Simulation of Micro Pedestrian Behaviour in Shopping Streets

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Abstract: Over the years, scholars have developed various models of pedestrian movement. These models can be used to assess the effects of detailed design decisions or to predict pedestrian behaviour under conditions of crowding. To date, not much attention has been paid to pedestrians’ shopping behaviour at the micro level. Therefore, the main purpose of this project is to test a model that aims at simulating micro pedestrian behaviour in shopping streets, including entering shops.

The model assumes a detailed network of links to represent the structure of street segments and entrances to the shops. The basic principle underlying the model is that a pedestrian moves from one link in the network to another, adjacent link. In fact, a pedestrian enters a segment at one side, heading for the other side of the segment. However, a pedestrian might enter the segment by leaving a shop as well. Then, the pedestrian might be heading for either side of the segment. While transferring from the current link to the next link, the pedestrian will be attracted by the shops along both sides of the street.

The study area is Antwerp’s main shopping street. During a one-week workshop in July 2004, students observed pedestrian movement in this shopping street. An inventory of some physical characteristics of the shopping street was made and pedestrians were tracked through two separate segments of the shopping street. In total, 334 pedestrians were tracked.

A conventional multinomial logit model is used to simulate pedestrians’ micro behaviour. The process of consecutively selecting links continues until the pedestrian has reached one of the terminal links or a shop. The model performs very well. Simulated routes were used to assess the validity of the model. Observed and simulated link loading correspond fairly well, however, the model seems to slightly mispredict the attraction of a number of shops.
1. INTRODUCTION

In the past, a number of models have been developed to predict shopping behaviour of pedestrians in shopping areas. Most of these models assume some predefined list of shops or types of shops to be visited by each pedestrian. More general, a schedule of activities to be conducted is assumed. For example, Borgers and Timmermans (1986) used observed shopping lists to predict shopping behaviour. This list consisted of planned types of products to be bought. It was assumed that at the start of the shopping trip, the pedestrian would decide where to buy the first item on the list. All shops selling this type of product were considered possible destinations. The decision which shop would be visited was modelled by means of a gravity like model including the supply of the shops and the shortest distance to the shops as explanatory variables. Having visited the first destination, the second item on the shopping list was used to select the second destination, and so on. The route choice to each destination was assumed to be dependent on the length of the route to the destination. Knowing that a significant proportion of the visited shops were not planned beforehand, a module was included to add unplanned shop visits on the route along the planned shop visits. This was done at the level of links in a network of shopping street segments.

In the meantime, more sophisticated approaches have been developed by amongst others Haklay et al (2001) and Dijkstra et al (2002). They also assume that pedestrians use a pre-defined schedule of activities to be conducted during their shopping trip. While the pedestrians walk to the next destination (e.g. a shop), they may be attracted by a shop or window display (e.g. Helbing and Molnár, 1995). This way, impulse stops can be incorporated into the model. Despite the potentials of this approach, a drawback may be that a significant number of pedestrians visiting large downtown shopping areas do not have pre-defined activity schedules at all. Borgers and Timmermans (2005a) reported that most of their respondents with hedonic shopping motivations in the city of Maastricht (the Netherlands) are not (very) familiar with the downtown area, nor have planned their route through the area. Knowing that downtown shopping areas attract many hedonic shoppers (see e.g. Timothy, 2005), the assumption of pre-defined activity schedules may not be applicable to a significant portion of downtown shoppers.

As an alternative to the recently introduced models of pedestrian behaviour in shopping areas, Borgers and Timmermans (2004, 2005b) developed a model of pedestrian shopping behaviour that does not assume pre-defined activity schedules or familiarity with the shopping area. Their model is based on a link-to-link approach. They assume that a pedestrian
will start his shopping trip at some entry-link and consecutively chooses links (street segments) to proceed. The choice of a link is assumed to depend on distances, attraction of shops, physical characteristics of the links, etcetera. In addition, it is assumed that after walking some distance, the pedestrian walks back into the direction of the exit-link, which is assumed to be equal or adjacent to the entry-link.

This model was tested in the downtown shopping areas of two medium sized cities in the Netherlands and performed quite satisfactory, even for utilitarian shoppers. However, the model only simulates route choice behaviour and does not include visiting shops. Therefore, the purpose of this paper is to investigate whether a model analogue to the Borgers and Timmermans (2005b) model can be used to model shopping behaviour at a more detailed level.

This paper is organised as follows. In the next section, we will describe the model. Then, the data used to estimate and validate the model will be described. In the next section, the model will be specified in more detail, estimated and validated. In the final section, conclusions will be drawn and directions for further research will be given.

2. THE MODEL

To model pedestrian movement at a detailed level a raster of cells is commonly used. A pedestrian’s path can be denoted by selecting the cells that the pedestrian will pass. The cell based method is almost directly linked to the cellular automata or agent based approach (e.g. Blue and Adler (2001), Kerridge et al (2001)) to model pedestrian movement. Another method would be to register the route by means of a polygon, represented by x-y coordinates. This method is well suited in case routes are observed by means of cameras or other automated systems (see e.g. Teknomo (2002) and Tanaka and Shibasaki (2005)). The model for pedestrian behaviour developed by Hoogendoorn (2003) is especially suited for this type of observed routes. However, to keep the analogy with the Borgers and Timmermans (2005b) model, it was decided to use a network approach to predict pedestrians’ shopping behaviour. Depending on the scale of the network, the use of cells or links in a network is more or less similar.

Observations carried out by Ciolek (1978) in a number of pedestrian settings have shown that one can distinguish three types of zones which are used by people for a variety of activities. The first zone is closest to the wall; solitary people or small groups stop to watch window-displays or wait. The second zone is a pedestrian traffic route and the third is usually furnished with trees, lamps, letter boxes, litter bins and so forth offering opportunities
for socializing and contact. Although the number and type of zones within a shopping street might differ, the assumption of different zones seems to hold for many downtown pedestrianized shopping areas. An example is shown in Figure 1. In this study, we will concentrate on pedestrians’ shopping behaviour within segments of a pedestrianized shopping street. On the surface of each street segment, a network of links will be superimposed, see Figure 2. This network of links will be used to model pedestrian movement.

Figure 1. A typical shopping street.  
Figure 2. A superimposed network.

The main principle of the model is that at his current location (a link in the network), the pedestrian can choose one of the adjacent links to continue his trip. Except for the links at the beginning or at the end of the street, each link usually has 14 adjacent links (see Figure 3). The probability each of these 14 links will be chosen is modelled by means of a discrete choice model, more specifically, a multinomial logit model (see e.g. Ben-Akiva and Lerman, 1985):

\[
p_{elj} = \frac{\exp(V_{elj})}{\sum_{j'} \exp(V_{elj'})}
\]  

where \( p_{elj} \) is the probability that a pedestrian at link \( l \) who started at entry-link \( e \) will choose alternative link \( j \); \( V_{elj} \) is the utility of alternative \( j \) for a pedestrian at link \( l \) who started at entry-link \( e \).

According to this model, the probability that a link will be chosen depends on the utility of each link that can be chosen. The utility of a link depends on a number of variables, which will be described consecutively. According to Ciolek (1978), different zones can be distinguished (see Figure 1). It might be expected that links located in different zones have different utilities. In addition, it might be expected that the utility of each zone
depends on the motivation of the shopper. For example, a run shopper might attach a higher utility to the pedestrian traffic zone than a fun shopper.

The next variable represents the preference of people on the Continent to walk on the right side of the street. So, in case of Figure 1, a pedestrian walking from west to east is likely to walk in the bottom zone, not in the top zone. In addition, pedestrians might prefer to ‘keep their lane’, implying that they do not like to transfer from one zone to another.

If a pedestrian enters the shopping street at the west side, the east side of the street is likely to be the destination of the pedestrian. Links heading to this destination will have a higher utility. Note, however, that after visiting a shop, the entry-side might become pedestrian’s destination as well.

The destination of a pedestrian might also be a shop in the street segment. Therefore, a set of variables should represent the attraction of different types of shops, expressed, for example, by the floor space in square meters per shop. In addition, the attraction of a shop might also be dependent on other variables like the size of shop windows or the number of advertising boards. Links heading to more attractive shops will have a higher utility than the other links. However, distance will play a role as well. Thus, the utility of a link will also depend on the attraction of shops and the distance to the shop.

3. DATA COLLECTION

During a one-week workshop in July 2004, six students collected data in the main shopping street of Antwerp, Belgium. The students made an inventory of the physical characteristics of the street and the buildings along the street, counted the number of pedestrians passing screen lines and tracked pedestrians. The data regarding the tracking of pedestrians is used in this paper. To track the pedestrians, the main shopping street, called ‘De Meir’, was divided into seven segments. Two segments (see Figure 4) were selected to track the pedestrians. From Figure 4 it can be observed that the
structure of the shopping street is different from the typical structure shown in Figure 2. The centre zone in Antwerp’s main shopping street can be considered as the traffic zone. Bikes are allowed in this zone as well. Along both sides of the central zone, a narrow zone contains street furniture like seats and lamps. Also a number of small cubes are placed in these zones to separate the centre zone from the zones along the buildings and shop windows. This latter zone, along the buildings, is only accessible by pedestrians.

The length of the two segments is approximately 120 and 100 m for segment A and B respectively. In segment A, 13 shops are located, mainly offering fashion products (10x clothing, 1x shoes, 2x fast food). In segment B, 14 shops offer a more divers supply (7x clothing, 2x shoes, 2 small department stores, 1x books, 2x electronics). Segments A and B are not connected to each other. Shops are also represented by links. Note one special link in the southwest part of segment A, the so called ‘Wapper’. This is a popular side-street giving access to a large fountain, terraces, outdoor cafés, and a famous museum.

At the time of data collection, weather conditions were fine and the number of pedestrians walking through the street was far below the maximum capacity of the street. Effects of crowding could thus be assumed to be absent. Pedestrians were tracked on a Thursday during two time intervals: from 11.15 to 12.20 h. and from 13.45 to 15.55 h. While tracking pedestrians, actions like walking, changing walking direction, transferring to another zone, window shopping, entering a shop, making a conversation, sitting down, etcetera were registered. The route of each pedestrian through the segment was drawn on a map. Care was taken pedestrians did not notice they were being observed. By taking strategic places, the students were able to examine the entire segment. Tracking of a pedestrian ceased when the
pedestrian reached one of the terminal points of the street segment. A new pedestrian to be tracked was randomly selected from the pedestrians entering the segment at this point. In case a pedestrian visited a shop for more than five minutes, the first person leaving the shop after five minutes was selected as the next person to be tracked. In total, 333 pedestrians were tracked (176 pedestrians in segment A and 157 in segment B). Figure 5 shows some examples of tracked routes. Note that entering a shop and window shopping were registered separately. However, in this paper we treat both as visiting a shop. Apart from moving through the segments and visiting shops, the other activities were hardly observed and will be paid no further attention to in this paper.

Figure 5. Some examples of tracked routes.

4. MODEL SPECIFICATION

According to equation 1, the probability a link will be chosen from the set of adjacent links depends on the utility of each alternative. In this section, we will define the variables that are used to determine the utility of each link. For ease of presentation, we will break down the structural utility of a link into four parts: $V_{el} = V_{1el} + V_{2el} + V_{3el} + V_{4el}$. The first part is related to characteristics of the links, the second part to the attraction of exits, the third part to the attraction of shops, and finally, the last part represents the utility of staying in a shop. It should be noted that the estimation process involved including and excluding several variables. Only the final results are presented in this paper.

The first variable of the first part of utility indicates whether choosing a particular link implies walking on the right-hand side of the shopping street. More specifically, the street segments in Antwerp are east-westward directed. If a person walks from east to west in the northern zone along the shops, he walks on the right-hand side. Similarly, if someone walks from
west to east in the southern zone, he also walks on the right-hand side. If a link implies walking on the right-hand side, the score will be equal to unity, otherwise the score will be equal to zero.

The second variable represents walking on the centre zone of the segment. If choosing a particular link implies walking in the centre zone, the score is equal to unity and zero otherwise. The third variable identifies whether choosing a particular link induces a transfer from one zone to another zone. All links connecting the centre zone to the northern zone or connecting the centre zone to the southern zone score 1.0 on this variable and zero otherwise.

If a pedestrian is close to an exit-link, the exit-link will be one of the links he can choose. If he does so, the pedestrian leaves the street segment. In case the exit-link is located at the entry-side of the segment, the utility of choosing the link will be negative, so the score of the link is set to -1.0. On the other hand, if the exit-link is located on the other side of the segment, the score will be equal to 1.0. However, if the pedestrian has visited a shop, the score of exit-links on both sides of the segment will be 1.0.

In sum, the first part of the utility of a link is equal to:

\[
V_{1e,j} = \alpha_{\text{right}} R_j + \alpha_{\text{centre}} C_j + \alpha_{\text{transfer}} T_j + \alpha_{\text{exit}} E_j
\]

where

- \( R_j \) indicates whether link \( j \) implies walking on the right-hand side (1=yes, 0=no);
- \( C_j \) indicates whether link \( j \) is located in the centre zone (1=yes, 0=no);
- \( T_j \) indicates whether link \( j \) is located in between the northern and centre zone or southern and centre zone (1=yes, 0=no);
- \( E_j \) indicates that link \( j \) is an exit-link (-1=on entry-side without having visited a shop, 1=on entry side with having visited a shop or on other side of segment, 0=no exit-link);

\( \alpha_{\text{right}}, \alpha_{\text{centre}}, \alpha_{\text{transfer}}, \text{and } \alpha_{\text{exit}} \) are corresponding parameters to be estimated.

It is assumed that the pedestrian is attracted by the exit-links at the exit-side of the street segment. The exit-side is the side opposite to the entry-side. If the observed trip started in a shop, all exit-links (on both sides of the segment) are assumed to attract the pedestrian. This attraction is called the main attraction. In case a pedestrian visited a shop for less than 5 minutes after entering the street segment, the exit-links on the entry-side of the segment may also attract the pedestrian after visiting the shop because the pedestrian might go back to the side of entry. However, this attraction might
differ from the previously defined main attraction. Therefore, a secondary attraction is introduced.

Links that point into the direction of exit-links have a higher utility than other links. Note in equation 3 that the distance from the alternative link $j$ to the exit-link $k$ is divided by the distance from the current link $l$ to the exit-link $k$. This is done to eliminate the distance-effect to a large extent in favour of the direction-effect.

\[
V_{2_{el,j}} = \sum_{k} \frac{\beta_{1_k} E_{1_k}}{d_{jk} / d_{lk}} + \sum_{k} \frac{\beta_{2_k} E_{2_k}}{d_{jk} / d_{lk}}
\]

where $E_{1_k} = \begin{cases} 1.0 & \text{if exit-link } k \text{ is not located on the entry-side of the segment, } 0.0 & \text{otherwise;} \\ 1.0 & \text{if exit-link } k \text{ is located on the entry-side of the segment and the pedestrian has visited a shop after entering the segment, } 0.0 & \text{otherwise;} \\
\beta_{1_k} & \text{represents the main attraction of exit-link } k; \\ \beta_{2_k} & \text{represents the secondary attraction of exit-link } k; \\ d_{jk} & \text{is the distance from link } j \text{ to exit-link } k; \\ d_{lk} & \text{is the distance from current link } l \text{ to exit-link } k; 
\end{cases}

In addition to the attraction of exit-links, shops will attract pedestrians as well. The attraction of a shop is measured by the floor space of the shop, multiplied by a parameter for the relevant type of shop. In this study, six types of shops were distinguished: clothing, footwear, department stores, fast food, books and electronics. However, if the shop is further away, the attraction will be less, so the floor space of each shop has to be divided by the distance from the alternative link $j$ to the shop.

If a shop has been visited once, the attraction of the shop is likely to change. Therefore, we differentiated between the main attraction (represented by the $\gamma_{1}$-parameter) and the secondary attraction (represented by the $\gamma_{2}$-parameter) of a shop. The main attraction applies if the shop has not been visited before, the secondary attraction if the shop has been visited at least once. In equation:

\[
V_{3_{el,j}} = \sum_{m} \frac{\gamma_{1} S_{1_m} F_{m}}{d_{jm}} + \sum_{m} \frac{\gamma_{2} S_{2_m} F_{m}}{d_{jm}}
\]
where $S_{1m} = 1.0$ if shop $m$ belongs to type $t$ and has not been visited before by the pedestrian, 0.0 otherwise; $S_{2m} = 1.0$ if shop $m$ belongs to type $t$ and has been visited before by the pedestrian, 0.0 otherwise; $F_m$ is the floor space of shop $m$; $d_m$ is the distance from link $j$ to shop $m$; $\gamma_1$ and $\gamma_2$ are parameters representing the main and secondary attraction of shops of type $t$.

The first part of the right-hand side of equation 4 represents the main attraction of the shops and the second part represents the secondary attraction. A link close to attractive shops will have a higher utility than a link further away from attractive shops.

Shops are represented by links. If a pedestrian chooses a link that represents a shop, the pedestrian will in fact visit the shop. The pedestrian might stay for more than 5 minutes in the shop. Then, tracking this pedestrian ceased. To simulate observed behaviour, we have to be able to predict the probability the pedestrian will stay for more than 5 minutes in the shop. This probability is predicted by adding a so called ‘Stop’-alternative to the set of adjacent links. In other words, the shop competes with its adjacent links to keep the pedestrian inside. The utility of not leaving the shop within 5 minutes ($V_4$) is measured by a type specific constant and a type specific parameter multiplied by the floor space of the shop. The constant represents a kind of average probability to stay more than 5 minutes in a particular type of shop, while the floor space parameter measures the effect of the size of the shops. It is expected that the probability to stay more than 5 minutes increases with increasing floor space. As said before, not leaving the shop competes with the links adjacent to the shop. The utility of these adjacent links is calculated according to equations 2-4. The $V_1$, $V_2$, and $V_3$-utility components are always equal to zero for the Stop-alternative and only the Stop-alternative has a non-zero $V_4$-utility component. Note that the utility of adjacent links depends, amongst other things, on the attraction of shops. If the current location of a pedestrian is a shop, this shop does not contribute to this attraction of shops.

$$V_{4_{el,j}} = \sum_t \delta_t S_{tl} + \lambda_t S_{tl} F_t$$

(5)

where $S_{tl} = 1.0$ if the shop at link $l$ belongs to type $t$, 0.0 otherwise; $F_t$ is the floor space of the shop at link $l$; $\delta_t$ and $\lambda_t$ are parameters representing the constant and the floor space effect of type $t$. 

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5. MODEL ESTIMATION AND VALIDATION

The parameters of the multinomial logit model are estimated by means of Limdep (Greene, 2003) and presented in Table 1. The model performs very well indicated by a high value for rho² (0.72). According to the estimated parameters, pedestrians prefer to walk on the right side of the street, dislike the centre zone which is also allowed for bikes, and dislike to a large extent switching to others zones. If one of the adjacent links is an exit-link at the opposite side of the entry-side of the street segment, or on the same side if the pedestrian has visited a shop, the link will have a relatively high utility according to \( \alpha_{\text{exit}} \). However, exit-links on the entry-side, if the pedestrian did not visit a shop, will have a relatively low utility because the value of \( \alpha_{\text{exit}} \) will be subtracted. Remember that choosing an exit-link implies the pedestrian leaves the street segment.

The main and secondary attraction of exit-links was measured for each exit-link separately. According to these \( \beta \)-parameters, all main attraction effects could be represented by just one common value. This value is positive, indicating that pedestrians have the propensity to walk to the other side of the street. In case of the secondary attraction parameters, all except one could be bound to one value. The exception is the popular side-street the ‘Wapper’, of which the secondary attraction is nearly equal to the main attraction of the exit-links. The secondary attraction of the other exit-links is still positive, although to a lesser extent. This implies that exit-links on the entry-side have a moderate attraction effect on pedestrians who have visited a shop in the segment.

The \( \gamma \)-parameters represent the attraction of shops. The parameters identify the attraction of a square meter floor space divided by the distance (in m) to the shop. The main attraction is positive for all types of shops, except for fast food outlets. The parameters for books and electronics are positive, but not significant at conventional levels. This is probably because of the small number of these types of shops in the street segments. The attraction of a shop visited before is negative, especially for fast food restaurants. For electronics and books, no significant \( \gamma_2 \)-parameters could be determined.

The parameters measuring the constant utility of ‘not leaving a shop within 5 minutes’ are very high, indicating that if pedestrians visit a shop, the probability of leaving the shop within 5 minutes is very small. Only for clothing and shoes significant effects per square meter floor space could be measured.

To assess the performance of the model, Monte Carlo Simulation was used to reproduce observed routes through both segments. For each tracked pedestrian, starting from the observed entry-link (which also might be a
shop), a consecutive set of links was chosen from the choice sets. Given each choice set, probabilities for each alternative link were calculated. A random number was used to select one of the alternatives. This process continued until the pedestrian reached an exit-link or did not leave a shop within five minutes. This process was repeated 50 times for each respondent.

Table 1. Estimated parameters.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Parameter</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha_{\text{right}}$</td>
<td>Walk in right-hand side zone</td>
<td>0.3583</td>
</tr>
<tr>
<td>$\alpha_{\text{centre}}$</td>
<td>Walk in centre-zone</td>
<td>-0.5091</td>
</tr>
<tr>
<td>$\alpha_{\text{transfer}}$</td>
<td>Transfer to other zone</td>
<td>-3.330</td>
</tr>
<tr>
<td>$\alpha_{\text{exit}}$</td>
<td>Terminate at exit-link</td>
<td>0.7400</td>
</tr>
<tr>
<td>$\beta_{1,\text{all}}$</td>
<td>Main attraction all exits</td>
<td>2.421</td>
</tr>
<tr>
<td>$\beta_{2,\text{Wapper}}$</td>
<td>Secondary attraction exit Wapper</td>
<td>2.323</td>
</tr>
<tr>
<td>$\beta_{2,\text{other}}$</td>
<td>Secondary attraction other exits</td>
<td>1.157</td>
</tr>
<tr>
<td>$\gamma_{1,1}$</td>
<td>- clothing</td>
<td>0.002893</td>
</tr>
<tr>
<td>$\gamma_{1,2}$</td>
<td>- shoes</td>
<td>0.01305</td>
</tr>
<tr>
<td>$\gamma_{1,3}$</td>
<td>- department stores</td>
<td>0.008874</td>
</tr>
<tr>
<td>$\gamma_{1,4}$</td>
<td>- fast food</td>
<td>-0.1014</td>
</tr>
<tr>
<td>$\gamma_{1,5}$</td>
<td>- books</td>
<td>0.01759</td>
</tr>
<tr>
<td>$\gamma_{1,6}$</td>
<td>- electronics</td>
<td>0.04188</td>
</tr>
<tr>
<td>$\gamma_{2,1}$</td>
<td>- clothing</td>
<td>-0.05320</td>
</tr>
<tr>
<td>$\gamma_{2,2}$</td>
<td>- shoes</td>
<td>-0.04427</td>
</tr>
<tr>
<td>$\gamma_{2,3}$</td>
<td>- department stores</td>
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</tr>
<tr>
<td>$\gamma_{2,4}$</td>
<td>- fast food</td>
<td>-1.701</td>
</tr>
<tr>
<td>$\delta_{1}$</td>
<td>- clothing</td>
<td>14.57</td>
</tr>
<tr>
<td>$\delta_{2}$</td>
<td>- shoes</td>
<td>9.023</td>
</tr>
<tr>
<td>$\delta_{3}$</td>
<td>- department stores</td>
<td>13.23</td>
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<tr>
<td>$\delta_{4}$</td>
<td>- books</td>
<td>13.45</td>
</tr>
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<td>$\delta_{5}$</td>
<td>- electronics</td>
<td>12.05</td>
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<tr>
<td>$\lambda_{1}$</td>
<td>- clothing</td>
<td>0.0007427</td>
</tr>
<tr>
<td>$\lambda_{2}$</td>
<td>- shoes</td>
<td>0.008628</td>
</tr>
</tbody>
</table>

The simulated routes were used to determine link loadings. In Figures 6 and 7, observed and simulated link loadings are shown. Observed and simulated link loading correspond fairly well. It is clearly visible that the three east-west paths represent the most frequent used routes, both observed and simulated. However, the simulated loadings on these links are somewhat underrepresented for the benefit of the diagonal and the perpendicular links. In segment B, the number of pedestrians in the middle part of the southern...
zone is underpredicted. Apparently, the attraction of the shops in this section is not well represented by the model. We do not observe this kind of local mispredictions in segment A.

In addition to the visual inspection of Figures 6 and 7, Table 2 provides some statistics to assess the performance of the model. Table 2 provides information about transitions between zones. The main zones represent the three east-west paths. The two secondary zones represent the zones located in between the main zones. The main zones facilitate direct east-west movement, while the secondary zones facilitate both diagonal and perpendicular transfers from one main zone to another main zone. Shops are located along the northern and southern main zone.

In both segments, the number of transitions into a shop (or Wapper) is over-simulated. Apparently, the shops attract too many pedestrians. This probably explains the other deviations between observations and simulations. Due to the relative high number of simulated shop-visits, the number of transitions out of shops is over-simulated as well. Because the shops attract too many pedestrians, the number of transitions from main to secondary zones and vice versa is over-simulated. This in turn explains the under-simulation of transitions within the main zones. Furthermore, if too many pedestrians enter a shop, the number of pedestrians that will stay in the
shop (and thus cease their trip) will be too high, causing a shorter mean distance than observed. Notwithstanding the deviations between observed and simulated pedestrian behaviour, the mean difference between the observed number of pedestrians per link and the simulated number of pedestrians per link is less than 4 persons, which may be considered a satisfactory result.

Table 2. Performance indicators.

<table>
<thead>
<tr>
<th></th>
<th>Segment A</th>
<th>Segment B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Observed</td>
<td>Simulated</td>
</tr>
<tr>
<td>Transitions into shops/Wapper (%)</td>
<td>5.9</td>
<td>9.7</td>
</tr>
<tr>
<td>Transitions out of shops/Wapper (%)</td>
<td>5.2</td>
<td>8.4</td>
</tr>
<tr>
<td>Transitions within main zone (%)</td>
<td>77.0</td>
<td>69.1</td>
</tr>
<tr>
<td>Transitions from main to secondary zone (%)</td>
<td>3.5</td>
<td>5.6</td>
</tr>
<tr>
<td>Transitions from secondary to main zone (%)</td>
<td>2.7</td>
<td>5.2</td>
</tr>
<tr>
<td>Mean length of route (m)</td>
<td>110.0</td>
<td>105.4</td>
</tr>
<tr>
<td>Mean absolute difference (#)</td>
<td>3.67</td>
<td></td>
</tr>
</tbody>
</table>

1) In this table, the ‘Wapper’ - the side-street in segment A - is treated like a shop.

6. CONCLUSIONS

In this paper, a model to simulate pedestrian behaviour in two segments of Antwerp’s most important shopping street was presented. A virtual network of links was superimposed on the shopping street segments. The model assumes that a pedestrian continues his trip by choosing one of the links that are connected to his current link. The probability a link will be chosen depends on the attraction of exit-links, the attraction of shops, and the tendency of pedestrians to walk on the right-hand side of the street, and the aversion of pedestrians against walking in the central zone, which is also used by bikers, and, to a much larger extent, the aversion against transferring to another zone. According to the high rho²-value, the model performs well, but according to the simulations, the attraction of shops on pedestrians seems to be somewhat overestimated.

Although the model performs well, some shortcomings should be discussed. One shortcoming of the model is the absence of the pedestrians’ history. Each pedestrian is observed during his movement through one segment only. Consequently, we do not know whether and which shops the pedestrian visited before. For example, if a pedestrian has visited a particular shop in a previous segment of the shopping street, the probability a shop will be visited while being observed might be affected. To prevent this problem,
the full trip of pedestrians through the shopping area should be observed, which is very time consuming.

Related to this problem is that the probability a particular shop will be visited is likely to be affected by having visited a shop of the same branch before. This effect might be either positive or negative. Visiting a particular shop might indicate the pedestrian is looking for a particular type of goods, and therefore, all shops selling this type of goods might have a relatively high probability to be chosen. On the other hand, however, after visiting a particular type of shop, the pedestrian might have no further needs regarding that type of products. Of course, both effects might cancel out each other.

The model presented in this paper only simulates pedestrians’ path choice and entering shops. Other activities like sitting down on a bench or making a conversation are not taken into consideration. These activities occurred seldom during the observations. Tracking more pedestrians would give better insight into this kind of activities. This also holds for pedestrians turning back without having visited a shop or done something else. During tracking pedestrians we observed a small number of pedestrians turning back. For that reason, we allowed pedestrians choosing each link adjacent to the current link, even those links implying a turn. In contrast, most models assume only options in front of the pedestrian to be appropriate alternatives. More observations will reveal the validity of this assumption.

Finally, the model is based on pedestrians’ behaviour observed in two segments of one shopping street of one city during a particular day of the week under nice weather conditions. Pedestrians’ behaviour might be different in other shopping streets or street segments, in other cities, during other days, under other weather conditions, etcetera. It goes without saying that this research should be repeated under different conditions.

From a theoretical point of view, the conventional multinomial logit model has some shortcomings as well. The model assumes that adding or deleting an alternative decreases or increases the probability of other alternatives to be chosen by equal proportions. This assumption is unrealistic when some alternatives are more similar than other alternatives which might be the case in this study. In this context, Antonini et al (2005) presented an interesting model of pedestrian movement. They assume that a pedestrian can move into one out of 11 radial cones, spanning a visual angle of 170°. Within each cone, a ‘keep the same speed’, ‘slow down’ or ‘accelerate’ option can be chosen, generating a choice set of 33 alternatives. To take into consideration the similarity between alternatives (same direction or same speed option), two different models were formulated: a cross-nested logit and a nested logit with error components. An alternative to these models would be a cross correlated logit model (see e.g. Bhat, 2003).
7. REFERENCES


