Journal of Environmental Psychology 36 (2013) 202–213

Contents lists available at ScienceDirect

Journal of Environmental Psychology

journal homepage: www.elsevier.com/locate/jep

Influence of infrastructural compatibility factors on walking and cycling route choices

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ARTICLE INFO

Article history:
Available online 22 August 2013

Keywords:
Pedestrian
Cyclist
Walkability
Bikeability
Factors
Route choice

ABSTRACT

This paper uses a two-pronged approach to assess which infrastructural compatibility factors affect people's willingness to select the desired route for walking or cycling. An intercept perception survey and walkability/bikeability audits were carried out to assess various factors. From the perception survey, rain shelter supplants distance as the most important factor for walking whereas security is the most important factor for cycling. A user-rated weighted point system is then utilised to establish the Safety and Accessibility Index (SAI) as metric for auditing of walkability and bikeability. Comparing segments between actual and shortest routes, comfort, shops and scenery showed up as significantly important factors for choosing favoured walking routes; comfort, stairs, accident risk and crowdedness are important considerations when choosing cycling routes.

1. Introduction

Route choice of pedestrians or cyclists is complex; it is not purely the quickest route, unlike motorists' route choice. The determinants for a pedestrian or cyclist choosing a particular route range from whether the route is safe to the level of comfort. Schlossberg, Agrawal, Irvin, and Bekkouche (2007) found that a pedestrian's primary goal in choosing a route is to minimise distance and time, but safety and aesthetic conditions are also important to them. Furthermore, he or she tends to follow that particular route everyday unless due to temporal change such as increment weather or short term activity (Grable & Kretz, 2010).

Understanding what a pedestrian or cyclist considers as an attractive route can allow planners to build cities that are considered attractive by the residents, resulting in more active transport (walking and cycling) activities, and in a long term creating a more liveable city. At a secondary level, a shop owner can also assess the value of the shop location and the possible number of walk-in customers.

Research work on route choice models revolved around two main methods namely, stated preference or revealed preference methods (Dill & Gliebe, 2008). The first method typically presents respondents with two options, usually trading offs a perceived higher quality facility with a longer travel time. Revealed preference studies attempt to associate actual route choices with the presence of specific infrastructure, against the shortest distance route. The extra time the user chooses to spend on the longer route demonstrates the value of the facility for that person.

Before improvement plans could be established, it is crucial to first measure the existing condition, that is, how walkable/bikeable the current situation is. Past literature on walkability and bikeability mainly utlised area-based analysis (Cervero & Duncan, 2003; Cervero, Sarmiento, Jacoby, Gomez, & Neiman, 2008; Forsyth, Hearst, Oakes, & Schmitz, 2008; Frank, Devlin, Johnstone, & Loon, 2010; Lin & Chang, 2010; Jacobs, 2011; Martincigh, 2011; Sundquist et al., 2011), and they seldom covered the detailed characteristics of routes or segments (Borst, Miedema, Vries, Graham, & Dongen, 2008; Millington et al., 2009). Even so, those audit techniques developed for fine grain attributes of the physical environment typically only covered sidewalks (those parallel to roadway). The local walking environment differs greatly from the above overseas studies, given the unique layout of local public housing. The ground level of public housing (known as void decks) are vacant spaces specially allocated for community gatherings and events and the blocks are usually not fenced, to allow high 'permeability' of residents in the local context (see Fig. 1). The presence of the void decks may affect a person's decision to 'cut through' these spaces instead of using the footpaths which are usually located alongside the roads. To the best knowledge of the authors, there has not been research into such environment.

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http://dx.doi.org/10.1016/j.jenvp.2013.08.001

Fig. 1. Unique layout of public housing.

Werner, Brown, and Gallimore (2010) measured micro-level environmental features of the block (both sides of a street between intersections) where the resident lives and matched to surveyed response on whether he or she walked to a transit stop. However, the whole walking journey was not measured. Also, there are some studies that are purely based on subjective rating and not systematical quantification, leading to lack of consistency and transferability (Sarkar, 2003). In contrast, this paper focuses on pedestrians' and cyclists' experience of local, micro-scale aspects of the physical environment through which they walk or cycle.

The purpose of this paper is to assess which infrastructural compatibility factors affect people's willingness to select the desired walking/cycling route for the last mile trips (emanating from the transit station to the onward destination) and to establish a walkability/bikeability index for evaluating the environment.

2. Relationship between human behaviour and the environment

The multi-disciplinary relationship between the environment and the human behaviour is typically known as environment psychology (Rartin et al., 2011). Human behaviour is the outcome of human's interpretation of the environment that matches his current need(s)/objective(s). People tend to seek out places where they feel competent and confident, where they can make sense of the environment while also being engaged with it. Therefore, by understanding what constitute a preferred environment (e.g. shade, scenery, shops) can effectively help planners to preserve, restore or create an environment that invites more users who gain better behavioural effectiveness. On the other hand, environmental stressors (e.g. noises, overly crowded area) are failures of preference. They possess prolonged uncertainty, unpredictability and overloading stimulus that human needs to adapt in order to cope. Malhotra (2007) viewed environmental psychology as the following equation: perception/cognition = *f*(functional properties). That is, how the user perceives the environment is a function of properties of the environment that matter to the user.

Theories of user decision making process normally take into account three different levels of behaviour that is, Strategic level, Tactical level and Operational level (Methorst et al., 2010). At the Strategic level, an individual makes a general plan on what he/she is going to do (activity), where he/she is going (destination) and the order of performance (modes of transport). This is the pre-trip decision. At Tactical level, the individual starts to gather information about the network and makes short term decision about the optimal route to take. The decision is mainly based on obstacles and macroscopic features of pedestrian flow (e.g. velocities, densities and flows). At the Operational level, the individual involves in the actual walking and how he/she adjusts the direction/speed to achieve the goals set at previous levels. The focus of this study is on the tactical level.

The list of infrastructural compatibility or environmental factors that affects walkability/bikeability from past literature include intersection safety, street design, land use, perceived safety, traffic (volume and speed), sidewalk completeness, security, greenery, shops, building height and number of people (Ewing, Handy, Brownson, Clemente, & Winston, 2006; Evans, 2009; Joo, Kim, & Kim, 2011; Duncan, Aldstadt, Whalen, & Melly, 2012). After reviewing the past literature and considering local operating conditions, this led to the selection of 11 infrastructural compatibility factors for the study (Koh & Wong, 2012b). They include security, detour, delays at road crossings, directional signs, comfort, weather protection, steps/slopes, accident risk, crowdedness, shops along routes and good scenery.

3. Methodology

The experimental design can be divided into three main parts namely, Part I – Gathering route details via perception survey, Part II – Auditing the routes and Part III – Establishing the Safety and Accessibility Index. Part II utilised some of the results from Part I survey.

3.1. Part I – gathering route details

Face to face interviews were conducted at exits of five selected rail transit stations in the residential areas in Singapore during evening peak hours. The selected rail transit stations represent a good geographical spread (see Fig. 2). The targeted respondents were those exiting from the transit stations and making their last mile trips to their destinations (typically home). Random transit passengers (without bias) were approached and interviewed at all exits of the stations. For those who were in a hurry and refused to do a face-to-face interview, they were distributed a mail-back envelope for them to self-fill at home and mail it out after completion. The intention was to increase the sample size. At each station, the target number of respondents (walk, cycle, take bus or other private transport after exiting the station) was set at 100. During the pilot survey, it was found that the proportion of cyclists was too low for meaningful interpretation of data. Hence, it was decided to intentionally 'capture' about additional 50 cyclists while they were unlocking their bicycles at each station. This led to a final sample size of 1146, collected over a two-month period at the five locations.

In the survey, the respondents were asked to rate the level of importance (1 – Not important, 2 – Somewhat important, 3 – Important, 4 – Very important) of the 11 pre-determined

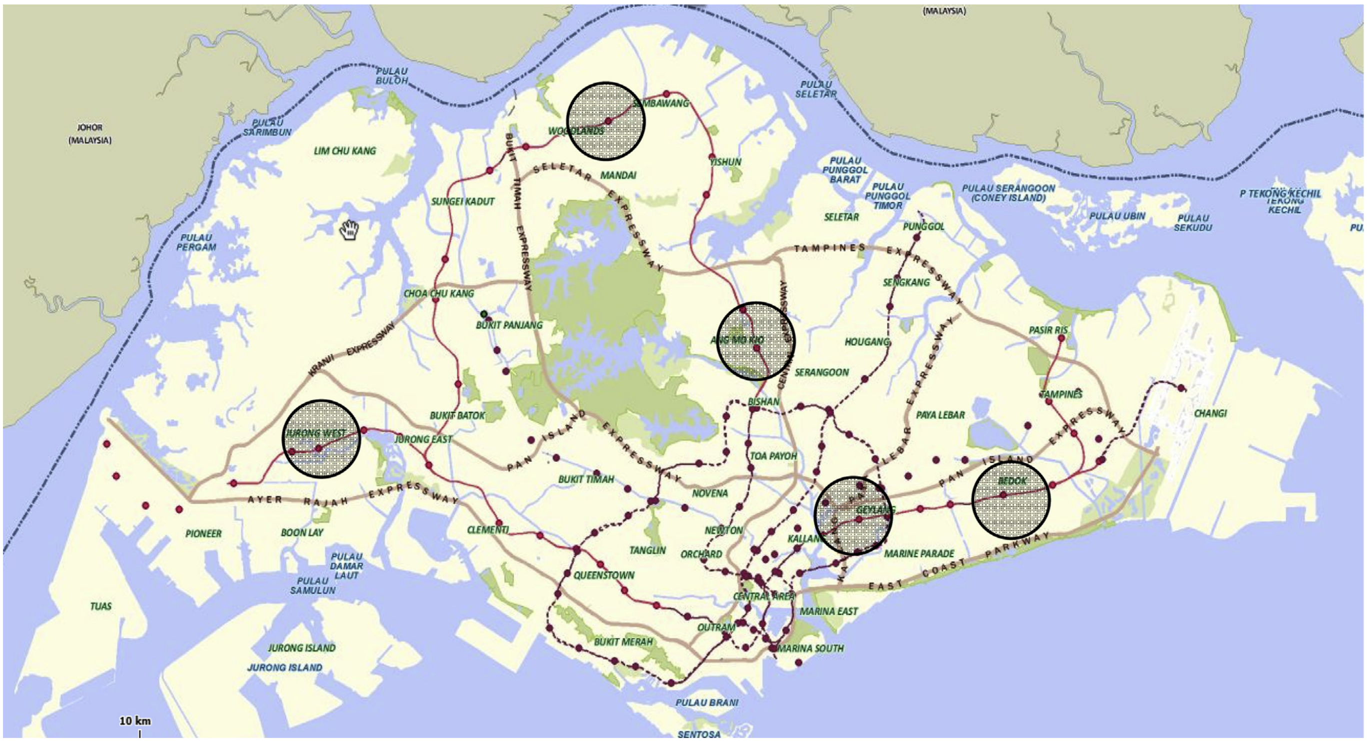

Fig. 2. The five study locations.

infrastructural compatibility factors as well as 'distance' factor in affecting their walking/cycling mode choice decision. All respondents were required to answer for walking (as everyone is a pedestrian) but only cyclists were required to answer for cycling.

Each respondent was also asked draw on the map provided the usual route he/she takes from the transit station to the destination. This technique has been shown to be highly effective in capturing respondents' routes (Schlossberg et al., 2007). The reliability of each route was validated by matching with the destination stated. In this study, 88% of the respondents who walked or cycled from the stations, provided matching route and destination. The non-matching records were dropped.

3.2. Part II – auditing the routes

In order to better understand what contribute to a pedestrian/cyclist in selecting a particular route, an audit of such routes was carried out to quantify the presence or absence of the 11 selected infrastructural compatibility factors. From the 860 plotted walking routes (in pink, in the web version), density plot was used to determine the five most frequently used routes emanating from each transit station (in well-distributed directions) for the audit (see Fig. 3). Five cycling routes were also selected using the same technique. The criteria for choosing the routes include being geographically well-distributed in multi-directions radiating from the transit station, being commonly used corridors and

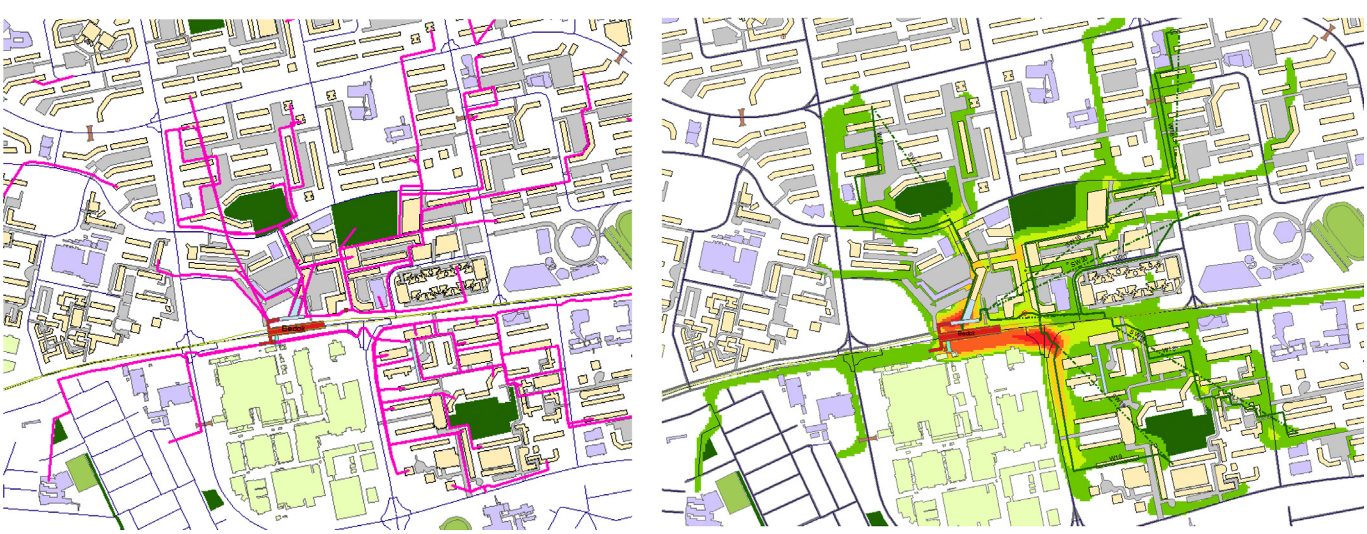

Fig. 3. All-respondent routes, density plot and selected routes for walking audits.

Table 1
Average importance score for pedestrians ($n = 810$).

Factors, F	Push/pull factor	Percentage distribution				Average score, S_F[a]	Tier	Point, P_F[b]
		Not important	Somewhat important	Important	Very important			
Weather protection	Pull	3	9	29	60	3.5	1	12
Distance	–	8	11	39	43	3.2	1	–
Comfort	Pull	5	18	46	31	3.0	2	10
Security	Pull	10	20	33	37	3.0	2	10
Traffic accident risk	Push	15	23	33	29	2.8	2	10
Crowdedness	Push	14	27	34	25	2.7	2	9
Detour	Push	16	26	36	23	2.6	2	9
Number of road crossings/delay	Push	14	30	34	22	2.6	2	9
Stairs/slope	Push	22	28	29	21	2.5	3	9
Directional signs	Pull	28	23	29	21	2.4	3	8
Good scenery	Pull	43	29	21	8	1.9	4	7
Shops along route	Pull	43	29	21	8	1.9	4	7
Total score (excluding 'Distance'), $\Sigma S_F = 28.9$, $\Sigma P_F = 100$								

[a] S_F is calculated as the mean across participants' ratings on a 4-point scale.
[b] P_F is the percentage point.

destinations in different precincts. Precinct is defined as a group of residential flats (typically 7–8 blocks), similarly-shaped and designed, and sharing a common driveway, car park and playground.

Each route was audited by segments which were defined as sections of the route having same characteristics (e.g. same surface type and width, with/without shelter). Points were awarded based on the 11 infrastructural compatibility factors by two independent project officers, for consistency. For each infrastructural compatibility factor, the definition of measurement (i.e. what condition to be awarded how many points) was clearly specified. On features that are based on judgemental level, photographic examples were used to achieve reasonable inter-rater reliability (Ewing et al., 2006). One officer concentrated on capturing real-time video footages from pedestrian/cyclist's perspective while the other took measurements and tallies (such as traffic signal timings and presence of infrastructure). In addition, for each selected route, the shortest possible route is identified and audited for the same factors. This is to find out which parameters affect one's decision to walk/cycle a route longer than the shortest possible route. The same factors have been used from the mode choice decision for better synergy.

3.3. Part III – establishing the safety and accessibility index

The overall Safety and Accessibility Index (SAI) for each route was also formed from the 11 infrastructure compatibility attributes, by summing up all the Points, P, collected as follows. For each segment,

$$\mathrm{SAI}_s = \sum P_i [\text{Maximum : 100 points}] \quad (1)$$

Then, for each route,

$$\mathrm{SAI}_r = (\mathrm{SAI}_1 s_1 + \mathrm{SAI}_2 s_2 + \mathrm{SAI}_3 s_3 + \ldots) / \sum s_r \quad (2)$$

where SAI_s is the safety and accessibility index for segment, s, F is the factor and P_F is the converted percentage points awarded to that audited segment. The SAI_r is the overall safety and accessibility index for the route, r, computed by multiplying SAI_i with the respective segment length, s_i normalised by the total route distance, $\sum s_r$. A low SAI_r suggests poor walkability or bikeability which implies that the studied factors are less favourable to the users.

4. Findings from Part I perception survey

4.1. Characteristics of respondents

A total of 1146 respondents completed the survey at the five selected transit stations. Of which, 703 intended to walk to their destination, 276 to cycle, 134 to take bus and another 18 of them to take private vehicle. There was close to 50–50 split among the gender. Three per cent of the respondents were below 15 years old

Table 2
Average importance score for cyclists ($n = 120$).

Factors, F	Push/pull factor	Percentage distribution				Average score, S_F[a]	Tier	Point, P_F[b]
		Not important	Somewhat important	Important	Very important			
Security	Pull	18	7	25	51	3.1	1	11
Distance	–	21	11	31	38	2.9	2	–
Traffic accident risk	Push	24	8	26	42	2.9	2	10
Crowdedness	Push	19	13	31	37	2.9	2	10
Stairs/slope	Push	27	13	34	26	2.6	2	10
Weather protection	Pull	29	16	28	22	2.5	3	9
Detour	Push	25	22	29	23	2.5	3	9
Comfort	Pull	27	23	28	22	2.5	3	9
Directional signs	Pull	34	11	27	28	2.5	3	9
Number of road crossings/delay	Push	32	19	27	22	2.4	3	9
Good scenery	Pull	50	26	17	8	1.8	4	7
Shops along route	Pull	57	13	20	9	1.8	4	7
Total score (excluding 'Distance'), $\Sigma S_F = 27.5$, $\Sigma P_F = 100$								

[a] S_F is calculated as the mean across participants' ratings on a 4-point scale.
[b] P_F is the percentage point.

(classified as Child), 73% were between 15–49 years old (Adult), 18% were between 50–64 years old (Pre-elderly) and 6% were 65 years or above (Elderly). Most of the respondents were employed (about 68%) which is not unexpected as the deployment periods were during PM peak periods where majority of the normal working group has knocked off from their work. About one in every three respondents has a private vehicle in the household. Majority of the respondents (82%) were on their way home which is not surprising as the five study locations were located in residential areas. 8% of them were going for recreational/social purposes, 5% were going to work/school and another 4% going for personal business (e.g. fetching child).

4.2. Importance rating of infrastructural compatibility factors

The average scores rated by 810 pedestrians (71% response rate) and 120 cyclists (43% response rate) for each of the 12 factors were summarised in Tables 1 and 2. Any blank for each of the 12 factors was treated as incomplete response for that question and the whole respondent string was excluded, hence resulting in the response rates. Though the response rate was not very high (especially for the cyclists as they tend to cycle off without completing the survey) and some representativeness of the sample was lost, the sample size was still respectable. ‘Distance’ which is famously known as an important determinant of walking/cycling decision (Agrawal, Schlossberg, & Irvin, 2008; Daniels & Mulley, 2011; Schlossberg et al., 2007), was ranked second both by pedestrians (after ‘Weather protection’) and cyclists (after ‘Security’). This suggests that the provision of rain shelters is a very important factor to pedestrians whereas the issue of security (in particular bicycle thefts) is a very important factor to local cyclists.

The presence of pull (seek) factors and absence of push (avoid) factors on a route not only affect a walking/cycling decision to be made, but also suggest a higher propensity of pedestrians/cyclists choosing that particular route. The ratings were made on a 4-point scale and the mean score, S_F, was computed for each factor, F, using the formula $(n_{NI}*1 + n_{SI}*2 + n_I*3 + n_{VI}*4)/n$. For example, if a factor is viewed by many pedestrians as very important, the factor’s average score is very close to 4. The higher the S_F, the more important is that factor. Examining the average score of each factor, the various factors could be divided into different tiers of importance. The different tiers suggest extent of need of the various

Table 3
Quantifying the factors.

Factors, *F*	Factor type	Measurement source	Walking	Cycling
Security, F1	Neighbourhood-based	Survey (w): sum of S1 and S2 (c): (sum of S2,S2 & S3)* 11/15 pts	10	11
Detour, F2	Route-based	RDI:1–1.42 (w)/1.51 (c) = 9-10 pts RDI > 1.42 (w)/1.51 (c) = 0 pt	9	9
Number of road crossings/delays, F3	Route-based	No crossing = 9 pts ΣD_i: 1– < 30 s × Σi = 4 pts $\Sigma D_i \geq$ 30 s × Σi = 0 pt	9	9
Directional signs, F4	Route-based	Maps, signs = 8/9 pts Nil = 0 pt	8	9
Comfort, F5	Segment-based	Surface quality: 1–5 pts Support facility: Yes +2 pts/+1 pt (c) Obstruction: No +3 pts	10	9
Weather protection, F6	Segment-based	Sheltered walkways/bridges = 12/9 pts Under buildings = 8 (w)/5 (c) pts No = 0 pt	12	9
Steps/slopes, F7	Segment-based	Nil/–(0.1–4.8)° = 9/10 pts Slope: +(0.1–4.8)° = 4 pts >±4.8°^ = 0 pts Stairs: 1–8 steps@ = 4 pts >±8 steps = 0 pt	9	10
Accident risk, F8	Segment-based	Shopping centre/walkway/void deck/grass verge/overhead bridge/underpass = 10 pts Bus interchange = 9/7 pts Staircase = 8 pts Sidewalk (shared use widened path: +1 pt; demarcated shared track: +2 pt; cyclists only exclusive cycle track: –3/+3 pt) = 7 pts Grass near carriageway = 6 pts Bus stop/along driveway = 5 pts Carpark = 4 pts Island = 3 pts Signalised PC* = 3–2 pts Across driveway/zebra crossing = 2 pts Temporary walkway = 1 pt Along/across carriageway (>2 lanes) = 0 pt	10	10
Crowdedness, F9	Segment-based	Acceptability level (>2.8) = 9/10 pts Acceptability level (2.2–2.8) = 5/6 pts Acceptability level (<2.2) = 0 pts [#pedestrians/h/m & #cyclists/h/m (applying LOSAM)]	9	10
Shops along route, F10	Segment-based	Town centre/shopping centre = 7 pts Row of shops = 5 pts Standalone shop = 3 pts Nil = 0 pt	7	7
Good scenery, F11	Segment-based	Reservoir, park, playground, lake, public realm = 7 pts Trees alongside = 5 pts Nil = 0 pt	7	7
Total points			**100**	**100**

factors. Tier 1 ($3.0 < S_F \leq 4.0$) represents the primary (must have) factors, Tier 2 ($2.5 < S_F \leq 3.0$) are the secondary factors whereas Tier 3 ($2.0 < S_F \leq 2.5$) and Tier 4 ($1.0 \leq S_F \leq 2.0$) are the 'good to have' supplementary factors. More than half of the respondents rated as 'Very important' to have rain shelter for pedestrians and good security for cyclists in Tier 1. More than 55% of the respondents rated those factors in Tier 2 as either 'Important' or 'Very Important'. For pedestrians, 'Comfort', 'Security', 'Traffic accident risk', 'Crowded walkway/roadway', 'Detour' and 'Number of road crossings/delays' are considered important factors whereas for cyclists, 'Traffic accident risk', 'Crowded walkway/roadway' and 'Stairs/slope' are the important factors.

These results suggest that transport planners and traffic engineers wanting to encourage walking/cycling should pay due attention to respective factors.

4.3. Converting average importance scores to points

The importance rating by the respondents provided a good basis to assign weightage to the various infrastructure compatibility factors. Each of the average Score, S_F is converted to Point, P_F to form a percentage possible point system (see Tables 1 and 2), for better inter-relation among the factors. In addition, a 100 percentage point also allows reader to better gauge the existing infrastructure provision of that particular audited route. The formula used for the conversion was $P_F = S_F/\Sigma S_F{}^*100$.

4.4. Quantifying infrastructural compatibility factors

For the audit, the factors are divided into three categories namely neighbourhood-based, route-based and segment based.

4.4.1. Neighbourhood-based factors

Security (F1) is considered as a neighbourhood-based factor as it is a perceived view the residents have over the entire neighbourhood. It is based on a person's own intuition and past experience of the area around him/her (Barnett, 2006). For pedestrians, security here means personal security e.g. thefts and assaults whereas for cyclists, it is mainly the issue of stolen bicycles. As "Security" is difficult to be measured quantitatively (Reid, 2008), this could be inferred from the level of agreement of some listed statements related to security issues, rated in a 5-point scale by the respondents staying in the study areas. The interview statements include (Statement 1) "The place where I stay has no security issue", (Statement 2) "The routes are brightly lit at night" and (Statement 3) "My bicycle never gets stolen" (for cyclists only).

For walking, the security point is the summation of the average points of above Statements 1 and 2 in each study area whereas for cycling, the security point is the summation of the average points of Statements 1–3 (with a maximum score of 15 points) in each study area redistributed on a 11 point scale ($\times$ 11/15) (see Table 3).

4.4.2. Route-based factors

Some factors are measured on per route basis, for example, amount of Detour (F2), Number of road crossings/delays encountered on the route (F3), and the Availability of directional signs (F4).

The detoured path that deviates from the point-to-point (crow-fly) route depends on existing surrounding land use. For example, if the route passes through private or institutional building, which is typically surrounded by fences with restricted entry/exit gates, one will have to skirt around on the premise perimeter. Koh, Wong, Chandrasekar, and Ho (2011) has found from an intercept survey with 581 pedestrians and 276 cyclists at transit stations that the 85th percentile route directness indices (RDI) are 1.42 and 1.51 for walking and cycling, respectively. RDI refers to the actual distance travelled divided by the direct origin–destination distance. The closer the RDI is to 1, the more direct is the route. Hence, any route having a RDI greater than the 85th percentile value is awarded 0 points whereas those having smaller than or equivalent 85th percentile value are pro-rated between 1–9 points. Route (1) of Fig. 4 depicts the actual route taken by the

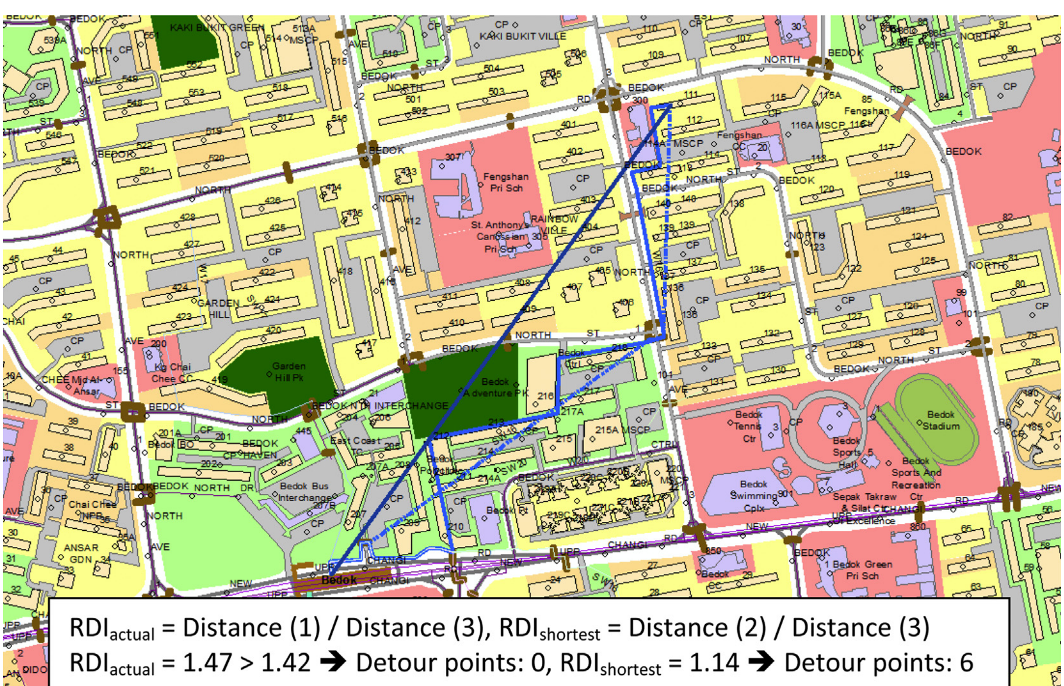

Fig. 4. An example of actual route (1), shortest possible route (2) and point-to-point route (3).

respondent, Route (2) is the shortest possible route through available designated crossing and Route (3) shows the crow-fly (point-to-point) route.

The number of road crossings encountered along the route may cause delays in the journey. For a motor-oriented country where priority is given to motorists, pedestrians are often made to wait and are only allowed to cross between long intervals to ensure minimal disruption to the smooth flowing traffic. Highway Capacity Manual 2010 (TRB, 2010) recommends the delay should be less than 30 seconds, otherwise the propensity of pedestrians disobeying the traffic signal will greatly increase. As such, if the route does not entail any crossing, it is awarded full 9 points. (This convention of first mention being for walking is used throughout the whole paper.) If the average delay of the crossings is less than 30 seconds, it is awarded 4 points; if it is more than or equal to 30 s, then it is awarded 0 points.

The provision of directional signs typically helps those unfamiliar with the area to get to their destination in the fastest way. For someone who just switches to walking or cycling, directional signs could be really useful. As road name plates are very common in the local context, only the provision of a facility map (with multi-routes) is considered as presence of directional signs. In this case, the route is awarded 8 or 9 points.

4.4.3. *Segment-based factors*

Some factors are best considered at segment-based level, for example, Comfort (F5), Weather protection (F6), Steps/slope (F7), Risk of traffic accident (F8), Crowdedness (F9), Shops along routes (F10), and Good scenery (F11).

The quality of the surface on which the pedestrian/cyclist travels on affects the level of comfort of the entire journey. If surface is poorly maintained with potholes or uneven with large cracks, this may cause some inconvenience to the pedestrians/cyclists to avoid it or to a worse extent, the pedestrian/cyclist may fall. Hence, such segments are graded 1 out of 5 points. On the other hand, if the surface is well-maintained or even paved with coloured textures (for aesthetics purpose), it is graded 5 points. If the segment is unobstructed by permanent road furniture (e.g. lamp post, electrical meter box, etc) with at least a clearance width of 1.2 m (BCA, 2007), it is awarded additional 3 points. If there are support facilities such as resting benches, smooth top railings, audio-tactile devices and Green man extension device, it is awarded additional 2 (for walking) or 1 (for cycling) points. Since such support facilities are of less relevance to a cyclist, 1 less point is awarded for the presence of the facilities. These are the additional "good-to-have" add-on requirements/facilities, especially meant for the mobility challenged user group (e.g. wheelchair users, elderly or people with special mobility needs). Without these add-ons, the facility is still operational.

The provision of shelters is an important factor for walking, especially in the hot and humid climate of Singapore. If the walkway or pedestrian overhead bridge is covered with shelters, it is awarded 12 points for walking or 9 points for cycling. Void decks and first floor corridors are considered sheltered pathways but they are not solely built for sheltering against bad weather, hence is awarded 8 or 5 points.

If the route consists of steps or upslope, one with knee problems may tend to avoid that route as he/she will need great effort to counter the terrain. According to the Code on Accessibility in the Built Environment standard, any ramp gradient should be less than 4.8° and the maximum number of steps for each flight of staircase should be not more than 8 steps (BCA, 2007). This is also consistent

Table 4
List of segment types and points.

Segment type	Separation distance from motorised traffic	Point (w)	Point (c)
Shopping centre/walkway/void deck/grass verge/overhead bridge/underpass	Far	10	11
Bus interchange (waiting area)		9	10
Staircase		8	9
Bus interchange sidewalk		7	8
Sidewalk (shared use path: +1; demarcated shared track: +2; cyclists only exclusive track: −3/+3)		7	8
Grass patch in between carriageway and sidewalk		6	7
Bus stop/along driveway		5	6
Carpark		4	5
Traffic island		3	4
Signalised pedestrian crossing[a]		3-2	4-3
Across driveway/zebra crossing		2	3
Temporary walkway	Near	1	2
Along/across carriageway		0	1

[a] ≥6 lanes (island–island) = Poor signalised pedestrian crossing (to be assigned lower point).

Table 5
Paired sample *t*-tests for comparisons of infrastructure compatibility factors (for walking) along entire routes.

Infrastructural compatibility factors	Actual (mean point)	Shortest (mean point)	Paired *t*-tests		
			t statistics	$P\ (T \le t)$ 2 tail	Bonferroni test[a]
Detour, F2	4.11	7.32	*−6.81*	*<0.001*	*S*
Road crossing delays, F3	5.04	5.08	−1.00	0.33	NS
Directional signs, F4	0.16	0.00	1.02	0.32	NS
Comfort, F5	7.03	6.53	*3.49*	*<0.001*	*S*
Weather protection, F6	3.04	3.44	−1.27	0.22	NS
Stairs/slope, F7	8.57	8.67	−1.03	0.31	NS
Accident risk, F8	7.15	7.09	0.31	0.76	NS
Crowdedness, F9	7.29	7.75	−1.77	0.09	NS
Shops along route, F10	0.74	0.44	1.71	0.10	NS
Good scenery, F11	2.15	1.21	*5.49*	*<0.001*	*S*

Italic represents significance at 95% confidence level.
[a] $\alpha = 0.05/10 = 0.005$.

Table 6
Paired sample *t*-tests for comparisons of infrastructure compatibility factors (for cycling) along entire routes.

Infrastructural compatibility factors	Actual (mean point)	Shortest (mean point)	Paired *t*-tests		
			t statistics	$P\ (T \le t)$ 2 tail	Bonferroni test
Detour, F2	4.08	6.20	*−5.46*	*<0.001*	*S*
Road crossing delays, F3	7.09	7.09	–	–	
Directional signs, F4	0.82	0.69	0.48	0.64	NS
Comfort, F5	6.97	6.72	0.43	*0.01*	NS
Weather protection, F6	1.40	1.66	−1.07	0.30	NS
Stairs/slope, F7	8.75	8.70	0.45	0.66	NS
Accident risk, F8	7.87	7.94	−0.43	0.67	NS
Crowdedness, F9	8.18	8.85	*−2.52*	*0.02*	NS
Shops along route, F10	0.64	0.66	−0.20	0.85	NS
Good scenery, F11	2.61	2.59	0.09	0.93	NS

Italic represents significance at 95% confidence level.

Table 7
Paired sample *t*-tests for comparisons of infrastructural compatibility factors (for walking) excluding overlaps.

Infrastructural compatibility factors	Actual (mean point)	Shortest (mean point)	Paired *t*-tests		
			t statistics	$P(T \le t)$ 2 tail	Bonferroni test
Detour, F2	4.11	7.32	*−6.81*	*<0.001*	*S*
Road crossing delays, F3	7.08	6.88	1.00	0.33	NS
Directional signs, F4	0.00	0.00	1.00	0.33	NS
Comfort, F5	6.86	6.31	*3.39*	*<0.001*	*S*
Weather protection, F6	2.59	3.00	−0.82	0.42	NS
Stairs/slope, F7	8.40	8.46	−0.35	0.73	NS
Accident risk, F8	7.38	7.27	0.37	0.71	NS
Crowdedness, F9	7.85	8.38	−1.74	0.09	NS
Shops along route, F10	0.57	0.18	2.05	*0.05*	NS
Good scenery, F11	2.17	1.06	*5.30*	*<0.001*	*S*

Italic represents significance at 95% confidence level.

with Canada's standard, where streets with 8% (equivalent to 4.6°) slopes are expected to have little or no bicycle traffic (Transport Canada, 2010). On the other hand, a slight downslope will aid walking/cycling as less effort is needed. These standards are hence used as the threshold values for awarding points. If it is a flat terrain or having a slight downslope (negative 0.1–4.8°), the segment is awarded full 9 points. If the segment has a slope between positive 0.1–4.8° or 1–8 steps of stairs, the segment is awarded 4 points and if the slope is more than 4.8° or more than 8 steps of stairs, no point is awarded.

Accident risk varies for different types of segments, mainly in terms of the separation distance from the motorised traffic (Michael, Green, & Farquhar, 2004). The type of segments and the respective points for walking are summarised in Table 4. For cycling, each segment type is scaled up by an extra point each.

The crowdedness of a segment can affect one's decision to use that route as it increases one's time to get to the destination. Crowded segments are often located near to the transit stations or activity centres where large volumes of pedestrians/cyclists are present. Counts of pedestrians and cyclists were taken for ten minutes during peak hours and converted to user-rated Acceptability Index (AI) using Level of Service Acceptability Matrix (LOSAM) (Koh & Wong, 2012a, 2012c). LOSAM is a user-rated matrix showing curves of various AI with pedestrian flow rates (pedestrians/h/m)

Table 8
Paired sample *t*-tests for comparisons of infrastructural compatibility factors (for cycling) excluding overlaps.

Infrastructural compatibility factors	Actual (mean point)	Shortest (mean point)	Paired *t*-tests		
			t statistics	$P(T \le t)$ 2 tail	Bonferroni test
Detour, F2	4.08	6.20	*−5.46*	*<0.001*	*S*
Road crossing delays, F3	6.72	6.72	–	–	–
Directional signs, F4	0.29	0.36	−0.32	0.75	NS
Comfort, F5	6.91	6.28	*4.68*	*<0.001*	*S*
Weather protection, F6	1.36	1.77	−1.21	0.24	NS
Stairs/slope, F7	8.76	8.50	1.93	0.07	NS
Accident risk, F8	8.05	8.52	*−2.34*	*0.03*	NS
Crowdedness, F9	8.74	9.64	*−2.74*	*0.01*	NS
Shops along route, F10	0.48	0.33	1.24	0.23	NS
Good scenery, F11	2.15	1.66	1.75	0.09	NS

Italic represents significance at 95% confidence level.

Table 9
Results of the final logistic regression model (for walking).

Variable	Estimate	Standard error	$\Pr > \chi^2$
Intercept	4.19	3.14	0.18
Scenery	0.96	0.34	0.01
Shops	1.44	0.77	0.06
Crowdedness	−0.75	0.40	0.06

plotted against cyclist flow rates (cyclists/h/m). An AI of less than 2.8 suggests that the volumes of pedestrians and cyclists are unacceptable (awarded 0 points); AI within 2.2–2.8 range suggests tolerable-acceptable level (5 or 6 points); AI of more than 2.8 suggests comfortable pedestrian and cyclist flows (9 or 11 points).

The provisions of shop(s) along the route may add convenience to a person who wishes to do shopping e.g. buy groceries on the way home. As he/she may not need to make a separate trip, the route that has shops nearby may thus be attractive to him/her. If the route cuts through a shopping centres/town centres with a variety of shops, the segment is awarded 7 or 6 points; if it is a row of shop (5 or 4 points); if it is a standalone shop (3 or 2 points).

Good scenery is another pull factor that attracts people (Borst et al., 2008; Tsukaguchi, Yeh, Jung, Vandebona, & Hsia, 2009). It could be in the form of a reservoir, park or playground which is awarded 7 points; or simply a row of neatly planted trees (awarded 5 points).

5. Comparison between actual and shortest routes

From the 50 selected walking and 50 cycling routes, a total of 867 walk segments (about 35 km) and 964 cycle segments (about 41 km) were audited by walking and cycling, respectively.

5.1. Paired sample t-tests

The comparison of infrastructure compatibility (environmental) attributes along the actual and shortest routes provides insights into the features of environment that may affect pedestrian's or cyclist's route choice. There could be various reasons why a person chooses a particular route instead of the shortest path. Comparing the scores for different aspects of infrastructure compatibility factors between the actual and shortest paths may shed information on the reasons. Tables 5 and 6 show the results of the paired sample *t*-tests (for walking and cycling) for F2–F11 except for the security factor, F1. This is because F1 is a neighbourhood-based factor and there will not be difference between actual and shortest routes within a given locality. Out of the ten factors, Detour, Comfort and Good scenery showed significant difference between actual and shortest routes at 95% confidence level for walking. It is not surprising to find that Detour factor scored significantly higher points (more direct) in favour of the shortest routes compared to the actual routes. It is found that pedestrians tend to choose more routes that provide more comfort and better scenery than the shortest ones. At 90% confidence level, Crowdedness and Shops were significant. The results of the more stringent Bonferroni Test were added to Tables 5–8 for comparison.

Table 10
Results of the final logistic regression model (for cycling).

Variable	Estimate	Standard error	$\Pr > \chi^2$
Intercept	−3.09	5.30	0.56
Crowdedness	−0.38	0.22	0.09
Stairs	1.14	0.62	0.07
Accident risk	−0.39	0.31	0.21

Table 11
The minimum, maximum and average SAI_s and the average points for the various factors (for walking) in each study area.

Study area	Min SAI_s	Max SAI_s	Ave SAI_s	Average Point										
				F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11
Admiralty	38	69	49	7.1	3.8	4.0	0.6	6.8	2.1	8.8	7.0	7.4	0.3	2.4
Aljunied	31	73	52	6.3	4.2	8.3	0.0	6.9	3.2	8.8	6.5	7.6	0.9	1.2
Ang Mo Kio	36	71	53	6.6	5.8	6.0	0.0	6.8	3.3	8.5	6.9	6.6	0.1	2.8
Bedok	29	70	48	7.2	1.5	4.0	0.0	6.9	3.2	8.7	7.7	7.0	1.9	2.4
Boon Lay	33	70	49	7.2	4.7	2.9	0.0	7.7	3.1	8.2	7.4	7.9	0.5	2.1
Full points	**0**	**100**	**100**	**10**	**9**	**9**	**8**	**10**	**12**	**9**	**10**	**9**	**7**	**7**

For cycling, only Comfort and Crowdedness show significant differences at 95% confidence level. Like pedestrians, cyclists tend to choose routes with greater comfort. Surprisingly, cyclists tend to choose routes with slightly more people compared to the shortest routes. Given that the scores for crowdedness are quite high (8 out of 11), this suggests that the audited routes are not very congested. The cyclists are more likely to choose routes with some presence of pedestrians and cyclists.

However, the actual and shortest path routes may include overlaps. In order to better appreciate and extract the extent to which infrastructure compatibility factors may cause pedestrian or cyclist to deviate from the shortest path, it may be useful to exclude segments common to both routes in the comparison analysis (see Tables 7 and 8). After excluding the overlapping segments, the paired sample *t*-tests showed that an additional factor, Shops, has significant impact (at 95% confidence level) for pedestrians when choosing routes relative to the shortest routes. For cycling, the additional factors that became significant were Accident Risk (at 95% confidence level) and Stairs/slopes and Good scenery (at 90% confidence level). It was found that cyclists tend to choose routes that are nearer to roadway (higher accident risk).

The findings therefore suggest that the overlapping segments can obscure some important factors that explain the deviation from the shortest routes. This is consistent with the observations by Lee, Jennings, and El-Geneidy (2011).

5.2. Probability of selecting a particular route

To help better contextualise and explain more robustly the results of the paired sample *t*-tests on the factors influencing pedestrian's and cyclist's route choice, logistic regression is used. The dependent variable is the probability of selecting the route (a binary response: Yes or No) while the independent variables are the audited points for each factor. Notwithstanding that Detour factor showed significant differences in the previous paired *t*-tests, Detour factor is excluded as a possible candidate (independent variable) of the model. This is because it merely showed that the detour for the selected route is larger than the shortest route (which is obvious) but does not explain much about the route choice. Multicollinearities among the independent variables were checked. It was found that "Accident risk and Weather protection" and "Crowdedness and Good Scenery" have R^2 values of 0.69 and -0.62 respectively. As such, during the stepwise logistic regression modelling, it is noted that either pair shall not appear together in the final model. Table 9 summarises the multivariate analysis of the final logistic regression models for walking route choice.

The probability of choosing a particular walking route is

$$P(Y=1)=\frac{e^{4.19+0.96\text{Scenery}+1.44\text{Shops}-0.75\text{Crowdedness}}}{1+e^{4.19+0.96\text{Scenery}+1.44\text{Shops}-0.75\text{Crowdedness}}}$$

From the Hosmer and Lemeshow, Deviance and Pearson goodness of fit tests, the final model was found to have a relatively good fit for the observed data as the chi-square statistic (10.02) was smaller than the critical value (14.07) of a chi-square distribution. From the table of 'association of predicted probabilities and observed responses', it was found that the percentage of concordant observations was 80.8% which is somewhat close to 100%.

From the parameter estimates, it is shown that the probability of selecting the route is higher if there is better scenery and more shops. Every 1 point increase of scenery would result in more than twice ($e^{0.96}=2.6$) the propensity of one choosing the route. Every 1 point increase of shops would results in 4.2 times the propensity of one choosing the route. Every 1 point decrease of crowdedness (pedestrian prefers places with presence of people) would results in 2.1 times the propensity of one choosing the route. Hence, planners and engineers should invest more to beautify the landscape as well as provide rows of shops to attract people to walk.

Table 10 summarises a similar logistic regression route choice model for cycling. The goodness of fit tests of the cycling model is not as good as the walking model (the percentage of concordant observations = 71.7%). Nevertheless, this shall not detract the findings of the calibrated model. From the parameter estimates of the final model, it is shown that the probability of selecting the cycling route is higher if the route has some people and the route does not comprise stairs/slopes. Hence, flat terrain is important for cycling. Cyclists were also found to prefer routes next to the roadways compared to taking short cuts through neighbourhood.

6. SAI interpretation

The SAI for the segments ranged between 30–74 points (see Tables 11 and 12). Aljunied has the best average SAI values for

Table 12
The minimum, maximum and average SAI_s and the average points for the various factors (for cycling) in each study area.

Study area	Min SAI_s	Max SAI_s	Ave SAI_s	Average Point										
				F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11
Admiralty	38	73	50	7.4	5.6	2.2	2.1	6.8	1.5	8.8	8.2	8.4	0.3	2.8
Aljunied	30	67	45	6.6	2.0	4.1	0.0	6.1	1.0	8.6	7.0	8.4	0.9	2.3
Ang Mo Kio	37	73	53	6.9	4.4	5.7	0.2	6.9	1.4	8.7	7.6	8.1	0.5	3.3
Bedok	31	70	49	7.2	3.2	3.1	0.3	7.3	1.5	8.8	7.7	8.3	1.1	2.5
Boon Lay	30	62	46	7.5	3.3	1.7	1.4	7.1	1.3	8.8	8.0	7.6	0.2	2.6
Full points	**0**	**100**	**100**	**11**	**9**	**8**	**9**	**9**	**9**	**9**	**11**	**11**	**7**	**7**

Fig. 5. Segment with low score for walking.

Fig. 7. Segment with low score for cycling.

walking while Admiralty and Ang Mo Kio have the best average SAI values for cycling. Figs. 5–8 depict examples of segments with lowest and highest scores for walking and cycling. Fig. 5 with a SAI of 31.6 for walking, has high accident risk and partially sheltered; Fig. 6 with a high SAI for walking is sheltered, has pleasant walking surface, has low accident risk and is near to shops; Fig. 7 with low SAI of 39.4 for cycling, has high accident risk; Fig. 8 with high SAI of 72.2 for cycling, has a dedicated track, pleasant scenery and low accident risk for cycling.

Factors 4 (Directional sign), 6 (Weather protection), 10 (Shops) and 11 (Good scenery) have the lowest average points, suggesting that the routes in all the five areas are insufficient in these aspects. Admiralty, Bedok and Boon Lay have higher security (F1) points than the other two study areas. This may be because these three residential estates are better maintained than the rest, hence look cleaner and more brightly lit. Ang Mo Kio has the highest point for pedestrian permeability (F2), suggesting the plots of land use surrounding the transit station are generally not fenced up and easily penetrable by walking. Cyclists in Admiralty tend to take the more direct routes, and this could be due to the availability of more cycling tracks in this area compared to the rest. For the delays caused by road crossings (F3), Aljunied scores the highest point for pedestrians. This showed that the selected walk routes generally either do not comprise crossings or comprise crossings with little delays. There is not much deviation on the comfort (F5) points across all study areas. This is not surprising as the infrastructure is generally well-maintained islandwide. What needs to be further improved can be the provision of support facilities such as resting benches and additional green man signal for the elderly. The provision of shelter (F6) is scored low despite that it is the most important factor for pedestrians. Hence, more efforts could be put in providing more sheltered walkways around the transit station vicinity. The study areas generally have flat terrain which explains the high score (near to full 9 points) for stairs/slope (F7). The type of segments encountered for both walking and cycling are generally well-distributed where there is no particular area that poses more accident risk (F8) than others. Ang Mo Kio has the lowest crowdedness walking score (F9) suggesting that some of the segments (especially those near the transit station) are overcrowded with people. May be some widening of the footpaths could help to alleviate the situations.

7. Discussions and conclusions

This research examined to what extent the infrastructural compatibility factors have on pedestrians' and cyclists' route choices as they commute to their destination (namely home) from

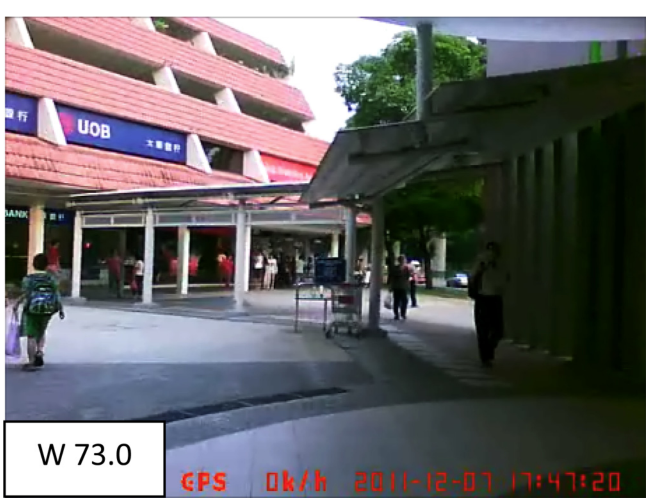

Fig. 6. Segment with high score for walking.

Fig. 8. Segment with high score for cycling.

their transit stop. The methodology and results presented here add another dimension on how pedestrians' and cyclists' route choices can be studied. As the study was intended to examine revealed preferences of users, the targeted survey respondents were commuters emanating from the transit stations to their onward destinations. The walkability and bikeability audits were carried out using quantitative measures to the furthest extent possible, to allow transferability of the methodology and comparison to other locations. This is superior to subjective assessment which, though quicker to collect, does not provide decision makers with any guidance on how to design or retrofit areas targeted for improvements of pedestrian or cyclist facilities.

The commuters' chosen routes were compared with shortest available routes based on 11 infrastructural compatibility factors. The paired sample *t*-tests at 95% confidence level revealed that a pedestrian would prefer a route that is comfortable, with shops and good scenery and preferably with the presence of other people (crowdedness). At 90% confidence level, Crowdedness has significant effect. For cyclists, they would prefer a route that is comfortable, closer to the roadways, with the presence of other pedestrians and cyclists (at 95% confidence level) and with flatter terrain (stairs/slope) and good scenery (at 90% confidence level). The logistic regression looks at the overall influence and confirms most of these factors.

Three out of 11 factors showed significant differences between the actual and shortest walking routes at 95% confidence level. When the more stringent Bonferroni Test was used, the factors, Comfort and Good Scenery still remained as significant factors of the longer routes chosen for walking. This suggests that these two factors should be considered seriously when planning for routes favouring walking. For cycling, Comfort is the important factor.

Though Weather protection is rated by pedestrians as the most important factor for walking, it did not show up to be significant both in the paired *t*-tests and logistic regression. This is likely because the main use of the rain shelters is typically during bad weather conditions such as heavy rain or very hot periods and the duration of audit is during evening hours of typical dry days. Hence, rain shelter is a situational factor and it is expected not to show up to be significant in the paired *t*-tests and logistic regression.

As for the factors Shops, Good scenery and Crowdedness, though they are not the top important factors for walking, they became significant between actual and shortest routes, indicating pedestrians tend to be significantly pulled towards these factors. This could be due to the lack of variability in the other more important factors among actual and shortest routes.

The findings in this work contribute to the general understanding of route choice and shall provide an insight for planners on what appear to be worthy to invest in upgrading routes that would be attractive to pedestrians and cyclists. More pedestrian/cyclist-friendly design also alleviates overcrowding by providing multiple equally attractive routes, thereby distributing commuters among multiple routes. This will in turn encourage more people to take on walking and cycling as sustainable modes of transport in connecting to the public transport system.

Acknowledgements

The authors would like to thank the student helpers who have contributed to participate in conducting the surveys and audits. The first author would also like to thank Dr. Chin Kian Keong for his moral support of the work. The content of the paper and any opinions expressed are the sole responsibility of the authors. All maps are adapted from Land Transport Authority and Singapore Land Authority.

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