Modelling for Walkability
Understanding pedestrians’ preferences in Singapore

Alex Erath, Michael van Eggermond, Sergio Ordóñez, Kay Axhausen

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23rd July 2015
Motivation

Walking is the most basic and prevalent form of transport (in cities).

Long legacy of elaborate planning tools and design guidelines for roads and public transport.

But most cities are just starting to plan for walkability.

Existing research highlights distance as dominant attribute.
Singapore context

Focus has been on creating an efficient, *modern* transport system.

Very effective (technocratic) civil service.

Walking and cycling are now big topics in Singapore’s Masterplan.

What can be measured counts more.
Situations pedestrians face in Singapore
Situations pedestrians face in Singapore
Addressed research questions

Surveying the **physical environment**
- What to measure?
- How to quantify?
- How do we measure it?

Surveying and modelling **behavior**
- Based on revealed preference
- Based on stated preference

**Developing a software tool for planners**
- For planners to assess infrastructure and policy measures
- A new ArcGIS add-in
Measurement framework

Physical characteristics
- Level of lighting
- Quality of surface
- Slipperiness
- Obstructions
- Separation - horizontal
- Separation - vertical
- Walkway width
- Level of construction
- Wheelchair accessibility
- Number of steps
- Number of pedestrians
- Noise level
- Vertical transport
- Coverage

Urban design qualities
- Greenery
- Shade from greenery
- Transparency
- Enclosure
- Imageability
- Human Scale
- Maintenance

Crossings
- Road type
- Type of crossing

Overall walking quality

Observed behavior

Individual perception
- Satisfaction
- Sense of safety
- Sense of comfort
- Level of interest

Extent of the pedestrian network

About 7.7 km\(^2\)
43 km walkways
### Beach road

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Width open walkway</strong></td>
<td>1-2m</td>
</tr>
<tr>
<td><strong>Width covered walkway</strong></td>
<td>n.a.</td>
</tr>
<tr>
<td><strong>Separation horizontal</strong></td>
<td>1-3m</td>
</tr>
<tr>
<td><strong>Separation vertical</strong></td>
<td>medium high hedge</td>
</tr>
<tr>
<td><strong>Noise level</strong></td>
<td>69db</td>
</tr>
<tr>
<td><strong>Noise source</strong></td>
<td>Mainly from street</td>
</tr>
<tr>
<td><strong>Maintenance</strong></td>
<td>5/5 – no rubbish in sight</td>
</tr>
<tr>
<td><strong>Slipperiness</strong></td>
<td>No, no tendency to slipperiness</td>
</tr>
<tr>
<td><strong>Greenery</strong></td>
<td>5/5 – lush greenery</td>
</tr>
<tr>
<td><strong>Shade from greenery</strong></td>
<td>4/5 - clearly shaded</td>
</tr>
<tr>
<td><strong>Obstructions</strong></td>
<td>0 – no obstructions in sight</td>
</tr>
<tr>
<td><strong>Construction</strong></td>
<td>0%</td>
</tr>
<tr>
<td><strong>Imageability</strong></td>
<td>1 feature</td>
</tr>
<tr>
<td><strong>Human scale</strong></td>
<td>1 feature</td>
</tr>
<tr>
<td><strong>Enclosure</strong></td>
<td>4/5</td>
</tr>
<tr>
<td><strong>Transparency</strong></td>
<td>0/100</td>
</tr>
<tr>
<td><strong>Level of lighting</strong></td>
<td>2/5 – small amount</td>
</tr>
<tr>
<td><strong>Number of persons</strong></td>
<td>5</td>
</tr>
<tr>
<td><strong>Wheelchair</strong></td>
<td>fully accessible</td>
</tr>
<tr>
<td><strong>Date</strong></td>
<td>6. July 2014</td>
</tr>
</tbody>
</table>
Sultan Gate

<table>
<thead>
<tr>
<th>Feature</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width open walkway</td>
<td>2 – 3 m</td>
</tr>
<tr>
<td>Width covered walkway</td>
<td>1 – 2m</td>
</tr>
<tr>
<td>Separation horizontal</td>
<td>1-3m</td>
</tr>
<tr>
<td>Separation vertical</td>
<td>grass</td>
</tr>
<tr>
<td>Noise level</td>
<td>60db</td>
</tr>
<tr>
<td>Noise source</td>
<td>Mainly from street</td>
</tr>
<tr>
<td>Maintenance</td>
<td>4/5 – a little rubbish in sight</td>
</tr>
<tr>
<td>Slipperiness</td>
<td>No, no tendency to slipperiness</td>
</tr>
<tr>
<td>Greenery</td>
<td>3/5 – some greenery</td>
</tr>
<tr>
<td>Shade from greenery</td>
<td>1/5 - no shade from greenery</td>
</tr>
<tr>
<td>Obstructions</td>
<td>0 – no obstructions in sight</td>
</tr>
<tr>
<td>Construction</td>
<td>0%</td>
</tr>
<tr>
<td>Imageability</td>
<td>2 features</td>
</tr>
<tr>
<td>Human scale</td>
<td>13 features</td>
</tr>
<tr>
<td>Enclosure</td>
<td>4/5</td>
</tr>
<tr>
<td>Transparency</td>
<td>40/100</td>
</tr>
<tr>
<td>Level of lighting</td>
<td>2/5 – small amount</td>
</tr>
<tr>
<td>Number of persons</td>
<td>4</td>
</tr>
<tr>
<td>Wheelchair</td>
<td>fully accessible</td>
</tr>
<tr>
<td>Date</td>
<td>8. July 2014</td>
</tr>
</tbody>
</table>
How people walk in Singapore

... and how they experience it.
**Some basic facts**

<table>
<thead>
<tr>
<th>Data collection period</th>
<th>March / April 2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of valid tracks:</td>
<td>1077</td>
</tr>
<tr>
<td>Average walking distance:</td>
<td>259 m</td>
</tr>
<tr>
<td>Median walking distance:</td>
<td>210 m</td>
</tr>
<tr>
<td>Lower quartile:</td>
<td>143 m</td>
</tr>
<tr>
<td>Upper quartile:</td>
<td>305 m</td>
</tr>
<tr>
<td>Max:</td>
<td>2059 m</td>
</tr>
<tr>
<td>Average walking duration</td>
<td>3.96 min</td>
</tr>
<tr>
<td>Median walking duration</td>
<td>3.23 min</td>
</tr>
<tr>
<td>Average walking speed</td>
<td>4.51 km/h</td>
</tr>
<tr>
<td>Median walking speed</td>
<td>3.98 km/h</td>
</tr>
</tbody>
</table>

**Comparison of average walking distance in other cities:**

- **Calgary, city centre (1986):** 330m
- **Portland, city centre / whole city (2014):** 790m / 446m
- **San Jose / Portland, MRT stops (2012):** 832m

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Who walks where?

Pedestrian tracks

Age [binned]
- n.a.
- 10 - 20
- 20 - 30
- 30 - 40
- 40 - 50
- 50 - 60
- 60 - 70
- above 70

Interactive graph available at: https://public.tableau.com/profile/alexerath#!vizhome/Directorsmeeting/Sampling1024
How long, why, when?

Distance [m]

Activity before

Activity after

Time of day
Sampling and walking distance by demography

Walking distances by age

Walking distances by gender

Walking distances by ethnicity

Walking distance [m]

Share of observations

Chinese Indian Malay Other

Female Male
Walking distance by weather

Compared to sunny conditions, people walk:

- Cloudy: +37 meters
- Drizzling: -98 meters

We have too few observation of walks in heavy rain condition to draw a valid conclusion.
Walking distance by activity before and after

None of the activity types statistically significantly explain walking distance
Pedestrian experience

Pedestrian experience

<table>
<thead>
<tr>
<th>Felt safe during all times</th>
<th>Noticed something interesting</th>
<th>People hanging out / socialising</th>
<th>Waiting at traffic light</th>
<th>Crowded footpath</th>
<th>Obstructions</th>
<th>Loud noise</th>
<th>Watching out for parking traffic</th>
<th>Heavy sweating</th>
<th>Watching out for traffic when crossing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Rating of walking experience [1-10]

0 50 100 150 200 250 300 350 400

Count of being mentioned
What impacts walking satisfaction?

<table>
<thead>
<tr>
<th>Variable</th>
<th>Experience</th>
<th>Environment</th>
<th>Sociodemography</th>
</tr>
</thead>
<tbody>
<tr>
<td>Felt safe, male</td>
<td>&gt; 99.9%</td>
<td>&gt; 99 %</td>
<td></td>
</tr>
<tr>
<td>Felt safe, female</td>
<td>&gt; 90 %</td>
<td>&gt; 90 %</td>
<td></td>
</tr>
<tr>
<td>Saw something interesting</td>
<td>&gt; 90 %</td>
<td>&gt; 90 %</td>
<td></td>
</tr>
<tr>
<td>Saw people socialising</td>
<td>&gt; 90 %</td>
<td>&gt; 90 %</td>
<td></td>
</tr>
<tr>
<td>Heavy sweating, male</td>
<td>&gt; 95 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loud noise, female</td>
<td>&gt; 95 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Obstructions</td>
<td>&gt; 95 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Watching out for traffic when crossing</td>
<td>&gt; 95 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>From zero to primarily transparent frontage</td>
<td>&gt; 95 %</td>
<td>&gt; 95 %</td>
<td></td>
</tr>
<tr>
<td>From bad to very good surface</td>
<td>&gt; 95 %</td>
<td>&gt; 95 %</td>
<td></td>
</tr>
<tr>
<td>From zero to lush greenery, female</td>
<td>&gt; 95 %</td>
<td>&gt; 95 %</td>
<td></td>
</tr>
<tr>
<td>From zero to lush greenery, male</td>
<td></td>
<td>&gt; 85%</td>
<td></td>
</tr>
<tr>
<td>Additional zebra crossing</td>
<td>&gt; 90 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>&gt; 90 %</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$r^2 = 0.124, n = 772$

Other variables that have been tested include: walking frequency, ethnicity, age, activity before and after, human scale, imageability, obstruction, maintenance, width, Enclosure, slipperiness, shade from greenery, availability of cover, horizontal and vertical separation, noise level, constructions site, weather, mode before and after.
Why this route, when it is sunny/cloudy?

- Shortest route
- Always take this route
- Pleasant walking environment
- Safe from traffic
- Good pavement
- Well shaded
- Shops along the way
- Avoid crowded areas
- Rain cover
- Avoids traffic lights
- Avoids jaywalking
- Avoids traffic over or underpass

Share of being mentioned
Why this route, when it is rainy?

- Shortest route: 70%
- Always take this route: 10%
- Pleasant walking environment: 10%
- Safe from traffic: 5%
- Good pavement: 5%
- Well shaded: 5%
- Shops along the way: 5%
- Avoid crowded areas: 5%
- Rain cover: 30%
- Avoids traffic lights: 5%
- Avoids traffic over or underpass: 5%

Share of being mentioned
Stated preference survey

Using illustrations to depict different walking conditions in a choice experiment
An illustration-based stated preference experiment

Some discussions at ISTSC

Other typical situations

- Through a park
- Underground / through block
## Experiment design

### Walking environment

**Road**
- Traffic
  - Minor (two way, 2 lanes) / Major (one way, 4 lanes)
- Greenery / horizontal separation
  - Yes / No
- Active frontage
  - with shops / without
- Rain cover
  - Yes / No

**Park**
- Greenery
  - Lush / little

**Underground**
- Scenery
  - With shops / without

### Road crossing

**Traffic lights**
- 0 / 1 / 2

**Overpasses**
- 0 / 1

**Inofficial crossing / jaywalk**
- 2 lanes (two way) / 4 lanes (one way)

**Underpass (only in subset)**
- with escalator / stairs

### Other factors

**Weather**
- Sunny / rainy / cloudy
Which route would you prefer?

ROUTE 1
- Major road, no shops, no cover, with trees
- 6 min walking
- Overhead bridge

ROUTE 2
- Minor road, with shops, no cover, without trees
- 12 min walking
- No crossing required

Day: Sunny
Time: 1:00 pm
**Response rates**

Overall: 315 from 1113 recruited persons -> 28.3 %
Specification of web-based route choice model

\[ U = \beta_t \cdot time \cdot ( \left( 1 + \beta_{\text{min}} \cdot \text{minor} + \beta_{\text{maj}} \cdot \text{major} + \beta_u \cdot \text{under} \cdot (1 + \beta_{ur} \cdot \text{rainy}) \right) \cdot \left( 1 + \beta_g \cdot \text{greenery} \right) \cdot \left( 1 + \beta_s \cdot \text{shops} \right) \cdot \left( 1 + \beta_c \cdot \text{cover} \cdot (1 + \beta_{cs} \cdot \text{sunny} + \beta_{cr} \cdot \text{rainy}) \right) + \beta_o \cdot \text{overpass} + \beta_{ol} \cdot \text{overpass}_{\text{lift}} + \beta_{j2} \cdot \text{jaywalk}_{\text{2lanes}} + \beta_{tl} \cdot \text{trafficlight}_{\text{wait}} \) \]
## Results of choice model

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
<th>Sign. (&gt;95%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walking time (through park, cloudy) [min]</td>
<td>-0.019</td>
<td>*</td>
</tr>
<tr>
<td>along major road</td>
<td>+59%</td>
<td>*</td>
</tr>
<tr>
<td>along minor road</td>
<td>+47%</td>
<td>*</td>
</tr>
<tr>
<td>cover</td>
<td>-18%</td>
<td>*</td>
</tr>
<tr>
<td>when rainy</td>
<td>-75%</td>
<td>*</td>
</tr>
<tr>
<td>when sunny</td>
<td>-51%</td>
<td>*</td>
</tr>
<tr>
<td>through block/underpass</td>
<td>-16%</td>
<td>*</td>
</tr>
<tr>
<td>when rainy</td>
<td>-66%</td>
<td>*</td>
</tr>
<tr>
<td>with greenery</td>
<td>-23%</td>
<td>*</td>
</tr>
<tr>
<td>with active frontage</td>
<td>-18%</td>
<td>*</td>
</tr>
<tr>
<td>Crossing 2-lane road</td>
<td>-0.015</td>
<td>*</td>
</tr>
<tr>
<td>Crossing 4-lane road</td>
<td>-0.094</td>
<td>*</td>
</tr>
<tr>
<td>Overpass</td>
<td>-0.082</td>
<td>*</td>
</tr>
<tr>
<td>Overpass with lift</td>
<td>-0.043</td>
<td>*</td>
</tr>
<tr>
<td>Trafficlight</td>
<td>-0.016</td>
<td>*</td>
</tr>
</tbody>
</table>

n = 2451, $\rho^2 = 0.131$
Numerical example

\[ U = -0.00193 \cdot 10 \cdot \left( 1 + 0.473 \cdot \text{minor} + \beta_{maj} \cdot 0 + \beta_{u} \cdot \text{under} \cdot \left( 1 + \beta_{ur} \cdot 0 \right) \right) \cdot \left( 1 + -0.228 \cdot \text{greenery} \right) \cdot \left( 1 + -0.175 \cdot \text{shops} \right) \cdot \left( 1 + -0.175 \cdot \text{cover} \cdot \left( 1 + 1.9 \cdot \text{sunny} + \beta_{cr} \cdot 0 \right) \right) + \beta_{o} \cdot 0 + \beta_{ol} \cdot 0 + \beta_{j2} \cdot 0 + \beta_{j4} \cdot 0 + \beta_{tl} \cdot 0 \]

\[ = -0.00193 \cdot 10 \cdot 0.62 \]
Interpretation of web-survey results

Reference case
Interpretation of web-survey results

Add greenery (-23%) and shops (-18%)
Interpretation of web-survey results

Add cover: -33% perceived walking time
Interpretation of web-survey results

Tropical rain sets in

Reference: 5.6 min

14.8 min

7.4 min

6.1 min
Crossings’ equivalent of walking time

- **Jaywalking, 4 lanes**: 4.9 min
- **Overpass**: 4.2 min
- **Traffic light**: 1 min
- **Jaywalking, 2 lanes**: 0.8 min
- **Overpass with lift**: 2.2 min
- **Underpass with stairs**: 2.0 min*
- **Underpass with Escalator**: 1 min*

*Stat. not significant as variable only available in subsample -> assumed values for walkability tool.
Synthesis

An ArcGIS add-in to plan for walkability
Heterogeneity in perceived distance when it is cloudy...
... and rainy.
New ArcGIS add-in for planners

https://vimeo.com/132168191
Distance weighted accessibility

\[ \lambda = \frac{1}{\text{mean(walking time)}} = \frac{1}{3.96} = 0.25 \]

\[ y = e^{-\lambda x} \]

Weighted impact

100% 28% 8% 2%
Connecting Hong Lim complex with Nankin Road
The barrier effect of the overhead bridge
The barrier effect of the overhead bridge

38% more area
47% more doors
Walkability in Singapore

The map illustrates the walkability levels in Singapore, with areas colored from low (blue) to high (orange/yellow) walkability. The map is sourced from various entities including Esri, HERE, DeLorme, TomTom, Intermap, Increment P Corp., GEBCO, USGS, FAO, NPS, NRCan, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community.
Remaining tasks and future research

Modelling of revealed preference data:
• Influence of turns, wayfinding
• Traffic lights
• Distance vs built environment attributes based on actual behavior

Other possible research avenues:
• Reported vs actual distance
• Structure equation modelling to explain perception of safety, comfort, interest
• Correlation of built environment attributes

Open questions:
• Influence of crowding and width of walkway
• Heterogeneity of built up environment
• Perceived cost of vertical movement
• Wind as a comfort factor
The team to make it happen

Michael van Eggermond
Spatial database, methodology

Sergio Ordonez
PhD student
App, ArcGIS add-in

Prof. Dr. Kay Axhausen
PI

Dr. Alex Erath
Survey, modelling, methodology

Kim Helmersen
Piloting

Atizaz Ali
Survey support, Network cleaning
Thank you!

Future Cities Laboratory
www.futurecities.ethz.ch

 @_fcl
 @alex_erath
Case study
Adding zebra crossings around Robinson Road
Conclusion and policy recommendations

Key findings
Key findings

Who walks?
- Primarily public transport users
- No real segmentation by age, sex or ethnicity
- To get to various types of activities

How to plan for a good walking experience?
- Safe walking environment
- Create social, interesting environments
- Provide shelter from sun and rain
Key findings

Most frequently mentioned suggestions for improvement:

- More shade / cover
- Wider sidewalk
- Shorter waiting time at traffic lights
- More direct route

How to make a walk shorter?

Greenery: -23%

Covered walkway: - 17% / - 33 % / -75% (cloudy / sunny / rainy)

Underground: - 17 % (as compared to park)

Active frontage: -18%
Remaining tasks and future research

Model pedestrian route choice to better understand influence of:
  • Influence of turns, wayfinding
  • Traffic lights
  • Distance vs built environment based on actual behavior

Open questions:
  • Influence of crowding and width of walkway
  • Heterogeneity of built up environment
  • Perceived cost of vertical movement
  • Wind as a comfort factor
Next steps

Role out of Walkability Tool
- Workshop in August 2015
- Preparation of ArcGIS geodatabase
- Archiving of survey data and models

Topics for potential next phase
- Walkability in new towns
- Understanding of destination choice
- Enhance Walkability tool
  - Link it to spatial databases, e.g. building inventory, MATSim
  - Map pedestrian potential
  - Model pedestrian flows
Appendices
Pedestrian network audit

Collecting information for 43km walkways
Network data collected by URA

At grade

- Open walkway (14005 features)
- Covered walkway (6195 features)
- Through block link (829 features)
- Traffic crossing (405 features)
- Unit link (4538 features)
- Unofficial crossing (1175 features)
- Zebra crossing (164 features)

Below grade

Above grade

Access points

Building entrances
Simplification of network to collect characteristics

At grade network (27311 features);
Each color represents a feature

Link clusters (2833 features);
Each color represents a cluster
Developing a survey manual

Walkability in Singapore
Pedestrian Network Survey Manual

Greenery

Step 1: Walk along the entire length of the link cluster.

Step 2: As you walk, note the level of greenery on your side of the road. Assess the total level of greenery comprised of lawns, hedges, trees, potted plants, and vertical planted greenery.

Step 3: Record the level of greenery using your tablet on a scale from 1 to 5.

If there are considerable differences in the level of greenery within a link cluster, use a weighted average and round it to the nearest integer. If about 40% of the area has no greenery at all, and the other 60% features lush greenery, this would result in the following calculation: (0.4 * 1 + 0.6 * 5) = 3.4 → 3

Note: Figures 1 to 5 show examples of the different levels of greenery. The figures show the scope of different types of greenery that you may encounter. Bear in mind that the different types don’t directly correspond to a particular level. i.e. level 4 does not necessarily require a hedge and trees. The figures are rather to give you an indication of the amount of greenery that refers to each level.
Collector for ArcGIS

Use your smartphone or tablet to collect and update information in the field, whether connected or disconnected.

Your update can include modifying the feature’s attributes and location, as well as adding and deleting photos.
Simplification for analysis

Pedestrians choose their route from a number of distinct routes;

A network containing many links generates many similar route alternatives. One can envisage this by enumerating the number of routes possible alongside a row of shophouses, where each covered and open walkway is a separate link.

The initial network is redrawn so that it is suitable for network analysis purposes, leading to faster analysis, and a network for which it is easier to collect data for.
Pedestrian experience

Interactive graph available at: https://public.tableau.com/views/Directorsmeeting/ExperienceMap_1024

Pedestrian tracks by overall rating of walking experience

Rating of walking experience [0-10]

- weather
  - n.a.
  - Sunny
  - Cloudy
  - Drizzling
  - Heavy rain

Experiences

- Felt safe during all times
- Noticed something interesting
- People hanging out / socialising
- Waiting at traffic light
- Crowded footpath
- Obstructions
- Loud noise
- Watching out for parking traffic
- Watching out for traffic when crossing

Overall rating

- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10
And how to improve the experience?

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Suggestions</th>
<th>Share of being mentioned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sunny</td>
<td>More shade</td>
<td>621 Observations</td>
</tr>
<tr>
<td></td>
<td>More rain cover</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wider sidewalk</td>
<td></td>
</tr>
<tr>
<td></td>
<td>More greenery</td>
<td></td>
</tr>
<tr>
<td></td>
<td>More direct route</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shorter waiting time at traffic light</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Marked crossing; e.g. zebra or tr.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fewer obstacles; e.g. curbs; gar.</td>
<td></td>
</tr>
<tr>
<td></td>
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Behavioral models
From actual to perceived distance
Walkability Tool

A new ArcGIS add-in to compute walkability