Predicting Walkability

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ABSTRACT

Urban designers and many other professionals, including many transport professionals, acknowledge that walking is a very important mode of transport in most urban areas and that the amount of walking that takes place is closely related to how liveable a city or town is considered to be. Walkability is a term that is used to specify "the extent to which the built environment is walking friendly".

In New Zealand the Community Street Review (CSR) process has been developed to assess the level of walkability of footpaths and road crossings. This method involves taking a group of pedestrians along a route consisting of a number of footpath sections and road crossings and asking them to rate across a number of factors (e.g. safe from falling and safe from traffic) how they felt on a scale of 1 to 7. Based on the ratings across the group and each factor, each section is given an average walkability score.

While there have been a number of CSR undertaken across New Zealand and it remains an effective means to measures walkability, transport professionals are interested in quantifying what elements of the walking environment and walking experience lead to high levels of walkability and hence more walking. From this they can develop walking environments that are more attractive for walking.

This paper outlines research that looks at the linkage between the walkability scores from CSRs and the physical and operational characteristics of a footpath and road crossing. In addition to layout information, such as width of footpath and road crossing distance, it considers road noise, urban design features, amount of greenery and even the temperature and amount of wind. In total 107 variables where considered across each of the regression models and 17 variables were found to be important.

This paper will interest practitioners interested in qualifying walkability and understanding what variables influence people perceptions in the walking environment the most. .

INTRODUCTION

Abley Transportation Consultants Ltd (Abley) and Beca Infrastructure Ltd (Beca) were commissioned by the New Zealand 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 Tools Research 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) as well as the NZTA Pedestrian Planning Design Guide (NZTA 2007) that Beca was a principal author.

This research has been produced to assist practitioners to quantify the quality of walking environment. Other modes of transport, and especially the private motor vehicle, have a high degree of measurability because these other modes have previously had significant study. Walking on the other hand lags behind in terms of research. This research fills some of the 'walking' knowledge gap and provides practitioners with a technique to quantify the quality of the pedestrian environment in a similar way that is possible for other modes of travel. In doing so it is thought that more care and attention will be given to walking by practitioners and assist NZ towards it transportation goal of achieving an affordable, integrated, safe, responsive, and sustainable land transport system.

BACKGROUND

Introduction

In transportation planning circles walking is generally considered the 'forgotten' mode, with very few analytical techniques that better enable practitioners to provide for this silent mode of travel.

Walking though remains a key element of a balanced transportation system. Overall walking is the second most popular form of travel in New Zealand and nearly one in five of all household trips is made on foot. For the 10 percent of households that have no car, for those in those households without a car access for much of the day, and for those that cannot, or choose not to drive, walking is an especially vital mode of transport (NZTA 2007).

Often walking is the first and last choice of many people who experience problems of accessibility, being it in a social or economic sense. Elderly people, people with impaired mobility and low income groups may find walking the only feasible form of transport open to them to access key areas and services. Additionally an individuals' propensity to walk may be reduced by the advent of providing a poor quality environment. It is therefore vitally important to identity low quality walking environments and take the necessary steps to prioritise and improve infrastructure that is failing the needs of people wishing to use walking as a practical, social and physically active mode of travel.

The fact that the quality of journeys undertaken on foot is not measured probably contributes in walking being considered an after thought for most decision makers. When walkability is considered in a majority of cases the determination of the walking environment is left to urban designers and landscape artists, who determine the visual appeal of the walking environment, and to engineers who assess the functionality of specific schemes. This detachment often leads to contradictory recommendations from the various parties. For example, landscape architects might recommend features that engineers might find unsafe, and vice versa engineers might recommend features that landscape architects might find unattractive. In addition, the community – the end-user of walking schemes – is rarely asked to comment on whether a suitable quality of provisions has been provided.

Limited tools are presently available for practitioners to measure the quality of the walking environment. In contrast, there are a number of tools available to measure the quality of provision for other transport modes, especially private motor vehicles. Given a pedestrian environment can vary largely due to an individuals' personal perception; this can make quantifying walkability very difficult. This difficultly in quantifying walkability may be a further contributing factor for the lack of practitioner tools in the area of walking.

There is a need then for analysis tools to be developed for walking to compete with these other transport modes and to better balance recommendations being put to decision makers. Predicting walkability is about anticipating the quality of a walking environment prior to it being constructed, providing a network planning tool so the whole of the walking network is considered and ultimately providing a tool where economic analysis can be undertaken.

Walkability: A Definition

Walkability and Walkable are common terms that have crept into the fields of engineering, planning and into the terminology of health professionals. This is probably due in part to the importance of walking being recognised by a wide range of professionals and the benefits walking can have on the social, health and economic wellbeing of a society.

Although not defined in the Oxford English Dictionary, mainly due to its fallibility as a jargon term used by professionals, Walkability was first recommended for definition for use in New Zealand as "…the extent to which the built environment is walking friendly" (Abley 2005). This definition was later accepted and publicised by the NZ Transport Agency in the Pedestrian and Planning Guide (NZTA 2007). Walkability is also noted as being "…a useful way to assess the characteristics of an area or a route, although it can be subjective" (NZTA 2007).

It is the issue of being able to assess walkability either quantitatively or qualitatively i.e. subjectively, that is the purposed of this research. This research provides the ability to calculate walkability qualitative results from quantitative measurements.

Problem Identification

Problems in the built environment and specifically in the highway and pedestrian environments are identified through a number of proactive mechanisms, including consultation, measuring the safety or efficiency of the link, or from recommendations made by the road controlling authority. More reactive responses may be a result of resident or user complaints, or the measurement of safety by the road controlling authority.

With reactive techniques it is often difficult to have any element of forward planning. Consequently the cost of remedial work is difficult to factor into yearly budgets other than by including broad brush guesses. Additionally only working reactively means funds may not be directed to projects and improvements that are the most in need, with unreported and unnoticed problems that may constitute those most at need not receiving funding. 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 in advance of the project taking place. Consequently they are budgeted for in advance and can be quantified using strong economic measures such as a detailed cost benefit ratio. This may be one reason why a number of quantifiable tools exist for measuring the quality of travel modes other than walking i.e. most walking infrastructure is fairly inexpensive.

After problem identification, it will usually require one of two responses. The first of these is that the problem is a maintenance issue, and can be acted upon immediately, or plans put in place to rectify the problem at the first available opportunity. The alternative is that the problem is an issue that requires further investigation, and the application of one of the proactive or reactive measures described earlier.

Proactive measures to improve the quality of the built environment are increasing in popularity amongst professionals, and result in performance design whereby the environment is tested against performance measure such as Walkability. Performance design can involve using design techniques such as reviewing, auditing and rating to assist practitioners to better understand problems and identify solutions.

Assessment Techniques

Three broad techniques (Abley 2005) are available to assess the performance of the built environment (and therefore walkability); these are:

- Reviewing: Applies to existing situations and may include audit and rating as well as other assessment tools. Develops options for and assesses how well proposed options improve walkability qualitatively.
- Auditing: Can be applied to existing and proposed designs. Identifies deficiencies against recognised standards and can propose solutions. Ideal for identifying maintenance issues and simple remedies both qualitatively and quantitatively.
- Rating: Tool for scoring walkability for an environment or facility. Can be used on existing or proposed designs, enables a practitioner to compare different walking environments quantitatively.

This earlier work identified there was a need for development of 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 applied when determining the quality of provision for say motorised vehicles that tend to be based on efficiency and safety issues and which are typically reported as quality of service (or level of service).

Levels of Service

Level of service (LOS) is a common term used in the engineering profession that is typically used to describe the quality of service provided to motorised travel. Fruin (1971) first identified LOS for pedestrians. Pedestrian levels of walkability were investigated in relation to the pedestrian flow rates and densities for particular purposes. Fruin calculated a LOS for specific infrastructure and proposed a number or mathematical formula for specific walking and queuing densities.

LOS is a qualitative measure of network performance that usually describes the operational conditions and flow of a transport network. It can be applied to walking and other modes and is typically based on an individuals' freedom of choice; choices regarding speed, overtaking opportunities, the ability to cross, to manoeuvre generally without conflicts and to cross traffic streams. Delay is typically also considered when an individual wishes to cross the road or is impeded by other users.

Six LOS, ranging from A to F are used to categorise the environment. Level A represents the best or safest walking conditions, whilst F indicated the least attractive and or the most unsafe walking conditions. It is important to note that Fruin did not take into account the individuals perception of safety.

LOS definitions exist for other modes and purposes of which the most widely used are defined in the Highway Capacity Manual (HCM) (2000). The HCM notes that environmental factors are an integral part of the pedestrian experience and therefore are key to ascertaining an accurate LOS. With the addition of environmental factors, LOS is a measure of comfort, convenience, security and economy of the pedestrian environment. Convenience factors are also included such as walking distances, pedestrian desire lines, gradient, sidewalk ramps, directional signalling, directory map and other features that make pedestrian travel more comfortable.

Community Street Reviews

A CSR is an assessment of 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 crossing environment and how they feel when walking. It collects data on safety, functionality of the pedestrian space, ease of road crossings, effects of urban design and other walkability factors. CSRs thus include not only a qualitative consumer audit but also a quantitative rating. A CSR benefits both the immediate community (auditing) and provides practitioners with an asset management tool (rating) to prioritise potential walking schemes.

CSR data in conjunction with physical and operational data was collected as a pilot for this project. The results of the earlier project were reported in NZ Transport Agency Walkability Research Tools – Summary Report, Research Report 356 (Abley 2008). As part of that project a database was created to facilitate the collection of data. The database 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 have been obtained for this research and the database at www.levelofservice.com 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 from the measured physical and operational factors in an existing or proposed walking environment. This will help practitioners to estimate the LOS for journeys undertaken on foot in a similar manner to that currently used for other modes of travel.

DATA COLLECTION METHODOLOGY

Introduction

The survey methodology consisted of two data collection processes:

1. Collection of physical and operational variables using the Walkability Tools Research Variables Collection Methodology (Abley 2006), and
2. Collection of perception survey data using the Community Street Review (CSR) Methodology (Abley 2010) (NZTA 2010).

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

Once this data was collected it was inputted and stored into a central database at www.levelofservice.com. This is the data that was later extracted to develop the mathematical models.

Christchurch, Gisborne, Auckland and Wellington were the cities selected as the locations for the four CSR surveys commissioned for this project. Each city required a group of at least 12 participants to be found and a suitable survey route to be selected. A number of control measures and variations were introduced to the general methodology as part of this research.

Experimental Control

It was considered that communities in different cities may score similar footpaths differently. To measure the extent of this, an experimental control was used in the form of a participant who scored all of the routes. This provided a ‘normal’ measure for which the other participants could be compared.

The control participant 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.

Following the Christchurch CSR four extra questions were added to the CSR path length forms. These questions were designed to ascertain from participants what physical elements contributed most significantly to their overall perceived levels of path length walkability. The components are:

i. The footpath (the immediate footpath, including the density of usage),
ii. The road (including the level of traffic on the road),
iii. The extent of separation between footpath and road,
iv. The larger environment beyond footpath and road (all aspects other than those in i, ii and iii that make the environment feel more or less comfortable to be in).

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

Summary

Surveying was undertaken in four locations throughout New Zealand. 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.

Overall 38 people of various ages with an approximately even split of males and females reviewed 111 path lengths and 124 road crossings. The Survey Summary **Table 1** shows the mix between path lengths and road crossings as well as a break down of the variety of participants.

Table 1: Survey Summary Table

Variable \ Location		Christchurch	Gisborne	Auckland	Total
Total Length (m)		5,800	6,100	7,800	***19,700***
Path lengths (number)		40	40	31	***111***
Road crossings (number)		41	39	34	***114***
Gender	**Males**	8	5	5	***18***
	Females	5	8	8	***21***
Age	**18 - 29**	7	5	3	***15***
	30 - 39	4	2	5	***11***
	>40	2	6	5	***13***

MODEL DEVELOPMENT METHODOLOGY

Selection of predictor variables

CSRs involved collection of 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. The variables collection methodology report also includes for the process to collect the variable. The variables themselves are listed in Appendix C along with the variable 'string name' i.e. the short hand name of the variable that was used in the statistical modelling software package. The modelling package that was used to undertake the analysis is Minitab version 16.

The exhaustive set of physical and operational variables for which data was collected during the CSR surveys was assessed to identify the variables that are 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 variable 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 variables represent those initially used for model development. All other physical and operational variables that were excluded at this stage were later tested during the development process to identify any other important variables that may have been overlooked.

Table 2 lists the variables that were included in the sample set for path lengths along with the variable type, i.e. whether continuous or discrete.

Table 2: 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 access ways	Discrete
	Visacc	5	Visibility to vehicle access ways	Discrete
	Useacc	6	Use of access ways	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
	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 spaces	Discrete
Weather	Weather	30	Survey weather	Discrete
	Rain	31	Weather, rain	Discrete

Category	Variable Name	S. No	Variable Description	Type
	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

Table 3 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 3: 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 obstacle	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 obstacle	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
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 obstacle	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

Variable 1	Variable 2	Correlation
Vandalism	Litter	0.361
Number of adjacent vehicles per hour	Noise in decibels	0.344
Average trip hazards	Number of vehicle access ways	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

Variables included in the modelling for road crossings are provided in **Table 4**.

Table 4: 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
	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
Crossing type	Crossct	24	Crossing control type	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	Litter	33	Litter	Discrete
	Deti	34	Detritus	Discrete

security	Vanda	35	Vandalism	Discrete
Delay	Delay	36	Crossing delay #	Continuous

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

Table 5 lists the significant correlations between road crossing predictor variables and all variables for which data was collected.

Table 5: 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

Data manipulation

Due to 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.

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

1. Adjustment of participant mean ratings: Participant 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.
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.

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)

The comparison of the walkability rating of the common participant and all other participants is shown in **Table 6** that leads to some interesting observations. Overall, it is observed that in Auckland, the common participant rated sections slightly higher than the rest, whereas it was the opposite case in Christchurch. The figures in other cities were mixed, with the walkability rating of the common participant being both higher and lower than the average of the other participants depending on the individual site.

Table 6: Percentage difference (adjusted walkability vs. raw walkability)

City	% Difference (adjusted walkability vs. raw walkability) – Path Lengths	% Difference (adjusted walkability vs. raw walkability) – Road Crossings
Auckland	10%	12%
Christchurch	-5%	-1%
Gisborne	3%	-4%
Wellington	2%	5%
All sites	**2%**	**3%**

PREDICTION MODELS

Figure 1 provides a summary illustration of the various model types for path lengths and road crossings. Those models that are recommended for practitioner use and published in this paper are 'circled'.

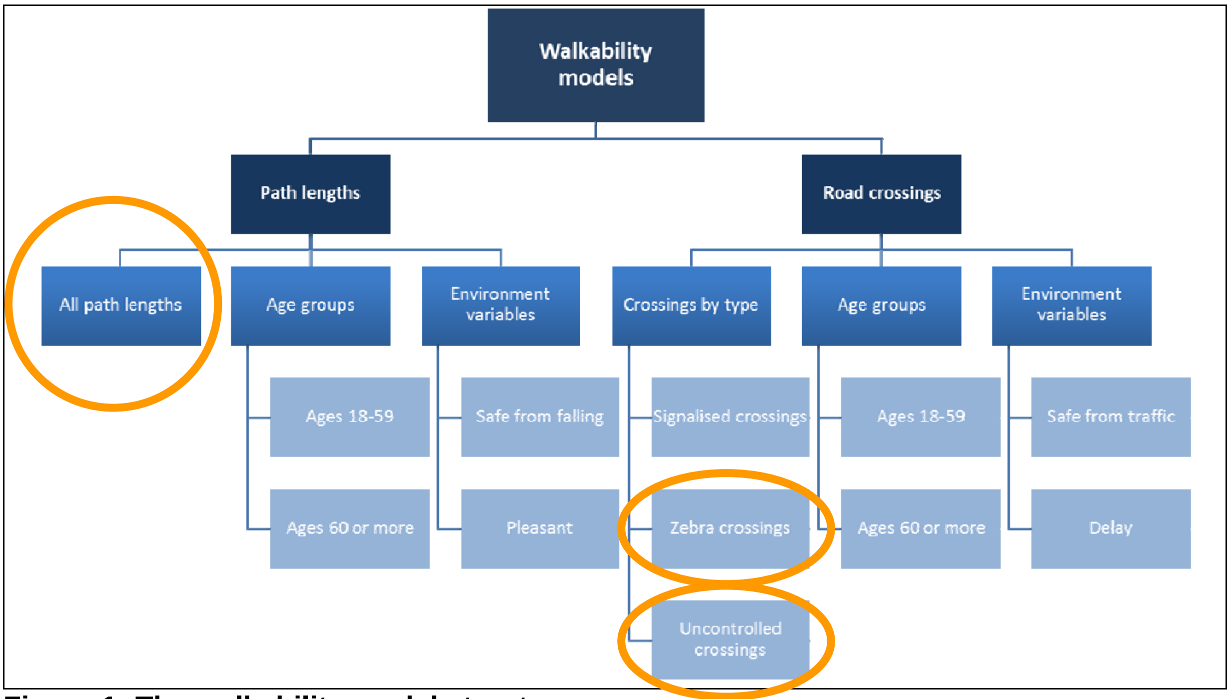


Figure 1: The walkability model structure

Path Length Model

The final set of selected variables identified earlier 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$_{\text{Path Length}}$ = 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

The descriptions and possible values of the variables in the model are shown in **Table 7**.

Table 7: 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 mm
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 2** shows 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.

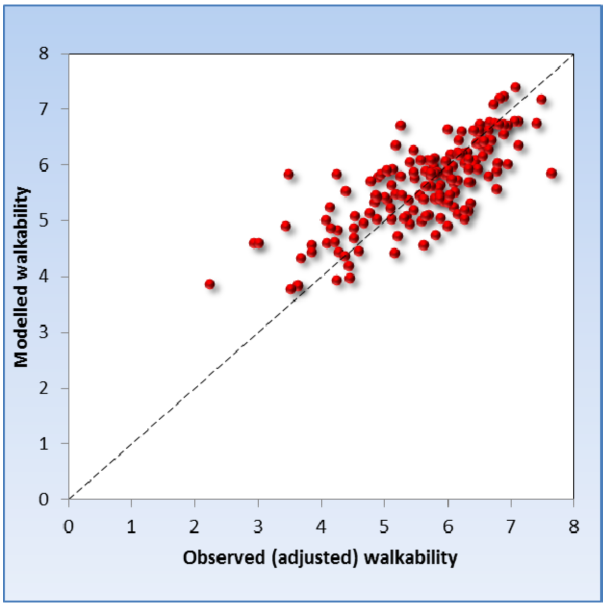
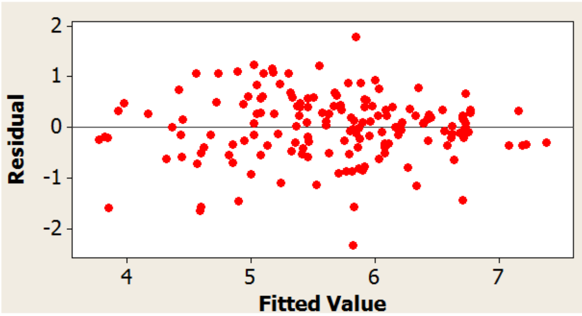


Figure 2: Path Length scatter plot of observed vs. modelled walkability

Figure 3 shows residual plots for the path length model.



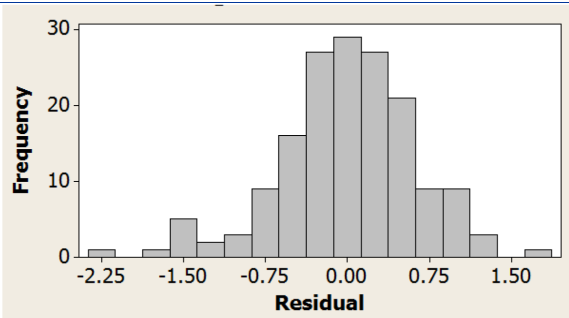


Figure 3: Residual plots: path length model

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 footpath and 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 the 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.

The number of hiding spaces and amount of detritus on the path also results in making a path less walkable, although not to as great an extent as deviation around obstacles and vehicle speed, due to the perceived personal security risks accompanied by the presence of these features.

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

Higher design effort i.e. the presence of functional streetscaping items, and presence of steps along the path are also seen to improve the walkability rating.

Signalised crossings

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

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.

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

The descriptions and range of possible values of the variables in the model are given in **Table 8** and the observed vs. modelled walkability shown in **Figure 4**.

Table 8: 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

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

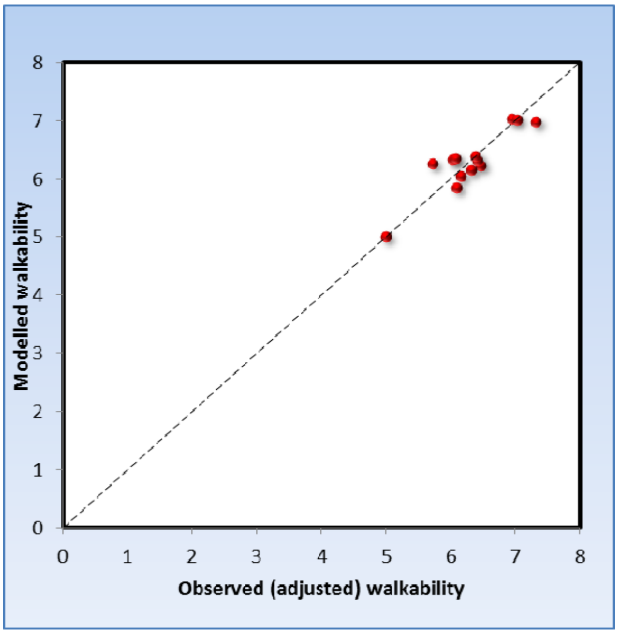


Figure 4: Zebra Crossing scatter plot of observed vs. modelled walkability

Figure 5 shows residual plots for the zebra crossings model

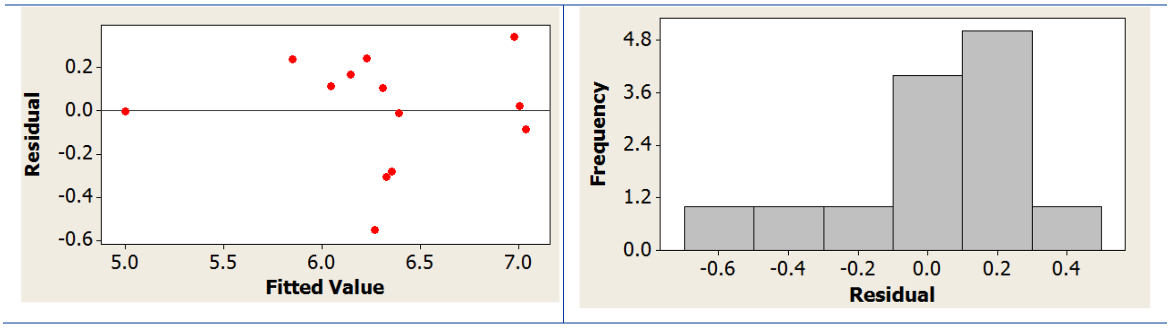


Figure 5: Residual plots: zebra crossings model

The R^2 of the model is observed to be quite high at 0.82, although this is likely to be a result 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.

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$_{\text{uncontroleld crossings}}$ **= 5.06 - 0.819 vspeed + 0.640 vis tra - 0.091 delay + 0.377 footcon + 0.706 rist - 0.05 crosdi**

The descriptions and range of possible values of the variables in the model are tabulated in **Table 9**.

Table 9: 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 is observed to have an R^2 value of 0.48 representing a reasonable fit. **Figure 6** shows the observed values of walkability against the values predicted by the walkability model for uncontrolled crossings.

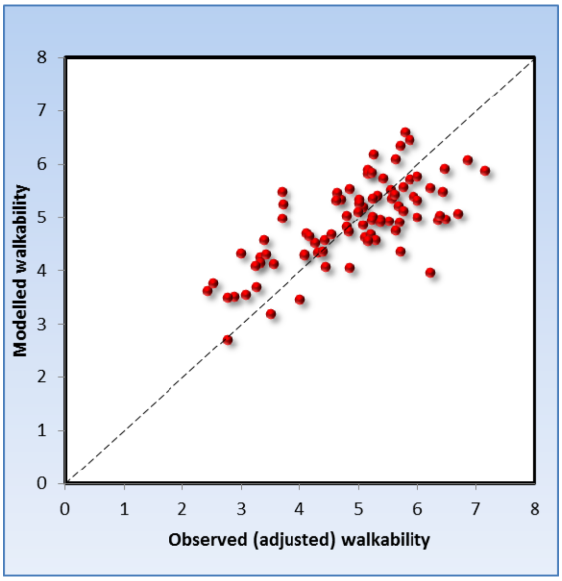


Figure 6: Uncontrolled Crossing scatter plot of observed vs. modelled walkability

Figure 7 shows residual plots for the uncontrolled crossings model

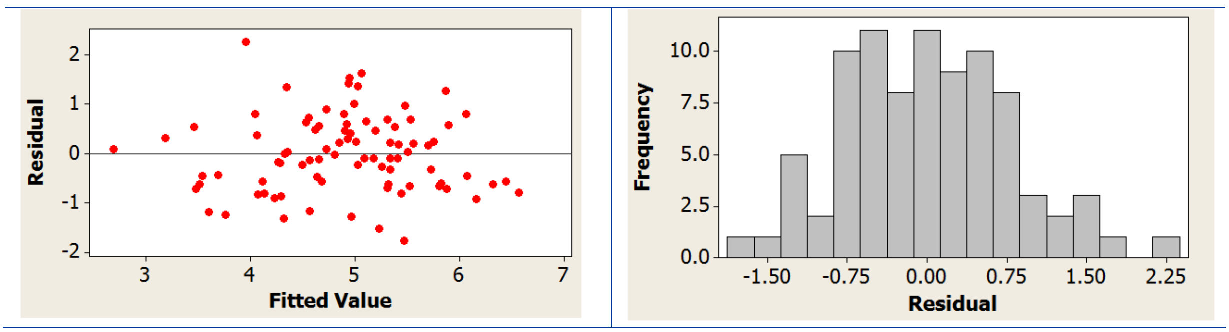


Figure 7: Residual plots: uncontrolled crossings model

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 are observed to have a negative effect on the walkability.

CONCLUSIONS

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 had significant study. Walking on the other hand requires limited infrastructure and it lags behind those other modes in terms of research. This research fills some of the 'walking' knowledge gap and provides practitioners with a technique to quantify the quality of the pedestrian environment in a similar way that exists for other modes of travel.

This research combines the NZ Transport Agency 'Guide to Undertaking Community Street Reviews' that provides a methodology to collect people's perception of the walking environment with the Variables Collection Methodology that enables the systematic collection physical and operational variables. These and other background material can be referenced at www.levelofservice.com.

This research included undertaking a number of surveys of the physical and operational characteristics of the street environment around NZ and correlating those measurements with how people felt about those environments in terms of safety, pleasantness and other variables. This research has then derived a number of predictive mathematical formulas that enable the perception of the qualitative quality of the street environment to be calculated using quantitative measurements.

Linear regression models for predicting walkability have been developed for path lengths and road crossings. Separate models have also been built for young/middle-aged and elderly participants and for predicting environment variables such as safe from falling and pleasant (for path lengths) and safe from traffic and lower waiting time (for road crossings). A number of formulas have been produced although the overall formulas recommended for use by practitioners are those for path lengths, zebra crossing and unsignalised crossings:

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