journey was made *extremely unpleasant* because of this footpath.	My journey was made *unpleasant* because of this footpath.	My journey was made *mildly unpleasant* because of this footpath.	My journey was made *neither pleasant nor unpleasant* because of this footpath.	My journey was made *mildly pleasant* because of this footpath.	My journey was made *pleasant* because of this footpath.	My journey was made *extremely pleasant* because of this footpath.
Road (circle)							
'I rate the contribution of the road alone to walkability.'	My journey was made *extremely unpleasant* because of the road.	My journey was made *unpleasant* because of the road.	My journey was made *mildly unpleasant* because of the road.	My journey was made *neither pleasant nor unpleasant* because of the road.	My journey was made *mildly pleasant* because of the road.	My journey was made *pleasant* because of the road.	My journey was made *extremely pleasant* because of the road.
Separation of footpath and road (circle)							
'I rate the contribution of the extent of separation between footpath and traffic alone to walkability.'	My journey was made *extremely unpleasant* because of the extent of separation between footpath and traffic.	My journey was made *unpleasant* because of the extent of separation between footpath and traffic.	My journey was made *mildly unpleasant* because of the extent of separation between footpath and traffic.	My journey was made *neither pleasant nor unpleasant* because of the extent of separation between footpath and traffic.	My journey was made *mildly pleasant* because of the extent of separation between footpath and traffic.	My journey was made *pleasant* because of the extent of separation between footpath and traffic.	My journey was made *extremely pleasant* because of the extent of separation between footpath and traffic.
Broader environment (circle)							
"I rate the contribution of the larger environment alone to walkability"	My journey was made *extremely unpleasant* because of the larger environment.	My journey was made *unpleasant* because of the larger environment.	My journey was made *mildly unpleasant* because of the larger environment.	My journey was made *neither pleasant nor unpleasant* because of the larger environment.	My journey was made *mildly pleasant* because of the larger environment.	My journey was made *pleasant* because of the larger environment.	My journey was made *extremely pleasant* because of the larger environment.

Appendix C   Variables

Table C1   Path-length variables

Variable string	Description
avg adj walk	Average adjusted walkability rating for each section
vspeed	Vehicle speed
vis tra	Visibility to traffic
footcon	Footpath condition
dbnoise	Noise in decibels
avgiwid	Average island eff. width
kerb cutdown	Entry OR exit kerb dropped?
crosdi	Crossing length distance (m)
rist	Refuge island
traffic	Volume of traffic
peoplenum	People flow (during crossing time)
density	People density
pospeed	Posted speed limit
rdcon	Road condition
avg stum	Average stumbling hazards (mm)
avg trip	Average trip hazards
croscyc	Number of cycle lanes to cross
manucom	How many comfort features
weather	Survey weather
cloud	Weather, cloudy
wind	Weather, windy
tpva	Tactile paving or visual aids
ddl	Deviation from desire line
litter	Litter
deti	Detritus
vanda	Vandalism
ekerbf	Entry kerb: footpath gradient
exitf	Exit kerb: footpath gradient
ekerbr	Entry kerb: road gradient
exitr	Exit kerb: road gradient
kerbwid	Kerb: effective width
kerbcross	Kerb: crossfall

Variable string	Description
kerb2wid	Kerb: effective width
kerb2cross	Kerb: crossfall
crostr	Number of traffic lanes to cross
pocrosdi	Possible crossing width distance
dese	Design effort
luclass	Land-use classification
refuge	Type of refuge island
oddir	Odd vehicle-approach direction
comfea	Comfort features
hazp	Protection from permanent hazards
thaz	Temporary hazards
temp	Temperature
humid	Humidity
timetak (sec)	Time taken

96

Appendix D   Variable correlations

Table D1   Correlations: path lengths

	Correlations: Path Lengths	Avg adj walk	footcon	green	peoplenum (hourly)	Adjusted gradient	vanda	weather	vspeed	Avg cfall	disveh	vaways	visacc	useacc	Avg ewidth	Surface	Avg stum	Avg trip	manyutil	manycom	numveh (hourly)	roadwid	numhveh (hourly)	dbnoise	density	litter	deti	cloud	wind	useosp
Avg adj walk	Average adj walkability rating for each section	1.000																												
footcon	Footpath condition	0.469	1.000																											
green	Quantity of greenery	0.282	-0.031	1.000																										
peoplenum (hourly)	People flow per hour	0.225	0.225	-0.230	1.000																									
Adjusted gradient	Downhill gradient assumed to be zero	-0.049	-0.105	0.278	-0.124	1.000																								
vanda	vandalism	-0.143	-0.071	-0.030	-0.090	-0.103	1.000																							
weather	Survey weather	-0.368	-0.079	-0.182	-0.012	-0.272	-0.090	1.000																						
vspeed	Vehicle speed	-0.191	-0.039	0.117	-0.296	0.013	0.134	0.088	1.000																					
Avg cfall	Average Crossfall (%)	0.073	0.051	0.099	0.120	-0.059	-0.040	0.072	0.060	1.000																				
disveh	Distance from moving vehicles (m)	0.019	-0.041	0.043	0.056	-0.121	-0.103	0.118	0.086	0.115	1.000																			
vaways	Number of vehicle access ways	-0.007	0.042	-0.013	-0.151	-0.074	0.064	0.242	-0.057	-0.056	0.229	1.000																		
visacc	Visibility to vehicle access ways	0.092	0.039	0.204	-0.013	-0.037	-0.095	-0.141	0.043	0.066	0.077	-0.021	1.000																	
useacc	Use of access ways	-0.066	0.007	-0.098	0.149	-0.015	-0.096	-0.034	-0.009	0.061	0.119	0.088	0.152	1.000																
Avg ewidth	Average effective width of path	0.086	0.164	-0.305	0.474	-0.193	-0.213	0.035	-0.106	0.151	0.115	-0.142	-0.022	0.086	1.000															
Surface	Concrete or Asphalt	-0.069	-0.025	0.015	-0.262	0.099	0.007	-0.050	0.306	-0.113	0.023	0.279	0.037	0.167	-0.233	1.000														
Avg stum	Average Stumbling hazards (mm)	0.013	-0.083	0.147	-0.064	-0.036	0.075	-0.061	0.006	-0.081	0.073	0.251	0.098	-0.036	-0.098	0.047	1.000													
Avg trip	Average trip hazards	-0.005	0.070	0.038	-0.077	-0.085	0.065	-0.118	-0.062	0.072	0.088	0.339	-0.024	0.028	-0.094	0.078	0.447	1.000												
manyutil	How many utilities	0.218	0.195	-0.216	0.556	-0.155	-0.146	-0.022	-0.184	0.048	0.136	-0.085	0.060	0.104	0.470	-0.265	0.140	-0.019	1.000											
manycom	How many comfort features	0.253	0.122	0.013	0.447	-0.097	-0.035	-0.165	-0.147	0.076	0.113	-0.162	0.044	0.063	0.372	-0.251	-0.042	-0.046	0.722	1.000										
numveh (hourly)	Number of adjacent vehicles per hour	-0.034	0.201	-0.251	0.289	-0.277	-0.154	0.394	0.108	0.040	0.258	-0.014	0.000	0.135	0.166	-0.084	-0.092	-0.056	0.260	0.059	1.000									
roadwid	Road width (m)	-0.116	0.008	-0.340	0.288	-0.214	-0.167	0.132	0.071	0.163	-0.074	0.026	0.237	0.429	-0.048	-0.096	-0.110	0.363	0.209	0.447	1.000									
numhveh (hourly)	Number of heavy vehicles per hour	-0.010	0.074	-0.077	0.195	-0.131	-0.037	0.099	-0.018	-0.074	-0.005	0.042	-0.010	0.039	0.074	0.032	-0.012	-0.089	0.228	0.078	0.309	0.092	1.000							
dbnoise	Noise in decibels	-0.150	0.039	-0.191	0.159	-0.244	-0.032	0.318	0.055	0.097	0.132	0.067	0.010	0.068	0.119	0.017	0.032	0.013	0.208	0.114	0.344	0.217	0.146	1.000						
density	People density	0.039	0.129	-0.313	0.645	-0.088	-0.026	0.040	-0.195	0.067	0.032	-0.102	0.294	0.318	-0.110	-0.048	-0.031	0.550	0.422	0.136	0.257	0.214	0.078		1.000					
litter	litter	-0.153	-0.194	-0.026	-0.047	-0.029	0.361	0.072	0.178	0.038	0.143	0.149	-0.107	-0.017	-0.147	0.007	0.151	0.030	-0.070	-0.048	0.008	-0.016	0.021	0.052	0.078	1.000				
deti	detritus	-0.067	-0.208	0.221	-0.213	0.356	0.181	-0.254	0.139	-0.018	-0.056	0.137	0.040	-0.089	-0.231	0.152	0.149	0.062	-0.208	-0.074	0.214	-0.146	-0.143	0.294	0.311	-0.205	1.000			
cloud	weather, cloudy	-0.078	0.203	-0.226	0.261	-0.169	-0.167	0.298	-0.094	0.055	-0.066	-0.090	-0.006	0.069	0.420	-0.149	-0.083	-0.070	0.260	0.208	0.214	0.275	0.096	0.294	0.311	-0.205	-0.300	1.000		
wind	weather, windy	-0.320	0.029	-0.134	-0.081	-0.209	-0.122	0.784	0.180	0.036	0.068	0.008	0.014	0.001	-0.012	0.020	-0.082	-0.091	-0.105	-0.167	0.366	0.120	0.071	0.295	-0.034	-0.026	-0.188	0.322	1.000	
useosp	Use of on-street parking	-0.057	0.054	-0.271	0.248	-0.094	-0.024	0.064	-0.160	-0.019	-0.024	-0.178	-0.011	0.054	0.297	-0.150	-0.050	-0.120	0.221	0.171	0.152	0.246	0.159	0.067	0.297	0.036	-0.056	0.413	0.003	1.000
shared	Shared path	0.288	0.068	0.318	0.131	-0.084	-0.106	-0.040	0.031	0.220	0.102	-0.162	0.133	0.071	0.188	-0.088	-0.052	-0.070	-0.051	-0.040	-0.051	-0.044	-0.002	0.121	0.036	-0.079	0.192			
Avg numob	Average Number of regular obstacles	-0.014	0.083	-0.392	0.361	-0.130	-0.148	0.219	-0.158	-0.013	0.074	-0.013	-0.068	0.290	0.389	-0.102	-0.013	-0.119	0.475	0.25536	0.351	0.334	0.197	0.212	0.476	0.007	-0.190	0.388	0.100	0.371
Avg effw	Average Effective width (M) of regular obstacle	-0.020	0.168	-0.319	0.358	-0.181	-0.194	0.253	-0.100	0.017	0.140	-0.068	-0.017	0.204	0.667	-0.165	-0.117	-0.136	0.451	0.292	0.314	0.360	0.189	0.269	0.284	-0.101	-0.287	0.454	0.182	0.278
Avg eff	Average Effctive width of permanent non regular obstacles	0.013	0.115	-0.241	0.314	-0.169	-0.071	0.114	0.006	0.074	0.072	0.008	0.051	0.070	0.765	-0.197	-0.042	0.040	0.317	0.217	0.075	0.232	0.081	0.152	0.226	-0.041	-0.161	0.421	0.054	0.219
Avg nustep	Average number of steps	-0.053	0.018	-0.044	-0.122	0.126	0.432	-0.184	-0.008	-0.015	-0.015	-0.169	0.000	0.000	-0.126	0.179	-0.095	-0.073	-0.134	-0.086	-0.231	-0.005	-0.078	-0.159	-0.094	0.076	0.145	-0.186	-0.159	0.000
Avg stepav	Combined Average step height	-0.021	0.042	0.050	-0.129	0.209	0.310	-0.207	-0.058	-0.046	-0.058	-0.190	0.000	0.000	-0.160	0.232	-0.088	-0.082	-0.152	-0.097	-0.239	-0.062	-0.028	-0.211	-0.098	0.020	0.121	-0.210	-0.179	0.000
storeysad	Number of storeys	0.088	0.103	-0.254	0.241	0.100	-0.042	-0.070	-0.103	-0.026	-0.036	-0.024	-0.049	0.052	0.315	-0.039	-0.016	-0.054	0.062	0.08552	0.080	0.052	0.016	-0.095	0.252	0.008	0.031	0.218	0.007	0.193
setbackad	Buliding set back from footpath (m)	0.088	-0.060	0.298	-0.170	0.086	-0.016	0.021	0.176	0.009	0.132	0.090	0.096	0.080	-0.200	0.174	-0.006	0.021	-0.213	-0.091	0.033	0.003	-0.098	0.004	-0.187	-0.081	0.136	-0.123	0.032	-0.199
storeysop	Number of storeys	0.011	0.090	-0.137	0.184	-0.002	-0.056	-0.123	-0.041	-0.014	-0.064	-0.054	-0.092	-0.009	0.358	-0.077	0.017	0.015	0.083	0.082	-0.054	0.143	-0.078	-0.103	0.204	-0.034	0.024	0.175	0.000	0.093
setbackop	Buliding setback from footpath (m)	-0.102	-0.116	0.164	-0.220	0.099	0.004	-0.006	0.128	-0.005	-0.018	-0.022	0.000	0.021	0.003	-0.003	0.025	0.010	-0.152	-0.117	-0.096	-0.035	-0.148	-0.019	-0.221	0.006	0.107	-0.052	0.064	-0.188
ddl	Deviation from desire line	-0.015	-0.187	0.216	-0.058	0.116	0.222	-0.135	-0.021	0.016	-0.035	-0.135	0.018	0.007	-0.069	-0.009	0.063	0.041	-0.089	0.09159	-0.186	-0.279	-0.071	-0.072	-0.092	0.105	0.157	-0.134	-0.113	0.082
streetact	Street activity	0.119	0.286	-0.286	0.536	-0.153	-0.223	0.051	-0.331	0.094	0.195	-0.094	0.207	0.219	0.468	-0.361	0.002	-0.005	0.567	0.342	0.256	0.360	0.109	0.144	0.507	-0.040	-0.320	0.435	-0.009	0.298
dirin	Directional information	0.240	0.274	-0.021	0.176	-0.179	0.052	-0.019	-0.137	-0.008	-0.196	0.045	0.113	-0.015	0.217	-0.190	0.055	-0.027	0.181	0.213	-0.124	-0.082	0.054	0.100	0.195	0.045	-0.006	0.236	-0.046	0.128
dese	Design effort	0.340	0.267	0.082	0.404	-0.168	-0.074	0.010		0.183	0.307	-0.066	0.058	0.017	0.412	-0.288	0.062	-0.014	0.443	0.519	0.190	0.233	-0.013	0.048	0.216	-0.059	-0.127	0.251	-0.028	0.218
veranda	Buliding veranda	-0.069	0.128	-0.401	0.375	-0.152	-0.066	0.010	-0.177	0.042	0.061	-0.043	0.086	0.128	0.419	-0.201	-0.016	0.050	0.437	0.15026	0.166	0.281	0.192	0.153	0.319	-0.039	-0.233	0.185	-0.045	0.133
luclass	Land use classification	-0.173	-0.118	-0.201	0.154	-0.092	0.016	-0.026	-0.008	0.110	0.132	-0.099	0.063	0.127	0.325	-0.138	-0.131	-0.018	0.142	0.225	0.015	0.245	0.043	0.074	0.117	0.153	0.086	0.036	-0.079	0.172
pava	Tactile paving or visual aids	0.077	0.073	-0.127	0.372	-0.057	-0.091	0.043	-0.235	0.075	-0.089	-0.130	-0.114	-0.029	0.294	-0.262	-0.094	-0.044	0.380	0.380	-0.041	0.092	-0.035	0.094	0.433	-0.063	-0.127	0.232	0.003	0.125
streetpark	On-street parking available	-0.168	-0.034	-0.080	-0.042	-0.186	-0.082	0.252	0.024	-0.179	0.372	-0.040	0.026	-0.037	-0.093	0.172	0.164	0.097	-0.006	0.228	0.191	0.166	0.190	0.103	0.132	-0.040	0.166	0.224	0.045	
utility	Utility features	0.221	0.161	-0.007	0.298	-0.183	-0.218	0.065	0.002	0.104	0.100	-0.078	0.122	0.084	0.385	-0.227	0.037	-0.074	0.641	0.36903	0.221	0.257	0.074	0.166	0.256	0.053	-0.089	0.262	0.050	0.066
protect	Protection from hazards	0.007	-0.017	0.100	-0.138	0.185	0.278	-0.273	-0.015	0.164	-0.138	-0.132	0.073	-0.047	-0.024	0.021	0.016	0.083	-0.065	-0.032	-0.203	-0.182	-0.043	-0.038	-0.132	0.121	0.183	-0.183	-0.228	0.003
comfort	Comfort features	0.309	0.140	-0.002	0.438	-0.120	-0.046	-0.154	-0.151	0.038	0.111	0.029	0.101	0.086	0.383	-0.167	0.034	-0.003	0.650	0.648	0.114	0.193	0.170	0.075	0.376	0.072	0.090	0.137	-0.128	0.134
cane201	Cane detectable permanent non regular obstacles	-0.069	0.134	-0.299	0.198	-0.228	-0.016	0.222	0.055	-0.023	-0.025	0.091	-0.041	0.088	0.445	-0.181	0.010	0.158	0.242	0.143	0.161	0.221	0.089	0.188	0.245	0.025	-0.150	0.460	0.164	0.248
caned01	Cane detectable regular obstacle	-0.111	0.110	-0.360	0.285	-0.139	-0.204	0.365	-0.103	-0.103	0.035	0.004	-0.074	0.203	0.398	-0.098	-0.136	-0.136	0.337	0.17309	0.318	0.291	0.216	0.221	0.315	-0.040	-0.232	0.503	0.274	0.372
avg obs ewidth	avg obstacle e width	0.167	0.169	-0.338	0.416	-0.103	-0.101	-0.001	-0.160	0.097	0.060	0.074	0.002	0.090	0.577	-0.149	-0.030	0.019	0.447	0.281	0.159	0.210	0.077	0.203	0.333	-0.061	-0.157	0.232	-0.034	0.278
thaz	Temp hazards	-0.040	0.084	-0.131	0.322	-0.025	-0.066	0.139	-0.222	0.047	-0.082	-0.014	-0.108	0.082	0.260	-0.077	0.128	0.102	0.195	0.187	-0.059	0.022	0.011	0.063	0.467	0.013	-0.124	0.253	0.092	0.127
temp	temp	0.161	-0.051	-0.007	-0.242	0.086	0.157	-0.385	0.082	-0.166	-0.167	0.223	-0.116	-0.134	-0.154	0.203	0.074	-0.034	-0.156	-0.071	-0.362	-0.244	0.010	-0.123	-0.098	0.065	0.324	-0.402	-0.348	-0.129
humid	humid	0.027	0.100	0.006	0.285	0.166	-0.136	-0.022	-0.080	0.046	-0.111	-0.146	0.080	0.097	0.298	-0.018	-0.069	0.104	0.290	0.18227	0.199	0.179	0.099	0.114	0.262	-0.107	-0.082	0.521	0.043	0.076
numhide	Number of hiding places	-0.043	0.076	-0.052	-0.101	0.205	-0.033	-0.012	-0.008	-0.069	0.141	0.258	-0.003	-0.015	0.174	-0.020	0.063	0.100	0.059	-0.064	-0.155	-0.046	-0.010	0.080	-0.064	0.133	0.080	0.036	-0.079	-0.039
devi	Deviation around obstacles	-0.232	-0.175	-0.156	0.141	0.154	-0.006	-0.001	-0.078	-0.045	-0.126	0.013	-0.140	0.097	0.188	0.029	-0.027	-0.029	0.146	0.109	0.018	0.007	0.131	0.118	0.343	-0.002	0.064	0.149	-0.139	0.100
wheels	Number of wheeled users	0.099	0.026	0.005	0.229	-0.036	-0.015	0.071	-0.076	0.114	-0.019	-0.052	-0.030	0.085	0.125	0.021	0.067	0.061	0.244	0.299	0.077	0.030	-0.006	0.138	0.379	0.026	-0.012	0.020	0.050	0.081

Correlations: Path Lengths

Code	Description	shared	Avg numob	Avg effw	Avg eff	Avg nustep	Avg stepav	storeysad	setbackad	storeysop	setbackop	ddl	streetact	dirin	dese	veranda	luclass	pava	streetpark	utility	protect	comfort	cane201	caned01	avg obs ewidth	thaz	temp	humid	numhide	devi	wheels
		Shared path	Average Number of regular obstacles	Average Effective width (M) of regular obstacle	Average Effctive width of permanent non regular obstacles	Average number of steps	Combined Average step height	Number of storeys	Buliding set back from footpath (m)	Number of storeys	Building setback from footpath (m)	Deviation from desire line	Street activity	Diectional information	Design effort	Buliding veranda	Land use classification	Tactile paving or visual aids	On-street parking available	Utility features	Protection from hazards	Comfort features	Cane detectable permanent non regular obstacles	Cane detectable regular obstacle	avg obstacle e width	Temp hazards	temp	humid	Number of hiding places	Deviation around obstacles	Number of wheeled users
Avg adj walk	Average adj walkability rating for each section																														
footcon	Footpath condition																														
green	Quantity of greenery																														
peoplenum (hourly)	People flow per hour																														
Adjusted gradient	Downhill gradient assumed to be zero																														
vanda	vandalism																														
weather	Survey weather																														
vspeed	Vehicle speed																														
Avg cfall	Average Crossfall (%)																														
disveh	Distance from moving vehicles (m)																														
vaways	Number of vehicle access ways																														
visacc	Visibility to vehicle access ways																														
useacc	Use of access ways																														
Avg ewidth	Average effective width of path																														
Surface	Concrete or Asphalt																														
Avg stum	Average Stumbling hazards (mm)																														
Avg trip	Average trip hazards																														
manyutil	How many utilities																														
manycom	How many comfort features																														
numveh (hourly)	Number of adjacent vehicles per hour																														
roadwid	Road width (m)																														
numhveh (hourly)	Number of heavy vehicles per hour																														
dbnoise	Noise in decibels																														
density	People density																														
litter	litter																														
deti	detritus																														
cloud	weather, cloudy																														
wind	weather, windy																														
useosp	Use of on-street parking																														
shared	Shared path	1.000																													
Avg numob	Average Number of regular obstacles	-0.038	1.000																												
Avg effw	Average Effective width (M) of regular obstacle	0.049	0.660	1.000																											
Avg eff	Average Effctive width of permanent non regular obstacles	0.166	0.264	0.587	1.000																										
Avg nustep	Average number of steps	-0.057	-0.137	-0.171	-0.135	1.000																									
Avg stepav	Combined Average step height	-0.064	-0.147	-0.193	-0.168	0.883	1.000																								
storeysad	Number of storeys	-0.112	0.205	0.103	0.272	0.053	0.035	1.000																							
setbackad	Buliding set back from footpath (m)	0.053	-0.334	-0.292	-0.197	-0.030	-0.031	-0.023	1.000																						
storeysop	Number of storeys	0.006	0.112	0.158	0.321	0.043	0.019	0.493	-0.133	1.000																					
setbackop	Building setback from footpath (m)	-0.007	-0.152	0.075	0.026	-0.036	-0.035	-0.173	0.346	0.189	1.000																				
ddl	Deviation from desire line	-0.024	-0.134	-0.136	0.008	0.076	0.079	0.133	-0.066	0.108	-0.038	1.000																			
streetact	Street activity	0.052	0.442	0.495	0.453	-0.145	-0.159	0.249	-0.226	0.186	-0.119	-0.119	1.000																		
dirin	Diectional information	0.163	0.022	0.088	0.292	-0.071	-0.053	0.130	-0.080	0.140	-0.139	-0.025	0.216	1.000																	
dese	Design effort	0.261	0.180	0.315	0.316	-0.121	-0.133	0.076	0.005	0.253	0.044	0.486	0.100	0.075	1.000																
veranda	Buliding veranda	-0.124	0.258	0.340	0.371	-0.053	-0.093	0.152	-0.279	0.085	-0.105	-0.091	0.553	0.100	0.075	1.000															
luclass	Land use classification	0.002	0.146	0.163	0.178	-0.005	-0.081	0.259	-0.004	0.153	-0.084	0.013	0.242	0.157	0.252	0.157	1.000														
pava	Tactile paving or visual aids	0.092	0.154	0.283	0.246	-0.047	-0.053	0.076	-0.158	0.181	-0.148	-0.038	0.335	0.232	0.241	0.133	0.011	1.000													
streetpark	On-street parking available	-0.158	0.297	0.206	0.037	-0.337	-0.372	-0.059	-0.096	-0.072	-0.134	-0.194	0.133	-0.093	0.001	0.093	-0.012	-0.022	1.000												
utility	Utility features	0.177	0.326	0.332	0.282	-0.227	-0.256	0.079	-0.117	0.168	0.010	-0.035	0.452	0.233	0.371	0.262	0.144	0.137	0.034	1.000											
protect	Protection from hazards	-0.036	-0.280	-0.176	0.014	0.273	0.300	-0.069	-0.048	-0.058	0.030	0.312	0.004	-0.038	0.004	0.041	-0.009	-0.032	-0.356	-0.050	1.000										
comfort	Comfort features	0.161	0.255	0.225	0.245	-0.145	-0.164	0.160	-0.153	0.148	-0.194	0.026	0.332	0.216	0.458	0.206	0.206	0.175	0.080	0.555	0.016	1.000									
cane201	Cane detectable permanent non regular obstacles	0.033	0.267	0.355	0.763	-0.162	-0.206	0.255	-0.191	0.239	-0.184	-0.018	0.390	0.376	0.154	0.276	0.172	0.161	0.221	0.261	-0.094	0.246	1.000								
caned01	Cane detectable regular obstacle	-0.067	0.773	0.790	0.385	-0.173	-0.188	0.210	-0.320	0.081	-0.134	-0.154	0.408	0.105	0.104	0.231	0.131	0.213	0.374	0.262	-0.326	0.129	0.411	1.000							
avg obs ewidth	avg obstacle e width	-0.015	0.466	0.573	0.522	-0.125	-0.156	0.038	-0.257	0.101	-0.066	-0.120	0.398	0.056	0.338	0.051	0.255	-0.059	0.240	0.327	0.435	0.056	0.338	0.340	1.000						
thaz	Temp hazards	0.020	0.244	0.325	0.306	-0.074	-0.083	0.091	-0.175	0.142	-0.022	-0.048	0.305	0.098	0.167	0.179	0.023	0.430	0.018	0.023	0.178	0.241	0.340	0.043	0.178	1.000					
temp	temp	-0.031	-0.174	-0.245	-0.196	0.213	0.208	0.008	-0.026	0.010	-0.027	0.116	-0.316	0.033	-0.278	-0.109	-0.055	-0.111	-0.203	-0.220	0.089	0.002	-0.220	-0.250	-0.053	-0.100	1.000				
humid	humid	0.029	0.227	0.228	0.299	-0.173	-0.132	0.196	-0.052	0.186	-0.001	-0.058	0.226	0.094	0.109	0.186	-0.020	0.079	0.041	0.333	0.065	0.255	0.289	0.225	0.150	0.130	-0.501	1.000			
numhide	Number of hiding places	-0.078	0.035	0.273	0.260	-0.013	-0.027	-0.009	-0.080	0.031	0.173	-0.052	0.084	-0.040	0.086	0.154	-0.043	0.039	0.058	0.007	0.094	0.015	-0.010	0.102	0.197	0.161	0.058	-0.066	1.000		
devi	Deviation around obstacles	-0.088	0.296	0.196	0.197	-0.079	-0.089	0.134	-0.065	0.061	0.010	-0.058	0.132	0.030	-0.045	0.238	0.100	0.067	0.070	-0.001	-0.075	0.081	0.155	0.214	0.229	0.294	0.134	0.147	-0.012	1.000	
wheels	Number of wheeled users	0.064	0.238	0.133	-0.021	-0.078	-0.088	0.021	0.006	0.054	-0.067	-0.061	0.044	0.052	0.225	0.035	0.170	0.234	0.058	0.166	0.057	0.196	-0.062	0.101	0.172	0.215	-0.187	0.147	-0.116	0.073	1.000

Table D2   Correlations: road crossings

Correlations: Road Crossings		Avg adj walk	crossct	vspeed	vis tra	footcon	dbnoise	Avgiwid	Kerb cutdown	crosdi	rist	traffic	peoplenum	density	pospeed	rdcon	Avg stum	Avg trip	croscyc	manucom	weather	cloud	wind
		Average adj walkability rating for each section	Crossing control type	Vehicle speed	Visibility to traffic	Footpath condition	Noise in decibels	Average island eff width	Entry OR exit kerb dropped?	Crossing length distance (m)	Refuge island	Volume of traffic	People flow (during crossing time)	People density	Posted speed limit	Road condition	Average Stumbling hazards (mm)	Avg Trip hazards	Number of cycle lanes to cross	How many comfort features	Survey weather	weather, cloudy	weather, windy
Avg adj walk	Average adj walkability rating for each section	1.000																					
crossct	Crossing control type	-0.492	1.000																				
vspeed	Vehicle speed	-0.292	-0.022	1.000																			
vis tra	Visibility to traffic	0.356	-0.229	-0.109	1.000																		
footcon	Footpath condition	0.330	-0.249	-0.011	0.017	1.000																	
dbnoise	Noise in decibels	0.071	-0.315	-0.060	0.279	0.076	1.000																
Avgiwid	Average island eff width	0.128	0.079	-0.160	0.014	-0.062	0.097	1.000															
Kerb cutdown	Entry OR exit kerb dropped?	0.167	-0.163	-0.134	0.256	0.033	0.060	0.037	1.000														
crosdi	Crossing length distance (m)	0.078	-0.264	0.140	0.094	0.030	0.158	0.020	0.073	1.000													
rist	Refuge island	0.058	0.140	-0.105	-0.029	-0.045	0.078	0.786	-0.018	0.002	1.000												
traffic	Volume of traffic	-0.085	-0.070	-0.073	0.278	0.108	0.402	0.269	-0.002	0.158	0.209	1.000											
peoplenum	People flow (during crossing time)	0.225	-0.264	0.131	0.129	0.105	0.142	-0.038	-0.038	0.023	-0.060	-0.032	1.000										
density	People density	0.227	-0.225	0.060	0.135	0.110	0.163	0.065	-0.094	-0.015	0.021	0.173	0.790	1.000									
pospeed	Posted speed limit	-0.125	0.034	0.149	-0.040	-0.042	-0.003	0.021	-0.035	0.047	0.027	#DIV/0!	-0.045	0.032	1.000								
rdcon	Road condition	0.256	-0.206	-0.077	0.222	0.306	0.131	0.055	-0.045	0.094	0.048	0.219	0.126	0.143	-0.033	1.000							
Avg stum	Average Stumbling hazards (mm)	-0.015	-0.008	0.040	0.021	0.034	-0.019	0.006	0.117	-0.011	-0.010	-0.041	0.118	0.034	0.024	0.048	1.000						
Avg trip	Avg Trip hazards	-0.074	-0.015	0.010	-0.142	-0.021	0.147	-0.004	-0.037	-0.008	0.017	-0.002	0.076	0.071	0.021	-0.060	0.084	1.000					
croscyc	Number of cycle lanes to cross	0.069	-0.357	0.160	0.124	0.129	0.120	-0.078	0.132	0.328	-0.099	0.178	0.070	0.097	0.027	0.043	0.133	0.086	1.000				
manucom	How many comfort features	0.097	0.073	-0.220	0.042	0.070	0.054	0.159	0.059	-0.028	0.083	0.256	-0.062	0.122	0.012	0.055	-0.003	-0.006	-0.017	1.000			
weather	Survey weather	0.006	-0.156	0.124	0.218	-0.148	0.263	-0.021	0.204	0.139	-0.070	0.200	-0.092	-0.118	-0.096	0.096	-0.117	0.141	0.270	-0.114	1.000		
cloud	weather, cloudy	0.303	-0.531	-0.137	0.153	0.166	0.304	-0.036	0.316	0.191	-0.144	-0.015	0.182	0.073	-0.089	0.083	0.295	0.044	0.245	0.048	0.165	1.000	
wind	weather, windy	0.056	-0.197	0.216	0.224	-0.004	0.235	-0.062	0.228	0.184	-0.074	0.106	-0.081	-0.172	-0.113	0.118	-0.142	0.000	0.241	-0.109	0.785	0.149	1.000
tpva	Tactile paving or visual aids	0.277	-0.298	-0.380	0.146	0.203	0.168	0.115	0.087	-0.025	0.131	0.168	0.155	0.192	-0.155	0.074	-0.109	-0.138	-0.043	0.226	-0.282	0.190	-0.232
ddl	Deviation from desire line	-0.028	0.086	0.021	-0.074	0.061	-0.038	0.293	-0.057	0.031	0.301	-0.025	-0.063	-0.055	0.013	0.053	0.254	-0.036	-0.043	-0.021	-0.120	0.057	-0.101
litter	litter	-0.199	0.170	0.168	-0.003	-0.201	-0.030	-0.057	0.002	0.001	-0.072	-0.197	-0.100	-0.087	0.020	-0.093	-0.066	-0.057	-0.074	-0.033	0.126	-0.224	0.100
deti	detritus	-0.045	0.204	0.032	-0.112	-0.143	-0.286	-0.054	-0.346	-0.087	-0.037	-0.301	-0.068	-0.032	0.036	-0.162	-0.119	-0.102	-0.134	-0.060	-0.191	-0.247	-0.182
vanda	vandalism	0.000	0.056	-0.135	0.071	-0.308	0.008	0.147	-0.078	-0.001	0.133	0.135	-0.066	-0.057	0.013	0.055	-0.043	-0.037	-0.049	-0.022	0.070	-0.148	-0.008
ekerbf	Entry kerb: Footpath gradient	-0.137	0.256	0.032	0.048	-0.054	-0.041	0.128	-0.060	-0.074	0.158	-0.093	0.041	-0.011	-0.110	-0.109	-0.028	-0.035	-0.184	-0.069	-0.107	-0.203	-0.115
exitf	Exit kerb: footpath gradient	-0.082	0.219	-0.021	-0.061	-0.091	-0.027	0.087	-0.136	-0.068	0.088	0.022	0.050	0.057	-0.079	-0.102	-0.052	0.045	-0.235	0.028	-0.110	-0.155	-0.117
ekerbr	Entry kerb: road gradient	-0.130	0.112	0.134	-0.175	-0.013	-0.258	-0.056	-0.085	0.014	0.000	0.158	-0.173	-0.122	0.091	0.134	-0.098	0.079	-0.068	0.023	-0.014	-0.273	0.016
exitr	Exit kerb: road gradient	0.029	0.010	0.022	-0.055	-0.015	-0.040	-0.109	-0.269	-0.049	-0.078	0.032	-0.221	-0.143	0.075	0.158	-0.084	-0.025	0.020	0.02003	0.007	-0.169	-0.001
kerbwid	Kerb: effective width	0.099	0.009	-0.170	-0.004	-0.011	-0.023	-0.032	-0.037	-0.079	-0.093	-0.007	0.137	0.172	-0.168	0.109	0.110	-0.007	-0.010	0.248	-0.155	0.085	-0.109
kerbcross	Kerb: crossfall	0.073	-0.082	0.031	0.145	0.025	-0.010	0.035	-0.147	0.047	0.094	-0.125	0.160	0.019	-0.064	0.088	0.160	0.068	0.153	-0.074	0.030	0.101	0.081
kerb2wid	Kerb: effective width	0.105	0.025	-0.027	0.056	0.062	0.032	-0.016	-0.235	-0.053	-0.036	0.002	0.418	0.471	-0.090	0.078	0.003	-0.009	-0.027	0.120	-0.122	0.153	-0.086
kerb2cross	Kerb: crossfall	-0.092	0.052	0.016	-0.017	0.083	-0.091	-0.096	-0.159	-0.050	-0.071	-0.030	0.096	-0.006	-0.149	0.012	0.195	0.035	0.116	-0.051	-0.049	0.113	-0.047
crostr	Number of traffic lanes to cross	0.288	-0.701	0.134	0.166	0.141	0.244	-0.039	0.151	0.338	-0.062	traffic	0.317	0.174	0.041	0.179	0.013	-0.009	0.105	-0.0527	-0.021	0.398	0.092
pocrosdi	Possible crossing width distance	0.040	0.248	-0.087	0.028	-0.008	-0.061	0.004	-0.157	-0.152	0.141	-0.110	0.032	0.116	-0.134	0.039	0.026	-0.003	-0.151	0.007	-0.132	-0.145	-0.114
dese	Design effort	0.192	-0.115	-0.269	0.111	0.117	0.023	0.033	0.019	-0.073	0.118	0.325	0.319	0.439	-0.216	0.148	0.029	0.057	0.083	0.339	-0.205	0.097	-0.201
luclass	Land use classification	0.090	-0.164	-0.147	0.093	-0.045	0.145	-0.083	-0.082	-0.065	-0.139	0.255	0.206	-0.033	-0.014	0.062	0.008	-0.029	0.047	-0.083	0.184	-0.141	
refuge	Type of refuge island	0.050	0.142	-0.062	0.015	-0.019	0.060	0.743	0.019	0.012	0.954	0.149	-0.061	0.020	0.027	0.042	0.028	0.016	-0.100	0.082	-0.093	-0.094	-0.098
oddir	Odd vehicle approach direction	0.172	-0.267	0.063	0.137	0.094	0.171	-0.073	0.047	0.290	-0.092	0.229	0.076	0.088	0.026	0.040	-0.004	-0.034	0.333	-0.043	0.220	0.251	0.221
comfea	Comfort features	0.048	0.073	-0.219	-0.023	0.107	-0.019	0.187	0.091	-0.018	0.185	0.435	-0.091	0.070	0.019	0.079	0.131	0.093	0.075	0.672	-0.121	0.010	-0.159
hazp	Protection from permanent hazards	0.122	0.047	-0.203	0.130	0.084	0.096	0.129	0.037	-0.012	0.310	0.191	0.039	0.133	0.024	0.107	0.005	-0.068	-0.090	0.291	-0.195	-0.046	-0.154
thaz	Temp hazards	0.072	-0.043	-0.015	-0.006	-0.009	-0.011	-0.041	0.069	-0.056	-0.053	-0.200	0.119	0.209	0.016	0.071	0.105	-0.045	0.045	-0.027	0.150	0.083	0.077
temp	temp	-0.150	0.222	0.040	-0.183	-0.281	-0.144	-0.037	-0.125	-0.162	0.011	-0.200	-0.052	-0.054	0.089	-0.155	-0.161	-0.006	-0.223	-0.118	-0.266	-0.330	-0.331
humid	humid	0.338	-0.360	-0.090	0.133	0.280	0.171	0.120	0.122	0.183	0.013	0.008	0.152	0.104	0.009	0.149	-0.041	-0.027	-0.046	0.020	-0.116	0.505	-0.066

Note: Cells that display #Div/0! mean there was no variation (and hence correlation) between variables

Correlations: Road Crossings

code	description	tpva	ddl	litter	deti	vanda	ekerbf	exitf	ekerbr	exitr	kerbwid	kerbcross	kerb2wid	kerb2cross	crostr	pocrosdi	dese	luclass	refuge	oddir	comfea	hazp	thaz	temp	humid
		Tactile paving or visual aids	Deviation from desire line	litter	detritus	vandalism	Entry kerb: Footpath gradient	Exit kerb: footpath gradient	Entry kerb: road gradient	Exit kerb: road gradient	Kerb: effective width	Kerb: crossfall	Kerb: effective width	Kerb: crossfall	Number of traffic lanes to cross	Possible crossing width distance	Design effort	Land use classification	Type of refuge island	Odd vehicle approach direction	Comfort features	Protection from permanent hazards	Temp hazards	temp	humid
Avg adj walk	Average adj walkability rating for each section																								
crossct	Crossing control type																								
vspeed	Vehicle speed																								
vis tra	Visibility to traffic																								
footcon	Footpath condition																								
dbnoise	Noise in decibels																								
Avgiwid	Average island eff width																								
Kerb cutdown	Entry OR exit kerb dropped?																								
crosdi	Crossing length distance (m)																								
rist	Refuge island																								
traffic	Volume of traffic																								
peoplenum	People flow (during crossing time)																								
density	People density																								
pospeed	Posted speed limit																								
rdcon	Road condition																								
Avg stum	Average Stumbling hazards (mm)																								
Avg trip	Avg Trip hazards																								
croscyc	Number of cycle lanes to cross																								
manucom	How many comfort features																								
weather	Survey weather																								
cloud	weather, cloudy																								
wind	weather, windy																								
tpva	Tactile paving or visual aids	1.000																							
ddl	Deviation from desire line	-0.044	1.000																						
litter	litter	-0.053	-0.029	1.000																					
deti	detritus	-0.199	-0.051	0.081	1.000																				
vanda	vandalism	-0.058	0.003	0.191	0.204	1.000																			
ekerbf	Entry kerb: Footpath gradient	0.012	-0.015	0.031	0.151	0.012	1.000																		
exitf	Exit kerb: footpath gradient	0.096	-0.028	0.136	0.093	0.120	0.424	1.000																	
ekerbr	Entry kerb: road gradient	-0.142	-0.112	0.045	0.180	-0.144	-0.105	-0.095	1.000																
exitr	Exit kerb: road gradient	-0.017	0.010	0.056	-0.021	-0.002	-0.299	-0.138	0.196	1.000															
kerbwid	Kerb: effective width	0.096	0.000	-0.008	0.117	0.145	0.096	0.236	-0.178	-0.140	1.000														
kerbcross	Kerb: crossfall	-0.103	0.028	-0.042	0.097	0.074	0.359	0.088	-0.182	-0.164	0.185	1.000													
kerb2wid	Kerb: effective width	0.064	0.003	-0.073	0.142	0.011	0.114	0.195	-0.153	-0.177	0.422	0.108	1.000												
kerb2cross	Kerb: crossfall	-0.034	0.089	-0.090	-0.149	-0.055	0.131	0.341	-0.244	-0.081	0.230	0.348	0.198	1.000											
crostr	Number of traffic lanes to cross	0.276	0.052	-0.111	-0.229	-0.073	-0.152	-0.150	0.002	-0.076	-0.017	0.030	0.000	-0.067	1.000										
pocrosdi	Possible crossing width distance	-0.008	-0.009	0.000	0.250	-0.011	0.136	0.128	0.000	-0.008	0.536	0.035	0.299	0.095	-0.238	1.000									
dese	Design effort	0.224	-0.034	-0.114	-0.033	0.044	-0.048	0.002	-0.025	-0.085	0.284	0.124	0.332	0.128	0.091	0.228	1.000								
luclass	Land use classification	0.160	-0.062	0.112	0.030	-0.037	0.029	0.162	-0.258	-0.154	0.168	0.219	0.248	0.134	0.031	0.139	0.321	1.000							
refuge	Type of refuge island	0.099	0.406	-0.062	-0.061	0.044	0.121	0.065	-0.012	-0.074	-0.082	0.093	-0.039	0.005	-0.035	0.141	0.096	-0.106	1.000						
oddir	Odd vehicle approach direction	-0.085	-0.044	-0.069	-0.028	-0.046	-0.120	-0.113	-0.046	0.004	0.139	0.036	0.058	0.020	0.126	0.102	0.029	-0.001	-0.093	1.000					
comfea	Comfort features	0.215	-0.032	-0.051	-0.092	-0.033	-0.098	0.039	0.044	-0.011	0.167	-0.045	0.045	-0.009	-0.058	-0.007	0.424	0.039	0.184	-0.065	1.000				
hazp	Protection from permanent hazards	0.307	0.275	-0.065	0.033	0.149	0.104	0.184	-0.066	-0.012	0.234	0.010	0.146	-0.005	0.022	0.353	0.392	0.091	0.310	0.020	0.213	1.000			
thaz	Temp hazards	0.022	-0.024	0.076	0.016	-0.028	-0.150	-0.065	0.016	-0.033	0.092	0.069	0.044	0.051	-0.086	0.062	0.119	0.019	-0.056	0.137	-0.041	-0.052	1.000		
temp	temp	-0.057	-0.066	0.074	0.078	0.064	0.091	0.117	0.093	0.108	0.023	-0.253	-0.133	-0.149	-0.063	0.000	-0.238	-0.233	0.006	-0.165	-0.175	-0.161	-0.138	1.000	
humid	humid	0.297	-0.043	-0.250	0.059	-0.154	0.016	-0.030	-0.109	-0.132	0.005	0.043	0.112	-0.100	0.292	0.068	-0.016	0.115	0.032	0.025	-0.001	0.097	-0.044	-0.341	1.000

Appendix E   Walkability adjustment

The adjusted walkability rating was calculated by using the following formula:

Adjusted walkability = (Raw walkability) – (Average walkability rating from a given participant for a given site) + (Average walkability rating from the common participant for that site)

Minitab worksheet structure:

- c18 has raw walkability measurements.

- c19 has the mean for a given participant in a given site (calculated using the macro given below).

- c20 has the mean for the common participant (participant 86) at each site.

Minitab macro:

```
gmacro

adjust

let k90 = count(c18)

Set C19

1( 1 : 1 / 1 )k90

End.

let c19 = c19-c19

do k1 = 6:50

do k2 = 11:112

let k3 = mean(((c4 = k1)and(c7 = k2))*c18)

let k4 = sum((c4 = k1)and(c7 = k2))

if (sum((c4 = k1)and(c7 = k2))>0)

let c19 = (k3*k90/k4)*((c4 = k1)and(c7 = k2))+c19

endif

enddo

enddo

endmacro
```

Appendix F   Model results

Figure F1   **Model: 'path length' – overall**

Alpha-to-Enter: 0.05 Alpha-to-Remove: 0.05

Response is Avg adj walk on 18 predictors, with N = 163

Step	1	2	3	4	5	6	7	8	9	10	11	12
Constan	5.231	5.456	5.472	5.345	5.067	4.906	4.597	4.527	3.227	3.128	2.984	2.996
footcon	0.733	0.748	0.759	0.711	0.657	0.641	0.582	0.58	0.576	0.581	0.594	0.561
T-Value	6.74	7.4	7.87	7.55	7.02	6.95	6.27	6.33	6.4	6.54	6.77	6.35
P-Value	0	0	0	0	0	0	0	0	0	0	0	0
wind		-0.71	-0.63	-0.57	-0.63	-0.65	-0.68	-0.63	-0.51	-0.51	-0.55	-0.54
T-Value		-5.15	-4.81	-4.46	-4.97	-5.2	-5.56	-5.12	-3.9	-3.99	-4.32	-4.29
P-Value		0	0	0	0	0	0	0	0	0	0	0
green			0.322	0.326	0.284	0.206	0.278	0.292	0.337	0.337	0.337	0.3
T-Value			4.13	4.32	3.8	2.59	3.39	3.59	4.12	4.18	4.25	3.71
P-Value			0	0	0	0.01	0.001	0	0	0	0	0
comfort				0.49	0.53	0.62	0.52	0.49	0.46	0.45	0.4	0.29
T-Value				3.47	3.82	4.41	3.62	3.47	3.31	3.27	2.87	2.01
P-Value				0.001	0	0	0	0.001	0.001	0.001	0.005	0.046
devi					-0.38	-0.35	-0.39	-0.4	-0.44	-0.45	-0.48	-0.46
T-Value					-3	-2.82	-3.23	-3.29	-3.68	-3.82	-4.1	-4
P-Value					0.003	0.005	0.002	0.001	0	0	0	0
pa+res						0.34	0.41	0.41	0.36	0.38	0.39	0.41
T-Value						2.62	3.17	3.26	2.83	3.04	3.17	3.37
P-Value						0.01	0.002	0.001	0.005	0.003	0.002	0.001
Min ewidth							0.153	0.141	0.174	0.198	0.195	0.17
T-Value							2.73	2.54	3.11	3.52	3.52	3.02
P-Value							0.007	0.012	0.002	0.001	0.001	0.003
vspeed								-0.34	-0.4	-0.39	-0.43	-0.38
T-Value								-2.26	-2.64	-2.67	-2.91	-2.58
P-Value								0.025	0.009	0.008	0.004	0.011
temp									0.047	0.05	0.057	0.065
T-Value									2.59	2.82	3.2	3.59
P-Value									0.01	0.006	0.002	0
numhide										-0.168	-0.175	-0.186
T-Value										-2.27	-2.4	-2.56
P-Value										0.025	0.018	0.012
Avg stepav											-0.0035	-0.0034
T-Value											-2.36	-2.3
P-Value											0.019	0.023
dese												0.201
T-Value												2.03
P-Value												0.044
S	0.888	0.825	0.786	0.76	0.742	0.728	0.714	0.704	0.692	0.682	0.672	0.666
R-Sq	22	33.1	39.57	43.86	46.91	49.14	51.47	53.03	55	56.47	58.03	59.15
R-Sq(ad	21.51	32.26	38.43	42.44	45.22	47.19	49.28	50.59	52.36	53.61	54.97	55.88
Mallows	139.4	98.9	76.2	61.8	52.1	45.6	38.7	34.7	29.1	25.5	21.6	19.3

Figure F2   Model: 'path length' – young and mature adult participants (18–59 years)

Alpha-to-Enter: 0.05 Alpha-to-Remove: 0.05

Response is Avg adj walk_A4 on 12 predictors, with N = 163

Step	1	2	3	4	5	6	7	8	9	10	11
Constant	5.235	5.453	5.468	5.347	5.092	4.982	4.816	4.532	3.144	3.157	3.065
footcon	0.717	0.732	0.742	0.697	0.648	0.641	0.624	0.568	0.563	0.529	0.531
T-Value	6.73	7.37	7.79	7.47	6.95	7.02	6.96	6.29	6.37	5.95	6.04
P-Value	0	0	0	0	0	0	0	0	0	0	0
wind		-0.68	-0.62	-0.56	-0.61	-0.55	-0.57	-0.6	-0.47	-0.46	-0.47
T-Value		-5.07	-4.72	-4.38	-4.83	-4.36	-4.58	-4.94	-3.67	-3.64	-3.71
P-Value		0	0	0	0	0	0	0	0	0	0
green			0.301	0.305	0.267	0.295	0.217	0.284	0.331	0.293	0.29
T-Value			3.91	4.08	3.58	4.01	2.79	3.54	4.13	3.59	3.59
P-Value			0	0	0	0	0.006	0.001	0	0	0
comfort				0.47	0.5	0.46	0.55	0.45	0.42	0.31	0.29
T-Value				3.32	3.63	3.34	3.95	3.22	3.04	2.14	2.04
P-Value				0.001	0	0.001	0	0.002	0.003	0.034	0.043
devi					-0.34	-0.35	-0.33	-0.37	-0.42	-0.4	-0.41
T-Value					-2.76	-2.9	-2.72	-3.11	-3.53	-3.43	-3.55
P-Value					0.006	0.004	0.007	0.002	0.001	0.001	0.001
vspeed						-0.43	-0.45	-0.41	-0.47	-0.42	-0.42
T-Value						-2.78	-2.94	-2.74	-3.18	-2.85	-2.85
P-Value						0.006	0.004	0.007	0.002	0.005	0.005
pa+res							0.34	0.4	0.35	0.37	0.39
T-Value							2.7	3.23	2.77	2.97	3.19
P-Value							0.008	0.002	0.006	0.003	0.002
Min ewidth								0.145	0.181	0.153	0.173
T-Value								2.66	3.28	2.73	3.09
P-Value								0.009	0.001	0.007	0.002
temp									0.05	0.058	0.062
T-Value									2.82	3.23	3.47
P-Value									0.005	0.002	0.001
dese										0.207	0.222
T-Value										2.07	2.25
P-Value										0.04	0.026
numhide											-0.159
T-Value											-2.2
P-Value											0.03
S	0.87	0.81	0.776	0.753	0.738	0.722	0.708	0.695	0.68	0.672	0.664
R-Sq	21.94	32.74	38.63	42.64	45.3	47.89	50.23	52.41	54.76	56	57.36
R-Sq(adj)	21.45	31.9	37.47	41.19	43.56	45.89	47.98	49.94	52.1	53.1	54.25
Mallows C	121.5	84.7	65.5	53.1	45.5	38.2	31.8	26	19.6	17.1	14.2

Figure F3   Model: 'path length', elderly participants (aged 60 or older)

Alpha-to- Enter: 0		.05 A	lpha-to-	Remove:		0.05			
Response Avg adj		walk_	A5 on 12	predic	tors,	with N = 163			
Step	1	2	3	4	5	6	7	8	9
Constant	5.201	5.456	5.474	5.316	5.025	5.098	5.021	4.707	4.757
footcon	0.79	0.81	0.82	0.76	0.73	0.75	0.74	0.68	0.7
T-Value	5.27	5.64	5.89	5.54	5.39	5.65	5.53	5.07	5.24
P-Value	0	0	0	0	0	0	0	0	0
wind		-0.8	-0.72	-0.64	-0.68	-0.7	-0.75	-0.81	-0.89
T-Value		-4.1	-3.75	-3.41	-3.69	-3.82	-4.12	-4.5	-4.89
P-Value		0	0	0.001	0	0	0	0	0
green			0.36	0.37	0.23	0.21			
T-Value			3.19	3.31	1.99	1.83			
P-Value			0.002	0.001	0.048	0.07			
comfort				0.61	0.76	0.77	0.8	0.83	0.76
T-Value				2.93	3.61	3.72	3.87	4.08	3.7
P-Value				0.004	0	0	0	0	0
pa+res					0.54	0.57	0.71	0.64	0.67
T-Value					2.82	3.04	4.07	3.7	3.88
P-Value					0.005	0.003	0	0	0
numhide						-0.29	-0.31	-0.31	-0.32
T-Value						-2.58	-2.7	-2.74	-2.85
P-Value						0.011	0.008	0.007	0.005
devi								-0.48	-0.51
T-Value								-2.68	-2.87
P-Value								0.008	0.005
Avg stepav									-0.0047
T-Value									-2.08
P-Value									0.039
S	1.23	1.17	1.14	1.11	1.09	1.07	1.08	1.06	1.05
R-Sq	14.73	22.84	27.47	31.2	34.52	37.2	35.86	38.68	40.34
R-Sq(adj)	14.2	21.87	26.1	29.46	32.44	34.79	33.81	36.32	37.65
Mallows C	66.3	46.8	36.6	28.7	22	16.9	18.4	13	10.6

Figure F4   Model: 'path length', 'environment variables', 'safe from falling'

Alpha-to-Enter: 0.05 Alpha-to-Remove: 0.05					
Response is avg safefall on 12 predictors, with N = 163					
Step	1	2	3	4	5
Constant	5.658	5.703	5.872	5.933	5.761
footcon	0.616	0.629	0.554	0.566	0.537
T-Value	6.77	7.17	6.23	6.44	6.08
P-Value	0	0	0	0	0
Avg stepav		-0.0054	-0.0047	-0.0048	-0.005
T-Value		-3.64	-3.24	-3.33	-3.53
P-Value		0	0.001	0.001	0.001
dese			0.259	0.272	0.27
T-Value			3.07	3.26	3.27
P-Value			0.003	0.001	0.001
numhide				-0.174	-0.174
T-Value				-2.38	-2.4
P-Value				0.019	0.017
devi					-0.23
T-Value					-2.06
P-Value					0.041
S	0.743	0.716	0.698	0.688	0.681
R-Sq	22.14	28.11	32.13	34.48	36.19
R-Sq(adj)	21.66	27.21	30.85	32.82	34.16
Mallows C-p	41	27.7	19.4	15.3	12.9

Figure F5   Model: 'path length', 'environment variables' – pleasant

Alpha-to-Enter: 0.05 Alpha-to-Remove: 0.05

Response is avg pleasant on 12 predictors, with N = 163

Step	1	2	3	4	5	6	7	8	9
Constant	4.425	4.715	4.325	4.317	4.045	3.837	2.328	1.617	1.059
dese	0.85	0.83	0.69	0.65	0.48	0.4	0.5	0.4	0.38
T-Value	6.26	6.55	5.51	5.36	3.6	3.02	3.65	2.93	2.83
P-Value	0	0	0	0	0	0.003	0	0.004	0.005
wind		-0.9	-0.93	-0.85	-0.78	-0.69	-0.53	-0.53	-0.57
T-Value		-4.93	-5.34	-5.03	-4.69	-4.15	-3.01	-3.06	-3.36
P-Value		0	0	0	0	0	0.003	0.003	0.001
footcon			0.56	0.58	0.57	0.58	0.57	0.53	0.47
T-Value			4.22	4.53	4.58	4.75	4.74	4.44	3.89
P-Value			0	0	0	0	0	0	0
green				0.349	0.367	0.413	0.423	0.565	0.547
T-Value				3.47	3.74	4.24	4.41	5.31	5.23
P-Value				0.001	0	0	0	0	0
comfort					0.61	0.6	0.54	0.44	0.46
T-Value					2.98	2.98	2.74	2.2	2.36
P-Value					0.003	0.003	0.007	0.029	0.019
vspeed						-0.6	-0.65	-0.64	-0.66
T-Value						-2.85	-3.13	-3.13	-3.28
P-Value						0.005	0.002	0.002	0.001
temp							0.06	0.072	0.078
T-Value							2.44	2.93	3.25
P-Value							0.016	0.004	0.001
Min ewidth								0.212	0.248
T-Value								2.82	3.3
P-Value								0.005	0.001
devi									-0.41
T-Value									-2.58
P-Value									0.011
S	1.17	1.1	1.04	1.01	0.984	0.962	0.947	0.927	0.91
R-Sq	19.57	30.19	37.23	41.68	44.81	47.53	49.47	51.96	53.95
R-Sq(adj)	19.07	29.32	36.04	40.2	43.05	45.51	47.19	49.46	51.25
Mallows C-p	110.5	76.9	55.3	42.4	33.9	26.8	22.3	16	11.3

Figure F6   Model: road crossing – zebra crossings

Delay introduced artifically:

```
   Alpha-to-Enter: 0.05  Alpha-to-Remove: 0.05


Response is Avg adj walk on 11 predictors, with N = 13


Step                 1        2        3
Constant         5.000    5.577    5.424

rdcon             1.41     1.69     1.46
T-Value           2.89     4.40     4.44
P-Value          0.015    0.001    0.002

crosdi                   -0.072   -0.053
T-Value                   -2.99    -2.48
P-Value                   0.013    0.035

tpva                               0.47
T-Value                            2.42
P-Value                            0.039

S                0.470    0.358    0.294
R-Sq             43.13    70.01    81.83
R-Sq(adj)        37.96    64.01    75.77
Mallows C-p     2727.6   1436.2    869.5
```

Final model:

The regression equation is
Avg adj walk = 5.51 + 1.40 rdcon + 0.477 tpva - 0.0517 crosdi - 0.0104 delay

S = 0.310640   R-Sq = 81.9%   R-Sq(adj) = 72.9%

Figure F7   Model: road crossing – uncontrolled crossings

Alpha-to-Enter: 0.05 Alpha-to-Remove: 0.05

Response is Avg adj walk on 10 predictors, with N = 86

Step	1	2	3	4	5	6
Constant	4.571	4.268	4.745	4.416	4.441	5.061
vspeed	-1.15	-1.05	-1.03	-1.01	-1	-0.82
T-Value	-4.06	-3.88	-4.15	-4.24	-4.28	-3.37
P-Value	0	0	0	0	0	0.001
vis tra		0.52	0.6	0.61	0.6	0.64
T-Value		3.31	4.08	4.34	4.34	4.71
P-Value		0.001	0	0	0	0
delay			-0.084	-0.078	-0.088	-0.091
T-Value			-3.89	-3.77	-4.22	-4.45
P-Value			0	0	0	0
footcon				0.45	0.42	0.38
T-Value				2.97	2.81	2.55
P-Value				0.004	0.006	0.013
rist					0.63	0.71
T-Value					2.08	2.37
P-Value					0.041	0.02
crosdi						-0.05
T-Value						-2.18
P-Value						0.032
S	1.02	0.96	0.887	0.848	0.831	0.812
R-Sq	16.4	26.15	37.68	43.79	46.67	49.71
R-Sq(adj)	15.4	24.37	35.4	41.01	43.34	45.89
Mallows	43	30.4	15.2	8	5.7	3.2

Appendix G Contributions to overall walkability score, by variable

The following tables describe various scenarios along with the associated model variable values and predicted walkability ratings for each.

The scenarios describe the effects of changes in one or more physical and operational variables on the overall predicted rating. For example, in the case of 'path lengths', the scenario describing a 'well-designed path' considers wide paths in good condition, located in residential zones, having comfort features and greenery, causing minimum deviation, with traffic travelling at below the speed limit, and no hiding places along the path.

Individual variables (such as presence of comfort features and land use) are then changed, while keeping all other variables the same, to describe the effect of changes in these physical and operational characteristics on the predicted rating.

Table G1   Path length

Variable	Wide path		No comfort features on path		Paths in commercial/ industrial zones, little or no greenery		Narrower path in poor condition and with hiding places		Poorly designed path	
	Variable values	*Walkability: significance value*	*Variable values*	*Walkability: significance value*	*Variable values*	*Walkability: significance value*	*Variable values*	*Walkability: significance value*	*Variable values*	*Walkability: significance value*
constant		4.426		4.426		4.426		4.426		4.426
footcon	1	0.561	1	0.561	1	0.561	-1	-0.561	-1	-0.561
green	1	0.3	1	0.3	0	0	1	0.3	-1	-0.3
comfort	1	0.294	0	0	1	0.294	1	0.294	-1	-0.294
devi	-1	0.464	-1	0.464	-1	0.464	-1	0.464	1	-0.464
min ewidth	3	0.51	3	0.51	3	0.51	1.5	0.255	1.5	0.255
vspeed	-1	0.378	-1	0.378	-1	0.378	-1	0.378	0	0
avg stepav	150	0.51	150	0.51	150	0.51	150	0.51	165	0.561
dese	1	0.201	-1	-0.201	1	0.201	1	0.201	-1	-0.201
numhide	0	0	0	0	0	0	1	-0.186	2	-0.372
pa+res	1	0.415	1	0.415	0	0	1	0.415	0	0
Predicted walkability rating	8.059		7.363		7.344		6.496		3.050	

Table G2   Path length – ages 18–59

Variable	Wide path		No comfort features on path		Paths in commercial/ industrial zones, little or no greenery		Narrower path in poor condition and with hiding places		Poorly designed path	
	Variable values	*Walkability: significance value*	*Variable values*	*Walkability: significance value*	*Variable values*	*Walkability: significance value*	*Variable values*	*Walkability: significance value*	*Variable values*	*Walkability: significance value*
constant		4.429		4.429		4.429		4.429		4.429
footcon	1	0.531	1	0.531	1	0.531	-1	-0.531	-1	-0.531
wind	0	0	0	0	0	0	0	0	0	0
green	1	0.29	1	0.29	0	0	1	0.29	-1	-0.29
comfort	1	0.29	0	0	1	0.29	1	0.29	-1	-0.29
devi	-1	0.41	-1	0.41	-1	0.41	-1	0.41	1	-0.41
min ewidth	3	0.519	3	0.519	3	0.519	1.5	0.2595	1.5	0.2595
vspeed	-1	0.42	-1	0.42	-1	0.42	-1	0.42	0	0
avg stepav										
dese	1	0.222	-1	-0.222	1	0.222	1	0.222	-1	-0.222
numhide	0	0	0	0	0	0	1	-0.159	2	-0.318
pa+res	1	0.39	1	0.39	0	0	1	0.39	0	0
Predicted walkability rating	7.501		6.767		6.821		6.021		2.628	

Table G3   Path length – ages 60 and above

Variable	Wide path		No comfort features on path		Paths in commercial/ industrial zones		Narrower path in poor condition and with hiding places		Poorly designed path	
	Variable values	*Walkability: significance value*	*Variable values*	*Walkability: significance value*	*Variable values*	*Walkability: significance value*	*Variable values*	*Walkability: significance value*	*Variable values*	*Walkability: significance value*
constant		4.757		4.757		4.757		4.757		4.757
footcon	1	0.7	1	0.7	1	0.7	-1	-0.7	-1	-0.7
green										
comfort	1	0.76	0	0	1	0.76	1	0.76	-1	-0.76
devi	-1	0.51	-1	0.51	-1	0.51	-1	0.51	1	-0.51
min ewidth										
vspeed										
avg stepav	150	-0.705	150	-0.705	150	-0.705	150	-0.705	165	-0.7755
dese										
numhide	0	0	0	0	0	0	1	-0.32	2	-0.64
pa+res	1	0.67	1	0.67	0	0	1	0.67	0	0
Predicted walkability rating	6.692		5.932		6.022		4.972		1.372	

Table G4   Path length – safe from falling rating

Variable	Wide path		Paths in commercial/ industrial zones		Paths in poor condition and with hiding places		Poorly designed path	
	Variable values	*Walkability: Significance value*	*Variable values*	*Walkability: Significance value*	*Variable values*	*Walkability: Significance value*	*Variable values*	*Walkability: Significance value*
constant		5.761		5.761		5.761		5.761
footcon	1	0.537	1	0.537	-1	-0.537	-1	-0.537
green								
comfort								
devi	-1	0.23	-1	0.23	-1	0.23	1	-0.23
min ewidth								
vspeed								
avg stepav	150	-0.75	150	-0.75	150	-0.75	165	-0.825
dese	1	0.27	1	0.27	1	0.27	-1	-0.27
numhide	0	0	0	0	1	-0.174	2	-0.348
pa+res								
'Safe from falling' rating	6.048		6.048		4.800		3.551	

Table G5   Path length – pleasant rating

Variable	Wide path		No comfort features on path		Paths with little or no greenery		Narrower path in poor condition		Poorly designed path	
	Variable values	*Walkability: significance*	*Variable values*	*Walkability: significance value*	*Variable values*	*Walkability: significance value*	*Variable values*	*Walkability: significance value*	*Variable values*	*Walkability: significance value*
constant		2.775		2.775		2.775		2.775		2.775
footcon	1	0.47	1	0.47	1	0.47	-1	-0.47	-1	-0.47
green	1	0.547	1	0.547	0	0	1	0.547	-1	-0.547
comfort	1	0.46	0	0	1	0.46	1	0.46	-1	-0.46
devi	-1	0.41	-1	0.41	-1	0.41	-1	0.41	1	-0.41
min ewidth	3	0.744	3	0.744	3	0.744	1.5	0.372	1.5	0.372
vspeed	-1	0.66	-1	0.66	-1	0.66	-1	0.66	0	0
avg stepav										
dese	1	0.38	-1	-0.38	1	0.38	1	0.38	-1	-0.38
numhide										
pa+res										
'Pleasant' rating	6.446		5.226		5.899		5.134		0.880	

Table G6   **Road crossing**

Variable	Zebra crossing: generic		Larger zebra crossing with increased delay[a]		Zebra crossing on a poorly maintained road, no tactiles		Uncontrolled crossing, with refuge		Larger uncontrolled crossing, with higher vehicle speeds and increased delay		Uncontrolled crossing with a poorly maintained footpath and no central island	
	Variable values	*Walkability: significance value*	*Variable values*	*Walkability: significance value*	*Variable values*	*Walkability: significance value*	*Variable values*	*Walkability: significance value*	*Variable values*	*Walkability: significance value*	*Variable values*	*Walkability: significance value*
constant		5.510		5.510		5.510		5.060		5.060		5.060
vspeed							-1	0.819	0	0	-1	0.819
vis tra							1	0.64	1	0.64	1	0.64
footcon							1	0.377	1	0.377	-1	-0.377
delay	5	-0.05	10	-0.1	5	-0.05	20	-1.82	30	-2.73	20	-1.82
crosdi	10	-0.52	15	-0.78	10	-0.52	10	-0.5	15	-0.75	10	-0.5
rdcon	1	1.4	1	1.4	-1	-1.4						
tpva	1	0.477	1	0.477	0	0						
rist							1	0.706	1	0.706	0	0
Predicted walkability rating	6.667		6.307		3.390		5.282		3.303		3.422	

a)   Note: Zebra crossings with high traffic flows can subject pedestrians to large delays as pedestrians confirm motorists will yield and allow them to cross. In these situations, a zebra crossing may not be the most appropriate crossing facility.