A NEW APPROACH TO MODEL DISTANCE-DECAY FUNCTIONS FOR ACCESSIBILITY AND TRANSPORT STUDIES

Acknowledgements

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Introduction

Background

q Spatial interactions models are a key component of transport demand modelling and accessibility studies.

q Three main research areas use these type of models:

§ Transport Geography

§ Accessibility assessment

§ Spatial choice research
Introduction

Objective of this research

- Absence of refinements to these models in the last decades
- The relevance of this topic and the inability to precisely reproduce spatial interactions phenomena
- Room to improve current formulations
- Use of a stated preferences survey to assess the willingness to travel to different activities depending on their access time
- Creation of a new methodology to estimate distance-decay functions – **bottom-up approach**
Two-stage approach:

**STAGE 1**
Modelling individual’s perception of spatial interaction

**STAGE 2**
Aggregate construction of distance-decay function

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From individual to aggregate distance-decay functions

Individual perception of spatial interaction

Conceptualisation

q Based on psychological value of the linguistic terms “near” and “far”

§ Psychology on the appetition-aversion concept
  • measured by an uni-dimensional attribute on a single assessment procedure

§ Cognitive studies on human perception of the objects in an environment
  • the brain is able to communicate an almost unlimited range of spatial-distance contrasts

Hypothesis: Willingness to go from point $a$ to point $b$ to carry out activity $c$, represented in a continuous appetition-aversion between “near” and “far” statements
From individual to aggregate distance-decay functions

Individual perception of spatial interaction

Formulation

q Consideration of “willingness to go” as a probability

q Monotonous function formed by linear segments between notable points:

§ “Near” and P (“Near”)
§ “Far” and P (“Far”)
§ “Very far” – A x “Far”

q According to our current approach there is the need to calibrate the following parameters:

§ P (“Near”)
§ P (“Far”)
§ A
From individual to aggregate distance-decay functions

Aggregate distance-decay function

Formulation

- Aggregation of individual curves to obtain the global distance-decay function of the population
  - Average of the values of time for each value of “willingness to go”

- Generation of a society empirical curve that will be used to calibrate analytical theoretical functions

- Change on the calibration process of distance-decay function – from matrixes of zones to a continuous curve
Survey structure and data description
Overview of the survey’s framework

q Survey integrated on the SOTUR project of the MIT-Portugal Program
   § Collected data about all the factors that influence residential choice and, in more detail, the impacts of accessibility on this choice

q Case-study – Lisbon Metropolitan Area:
   § 2,682,687 inhabitants (21% in Lisbon Municipality)
   § 19 municipalities, with a total area of 3,195 km² (2.8% in Lisbon Municipality)

q Survey developed in three different phases
   1. Invitation e-mail to members of our research group mailing list (91)
   2. freely accessible online version (162)
   3. Computer Assisted In-Person Interviews (CAPI) (1,030)

THIS RESULTED IN 1,282 VALID ANSWERS
Survey structure and data description

Accessibility section specification

Structure

1. Apart from the socio-demographic characterisation, two different questions were asked about the perception of what is “near” and “far” to access different activities:
   - Public transport stations and ATMs (mandatory question)
   - Choice of 5 frequently performed activities among a set of 18

2. Additional characterisation of the second set of questions:
   - Transport mode (e.g. walk, car and subway)
   - Stability of choice related to the visited place
   - Most regular base point for this travel
   - Trip chain in which this activity is normally included

It was obtained a minimum of 9 activities per answer, with an average of 14
Survey structure and data description

Obtained data characterisation

1. Aggregate assessment of the “near” and “far” reporting
   - Regular peaking at traditional values as 5, 10 and 15 minutes
   - “Near” classification less dispersed than “Far”
   - “Far” dispersion is related to the residential location (daily experienced)
Survey structure and data description

Obtained data characterisation

q Ratio between statement of “far” and “near” for the same activity

§ Trend for the values to be concentrated in 2.5 times greater than “near”

§ Expected approximate relation of 3 between these two indicators (e.g. 5 to 15 minutes)

§ Yet, it can be observed some persons more tolerable to the concept of “far”
## Survey structure and data description

**Obtained data characterisation**

q Different perception for the land use types (nature of the activity)

<table>
<thead>
<tr>
<th>Land Uses / Public Transport stops and stations</th>
<th>Average &quot;Near&quot; perception [minutes]</th>
<th>St. dev. &quot;Near&quot; perception [minutes]</th>
<th>Average &quot;Far&quot; perception [minutes]</th>
<th>St. dev. &quot;Far&quot; perception [minutes]</th>
<th>Average ratio between &quot;Far&quot; and &quot;Near&quot; perception</th>
<th>Total number of answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>8.18</td>
<td>5.36</td>
<td>18.48</td>
<td>9.22</td>
<td>2.88</td>
<td>14,882</td>
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<td>Bus stop</td>
<td>6.04</td>
<td>3.74</td>
<td>14.91</td>
<td>7.15</td>
<td>3.04</td>
<td>1,195</td>
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<tr>
<td>Subway station</td>
<td>7.60</td>
<td>5.10</td>
<td>16.67</td>
<td>7.45</td>
<td>2.74</td>
<td>1,125</td>
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<tr>
<td>Train station</td>
<td>8.53</td>
<td>5.04</td>
<td>18.08</td>
<td>7.68</td>
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<td>1,177</td>
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<td>ATM</td>
<td>5.78</td>
<td>3.76</td>
<td>14.22</td>
<td>7.34</td>
<td>3.12</td>
<td>1,222</td>
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<tr>
<td>Grocery stores</td>
<td>6.78</td>
<td>4.38</td>
<td>15.96</td>
<td>8.43</td>
<td>2.82</td>
<td>898</td>
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<tr>
<td>Supermarkets</td>
<td>7.88</td>
<td>4.43</td>
<td>18.42</td>
<td>8.68</td>
<td>2.73</td>
<td>1,101</td>
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<tr>
<td>Hairdressers</td>
<td>7.85</td>
<td>5.43</td>
<td>17.87</td>
<td>8.79</td>
<td>3.07</td>
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<tr>
<td>Health Centres</td>
<td>8.46</td>
<td>5.13</td>
<td>19.35</td>
<td>9.03</td>
<td>2.82</td>
<td>910</td>
</tr>
<tr>
<td>Pharmacies</td>
<td>6.77</td>
<td>4.41</td>
<td>16.34</td>
<td>8.08</td>
<td>2.90</td>
<td>982</td>
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<tr>
<td>Bank offices</td>
<td>7.49</td>
<td>4.60</td>
<td>17.81</td>
<td>8.42</td>
<td>2.99</td>
<td>622</td>
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<tr>
<td>Public services</td>
<td>9.63</td>
<td>5.50</td>
<td>21.15</td>
<td>9.19</td>
<td>2.73</td>
<td>582</td>
</tr>
<tr>
<td>Cinemas</td>
<td>11.15</td>
<td>6.05</td>
<td>24.82</td>
<td>9.95</td>
<td>2.90</td>
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<td>Coffee houses</td>
<td>5.99</td>
<td>4.22</td>
<td>15.19</td>
<td>8.68</td>
<td>3.41</td>
<td>825</td>
</tr>
</tbody>
</table>
Application of the methodology to the case study

Experiment design

Definition of parameters of the individual distance-decay function

- \( P \) ("near") ranging from 0.75 to 0.95, with 0.05 interval
- \( P \) ("far") ranging from 0.05 to 0.25, with 0.05 interval
- "A" was set equal to 2

GENERATION OF 25 DIFFERENT SCENARIOS
Application of the methodology to the case study

Experimental design

- Test of a new formulation
- **Hypothesis:** Richard’s function is able to adjust better to the stated empirical curve
  -Never used in Gravity models, with origins in Botanic
  -Formulation:

$$f(x) = \frac{K - A}{(1 + Qe^{-B(x-M)})^{1/ν}}$$

- Comparison of Richard’s formulation with four different possible calibration curves

<table>
<thead>
<tr>
<th>Impedance function</th>
<th>Basic form in literature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exponential function</td>
<td>$e^{βx}$</td>
</tr>
<tr>
<td>Power function</td>
<td>$x^β$</td>
</tr>
<tr>
<td>Tanner function</td>
<td>$x^{β_1}e^{β_2x}$</td>
</tr>
<tr>
<td>Box-Cox function</td>
<td>[ \begin{cases} \exp\left(β\frac{x^λ - 1}{λ}\right), &amp; λ \neq 0 \ x^β, &amp; λ = 0 \end{cases} ]</td>
</tr>
</tbody>
</table>
Application of the methodology to the case study

Experimental design

- Least minimum square calibration, which is equivalent to maximum likelihood in this case
- Use of four different indicators to compare calibration functions
  - Residual sum of squares (RSS)
  - Standard error of calibration (SEC), \( SEC = \sqrt{\frac{\sum (y_i - \hat{y}_i)^2}{n-p-1}} \), where \( n \) is the number of calibration points and \( p \) the number of parameters estimated
  - \( R^2 \)
  - Quality comparison indicator defined as the ratio between the SEC of each impedance function and the SEC of the Richards function (Richards ratio - RQ)
Application of the methodology to the case study

Functions overview

BEHAVIOUR OF EACH FUNCTION CALIBRATED FOR ONE SCENARIO OF THE EMPIRICAL DATA
Application of the methodology to the case study
Comparison among formulations

Box-Cox is the only function that presents similar performance indicators as the Richard’s formulation.

However, the Box-Cox function has a problem in the calibration of f(0), presenting values above 1.
Application of the methodology to the case study

Comparison among formulations

- Exponential function presents a calibration significantly below Richard’s function, although with high $R^2$ values
- When the empirical curve presents a shape approximately linear, the exponential curve improves its fit.
Application of the methodology to the case study  
Comparison among formulations

- Power function is the worst in the reproduction of the empirical data
- Its accuracy improves for high values of \( P \) ("far") and \( P \) ("near")
Application of the methodology to the case study
Comparison among formulations

- Tanner function presents a big limitation since \( f(0) = 0 \), having high errors in the initial section of the empirical curve.
- The shorter the initial section (high value of \( P \) (“near”)) the better.
Application of the methodology to the case study
Richard’s function characterisation

- Better behaviour in non-linear experimental curve shapes, when compared to the other formulations
- Yet, it can be seen that the error of the calibration also increases in curves with greater variation.
Conclusions and further developments

Methodology developed

**Formulation**

- Development of a new approach for distance-decay function estimation
- Based on stated preferences micro-data instead of O/D matrixes (emergent approach)
- Test of a new impedance function based on a curve from Botany

**Results analysis**

- Good approach to model processes where short range accessibility is relevant
  - Increase of the relevancy of short distance trips, which normally are neglected in current approaches

§ Possible to integrate Richard’s function in traditional spatial interaction models (e.g. Gravity Models)
Conclusions and further developments

Envisaged research

- Imprecision in the establishment of the individual curve’s notable points
- Need to conduct a stated preferences survey to extract the users’ perceptions on “near” and “far” probabilities
- Future steps of this research may allow the segmentation of spatial interaction functions for different activities and access transport modes
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