Daily Urban Mobility:  
a Multi-level Analysis of Survey Data  

Mobilità Giornaliera: un Modello Multilivello Applicato a Dati Campionari

Marco Bottai  
Dip. di Statistica e Matematica Applicata all’Economia, via Ridolfi 10, 56124 Pisa,  
e-mail: marcomit@ec.unipi.it

Nicola Salvati  
Dip. di Statistica “G.Parenti”, viale Morgagni 59, 50134 Firenze,  
e-mail: salvati@ds.unifi.it

Riassunto: Questo lavoro presenta i primi risultati di un’indagine campionaria effettuata presso i residenti del comune di Pisa su un campione casuale di 373 intervistati nell’autunno del 2002. Fra le altre cose l’indagine ricostruiva tutti gli spostamenti effettuati in una giornata da ciascuno dei membri del nucleo familiare dell’intervistato. Un particolare valore informativo il lavoro assume in ordine agli aspetti meno indagati della fruizione dello spazio come ad esempio le differenze dell’uso dello spazio per maschi e femmine, per giovani e adulti. Per far questo abbiamo utilizzato un modello multilivello e come variabile di studio la distanza percorsa e il numero di spostamenti.

Keywords: spatial behaviour, daily mobility, multi-level model.

1. Introduction

The steadily increasing use of polluting means of transportation for moving about is of growing concern in urban areas across the country. In particular, cars are used too often and car pools are too seldom seen. Commuting to work or school has been extensively studied in the past. On the other hand, less is known about trips that are related to the family network, shopping or vacations. These trips combined represent about 60% of all the trips taken daily (Bottai, Barsotti, 1994).

This research project is aimed at modeling the distance covered and the number of trips as functions of the numerous characteristics that have been collected on each individual. Moreover, a great deal of attention is devoted to graphs as a way to more easily understand the individual spatial behaviour of individual subgroups, time variables, reasons and means of transportation (Baccaïni, 1997; Camstra, 1996; Tkocz e Kristensen, 1994).

2. The Data

A survey on the daily mobility-related behaviour of people living in the Municipality of Pisa was carried out. A total of about 3,304 trips taken by 806 individuals belonging to 373 families were recorded.  
Data was collected by means of questionnaires that were delivered by trained interviewers and were collected 48 hours later. Along with sex, age, marital status, working
status, workplace address and educational level, each member of the household was asked to report every trip he/she took over one whole day of observation. For each trip, departure time, address of destination, distance (km), time elapsed (minutes), means of transportation, reason for the trip, other people joining in, were reported. The number of sampled individuals was consistent over the days of the week by design. Also, those polled are geographically distributed throughout the 38 areas, called U.T.O.E., that comprise Pisa.

These data structures are often hierarchical in the following sense: we have variables describing individuals, but the individuals are also grouped into larger units (households), each unit consisting of a number of individuals. This data structure arises in many areas as diverse as environment, economics, age, education and typically reflects the sampling design. In particular, hierarchical or multi-level data structures occur naturally in geography where individuals (first level) are grouped in households (second level) and households are grouped in geographical areas (third level) and so on (Table 1).

Given how important hierarchical data is, in order to take the potential intra-household and intra-area correlations of the observations into account, we used multi-level models. Individuals and households were assumed to be random units sampled from the larger population of Pisa. Random effect components were introduced and some symmetrical location-scale family distribution were assumed (e.g. Normal, as a starting guess).

### Table 1: Hierarchical Data Structure.

<table>
<thead>
<tr>
<th>LEVEL</th>
<th>UNIT</th>
<th>SUBSCRIPT</th>
<th>RANGE</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Individual</td>
<td>$j = 1 \ldots n_i$</td>
<td>$1 \leq n_i \leq 5$</td>
<td>N=806</td>
</tr>
<tr>
<td>2</td>
<td>Household</td>
<td>$i = 1 \ldots m_i$</td>
<td>$1 \leq m_i \leq 76$</td>
<td>M=373</td>
</tr>
<tr>
<td>3</td>
<td>Area</td>
<td>$k = 1 \ldots K$</td>
<td></td>
<td>K=38</td>
</tr>
</tbody>
</table>

We cannot use the assumption of independence of observations, which is the basic assumption in classic statistical methodology. Thus, we can model the correlation between observations by using random variables (or variance components) and relative assumptions at different levels of the hierarchy.

### 3. Descriptive analysis

With this kind of database many analyses can be made, different variables can be studied and some answers can be offered sociologists and urban planners on the space used daily in an urban area: why are people mobile? What means do they use? When during the day? When during the week? To what extent according to sex and age?

In this paper, just as an example, we discuss mobility by means of transportation (Figure 1 shows the cumulative proportions of females in transit during the day). Privately-owned cars are the most popular means of transportation. People take as many as 47% of their trips in their own car. By adding trips by motorcycle or scooter we reach 56%. By adding trips with other people's cars or scooters we achieve 63% of total trips, which is the equivalent of 2.23 average trips per person per day. In terms of distance the percentage covered by private motorized means rises to 78%. We can estimate that the inhabitants of Pisa (about 92,000) cover about 2.5 million kilometres, a day: 62.5 times the earth round.
Males prevail in the use of privately owned cars (32% more than females) and even more so as regards motorcycles (79% more). In contrast, women are more likely to get a ride with someone. Males are more likely to bike. Females prevail both in walking and in travelling by bus. The preference for private vehicles is enormous: by bus, people cover only 3.2% of the space used and by train, only 8%.

How are means of transportation used over a lifetime? Walking increases over a lifetime and achieves its peak in old age. Gender differences are clear in the adult and elderly phases of life. Biking is not as popular. Women don’t dislike biking, but with the passage of time they stop doing it. Scooters and motorcycles are typically used by young people and later on are almost exclusively used by males.

Figure 1: proportion of moving females by mean during the day.

Most trips are taken by car, even in childhood, when babies are accompanied by their parents. From the age of forty, travelling by private car is a male privilege, so in old age males take two and a half times the number of trips performed by females. The use of public means of transportation is parabolic, i.e., it is used mainly in the first and last phases of life. Finally, we can say that in spatial behavior well-known consumer practices are confirmed. Women are not exempt even though they are more likely to walk, get rides and use the bus; but they do not like biking as much.

4. Multi-level Model

The aim of the research was to study daily mobility behaviour. To achieve the target, the log of distance covered and the number of trips were modelled as functions of some characteristics that were collected regarding each individual: sex and age brackets. Multi-level (mixed) models were applied. The results were obtained by using the STATA program (Rabe-Hesketh et al., 2001). The 2-level and 3-level normal models were applied when the log of distance covered was the response variable, whereas if the number of trips was the dependent variable, the Poisson model was selected. Many interesting results could be discussed. Here, however, we only have room for a few exam-
It is possible to note that females cover 37% less territory than males per day, but they make only 0.04 trips per day less than men. The 30-44 age bracket is the most mobile. Except for the old age bracket, the childhood bracket is the least mobile both as regards number of trips and distance covered. The variance of mobility is strong over a lifetime; more so in terms of space used than in terms of frequency of moves.

**Table 1:** maximum likelihood estimates of the 2-Level random intercept normal (log-covered distance) and Poisson (number of trips) model.

<table>
<thead>
<tr>
<th>Coefficients</th>
<th>Log-covered distance</th>
<th>Number of trips</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimate</td>
<td>Pr(&gt;</td>
</tr>
<tr>
<td>Sex (1=Female)</td>
<td>-0.4601</td>
<td>0.000</td>
</tr>
<tr>
<td>15-29</td>
<td>0.8364</td>
<td>0.000</td>
</tr>
<tr>
<td>30-44</td>
<td>0.8642</td>
<td>0.000</td>
</tr>
<tr>
<td>45-59</td>
<td>0.6119</td>
<td>0.000</td>
</tr>
<tr>
<td>60-74</td>
<td>0.3100</td>
<td>0.123</td>
</tr>
<tr>
<td>&gt;74</td>
<td>-1.2597</td>
<td>0.023</td>
</tr>
<tr>
<td>Const.</td>
<td>2.1562</td>
<td>0.000</td>
</tr>
<tr>
<td>Variance at level 1</td>
<td>1.1186</td>
<td></td>
</tr>
<tr>
<td>Variance at level 2</td>
<td>0.6677</td>
<td>0.0342</td>
</tr>
</tbody>
</table>

As to the hypothesis tests used to assess the statistical significance of maximum likelihood estimates, we applied the Wald test for regression coefficients and the likelihood ratio test (LRT) for variance components.

**5. Final Remarks**

The final results will provide useful insights in interpreting people’s mobility behaviour and use of the territory. Other explicative co-variates could be introduced to increase knowledge about people’s daily mobility behaviour, such as the means of transportation. Moreover, it would be interesting to insert, as a dependent variable, the reason for the trips. Furthermore, the same methodological approach could be usefully applied in other similar studies.

**References**


