Modelling Pedestrian Route Choice Behaviour and Its Application to the Planning of Underground Shopping Streets

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ABSTRACT

Most populous cities in Japan have large underground shopping streets located at transportation hubs. These areas are used for retail purposes and also serve as commuter links between adjacent railway stations and attractions. Through detailed observations and surveys, this study developed pedestrian route-choice models in these large, underground shopping areas. These models have the potential to play an important role in the planning of underground shopping malls, including plans for stimulating retail activity during non-threatening times and a refuge plan during times of emergency.

1. INTRODUCTION

Most large cities in Japan have large underground shopping malls at their transportation hubs and terminals. These areas are not only used for retail activities, but also serve as the route for commuters walking between adjacent railway stations. In addition, these malls also form the routes to and from major attractions and cities within these terminals. Pedestrians on their way to specific destinations presumably select the most efficient route by assessing the relationship between their current location and their destination.

Even small street networks provide a number of alternative paths between a given origin and destination. In fact, while a large number of potential paths can exist, attempts at reducing walking effort results in the pedestrian considering only some of the shortest paths with similar length. It is very important to know which paths are most likely to be used by pedestrians in order to make streets safer and easier to use.

While numerous studies have analysed pedestrian route choice behaviour, most previous models focused on factors related to the walking environment along a street. Consequently, these approaches may have reduced the applicability of these models to other sites. The authors therefore employed an alternative strategy involving a ‘turning movement probability’ at intersections, which is similar to the approach adopted by Garbrecht (1970, 1971).

Having conducted precise observation surveys of pedestrian flows on aboveground street networks, the authors have already developed a pedestrian route choice model that can be applied to variety of street networks (Tsukaguchi et al. (2003), Takegami and Tsukaguchi (2006)). Based on the same concept, this study attempts to analyse pedestrian route choice behaviour in underground shopping centres. The purpose of this study was thus to analyse the mechanism underlying pedestrian route choice and propose pedestrian route choice models that could subsequently be applied to planning underground shopping streets.

This study consisted of the following stages: Firstly, field surveys were conducted in large underground shopping centres in order to obtain pedestrian route choice data. A shadowing technique was adopted to perform the observational survey. Secondly, the relationship between the pedestrian route selection behaviour and two primary angles related to pedestrians’ movements were determined.
in order to develop pedestrian route choice models. Thirdly, this study discusses the potential application of the route choice model to the planning of underground malls.

2. BASIC CONCEPT OF MODELLING PEDESTRIAN ROUTE CHOICE BEHAVIOUR

Traffic engineering variables, such as route length, street width, level of vehicular traffic, availability of sidewalks, and amenities along a street, all contribute to pedestrian route choice behaviour and have been used to develop pedestrian route choice models (Takeuchi (1977) and Takatsuji and Fukami (1983)). However, in general, these pedestrian route choice models lack high reproducibility and the potential for global application. Most previous models place too much emphasis on the effects of such factors relative to the walling environment along a street, which may reduce their applicability to other sites.

This study assumes that pedestrians tend to select straight routes over branched routes of similar length, a behavioural tendency that is similar to inertia in physics. The study also assumes that pedestrians prefer to minimize the geometric angle between the current movement vector and the imaginary vector that connects the present location to the destination. Consequently, the assumptions related to the pedestrian route choice mechanism in this study include:

1) Tendency similar to inertia: Pedestrians have a particular probabilistic distribution of turning movements. Typically, the straight-through movement, including the relatively straight movement in non-grid networks, is the most favoured action at an intersection where alternative paths are of similar length.

2) Minimizing the angle of orientation: Pedestrians are aware of the angle between their current movement vector and the vector to their destination. Typically, they select a route that minimizes the angle between the route and line origin-destination (OD).

For example, suppose a pedestrian is approaching point O, which is the origin or temporary origin of a path that has a final destination of point D, as shown in Figure 1. This study assumes that if $\alpha$ is smaller than $\beta$, the pedestrian is likely to choose route 1. Conversely, if $\alpha$ is larger than $\beta$, the pedestrian is likely to use route 2. In addition, this study assumes that if $\gamma$ is smaller than $\delta$, the pedestrian is likely to choose route 1, while if $\gamma$ is larger than $\delta$, the pedestrian is likely to choose route 2.

There are a great number of shortest paths for the same OD pair in grid type networks. Since all of these paths are feasible for use by pedestrians, they must be considered when analysing pedestrian route selection behaviour. For non-grid networks, feasible paths must be chosen in the initial phase of

![Diagram](image-url)

Fig. 1. Relationship between angles describing pedestrian movement at an intersection.
the analysis. The observation survey clearly demonstrated that pedestrians rarely use paths that are 1.3 times longer than the shortest path. Consequently, this study only considers paths that are less than 1.3 times the length of the longest path as feasible.

The authors recognize the effects of the street environment on pedestrian route choice behaviour, but this study focuses on the afore-mentioned characteristics and examines whether only these characteristics can explain pedestrian route choice behaviour.

3. FIELD SURVEY

Two underground shopping malls located in the downtown areas of Osaka and Tokyo were selected for this study. The road networks of each site are illustrated in Figure 2. While these underground shopping facilities consist of several independent underground shopping malls, we simply refer to these as the ‘Umeda’ and ‘Yaesu’ underground shopping malls, respectively. The Umeda area consists of complex networks, including grid and non-grid types, while the Yaesu area consists mostly of grid networks.

Field surveys were conducted to observe pedestrian route-choice using a shadowing technique to gather observational data. The shadowing surveys in the districts were conducted in 2004 and 2006. The surveys were performed by several observers who discretely followed pedestrians from their origins, including temporary origins, to their destinations in the networks. A total of 588 subjects were observed in the Umeda area and 462 subjects in the Yaesu area. Using these field observation data, the necessary angles at every intersection between the origin and destination pair were measured to verify the study assumptions.

As described previously, the authors have already developed a pedestrian route choice model for aboveground street networks in Osaka, Kobe and Kyoto, Japan, typical examples of which are illustrated in Figure 3. The survey technique adopted in this study is exactly the same as the one adopted for the aboveground scenarios.

![Fig. 2. Underground shopping mall networks for the observation survey.](image-url)
4. MODELING OF PEDESTRIAN ROUTE CHOICE BEHAVIOUR

At every intersection located between the origin and the destination of a pedestrian, angles shown in Figure 1 were measured and disaggregate route choice models for these routes were developed. As shown in equation (1), the explanatory variables of the utility function of the binary logit model are the angles related to the assumption described.

\[ V_i = \sum_{j=1}^{2} \omega_j X_{ij} (i = 1, 2) \]  

where, \( X_{11} = a, X_{12} = b, X_{21} = c, \) and \( X_{22} = d. \)

The choice rate of the Routes 1 and 2 are expressed as:

\[ P_1 = \frac{e^{r_1}}{e^{r_1} + e^{r_2}} \]  

\[ P_2 = \frac{e^{r_2}}{e^{r_1} + e^{r_2}} \]  

The parameters (\( \omega_j \)) estimated in this study are shown in Table 1. After considering indices such as t value, \( \chi^2 \) value, likelihood ratio \( \rho^2 \), and reproducibility of the model, a pedestrian route selection model using only two variables - the angle of orientation and the angle related to turning movement - could be developed for the two underground shopping malls.

In order to compare the models developed for the aboveground and the underground streets and malls, Table 1 also shows a pedestrian route choice model developed for street networks on the ground, which has general applicability to a wide variety of situations. The situations for aboveground and underground streets are quite different, with the primary difference being that it is more difficult for pedestrians to understand the direction they are walking in when they use underground streets. However, the analysis suggests that, generally, the structure of the models developed for the aboveground and the underground scenarios are similar with the pedestrian route selection mechanism for underground streets appearing to be similar to that employed aboveground.
Table 1. Estimated parameters of the route choice models.

<table>
<thead>
<tr>
<th>Area</th>
<th>Angle of orientation (degree)</th>
<th>Angle related to turning movement (degree)</th>
<th>Likelihood ratio $\rho^2$</th>
<th>Reproducibility of the model (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Underground shopping centre</td>
<td>-9.57 \times 10^{-3}</td>
<td>-1.30 \times 10^{-2}</td>
<td>0.21</td>
<td>74.0 (478/646)</td>
</tr>
<tr>
<td>Yaesu</td>
<td>-1.31 \times 10^{-2}</td>
<td>-1.30 \times 10^{-2}</td>
<td>0.18</td>
<td>70.1 (705/1005)</td>
</tr>
<tr>
<td>Aboveground streets**</td>
<td>-1.53 \times 10^{-2}</td>
<td>-19.4 \times 10^{-3}</td>
<td>0.17</td>
<td>70.0 (3461/4945)</td>
</tr>
</tbody>
</table>

1)* 1% significance 
2)** Routes that were 1.2 times longer than the shortest path were excluded, because the survey results shows that these paths are seldom used by pedestrians in aboveground streets.

When we consider the models in greater detail, several differences between the three route choice models shown in Table 1, the Umeda model, Yaesu model and the model developed for aboveground streets, become apparent, with a distinct difference in the relationship of the parameters in the Umeda model and that of Yaesu model becoming apparent. In the Umeda model, the straight-through movement was found to be superior to that of the orientation angle, with the corollary being true for the Yaesu model. While the reason for this disparity has not yet been determined, the various network types in the districts may have some effect on the differences exhibited in pedestrian route choice behaviour.

5. SOME CONSIDERATION ON APPLICATION OF THE MODEL

When we apply the pedestrian route selection model for the aboveground scenario to an underground situation, we can identify paths that are likely to be selected by the pedestrians on that floor. Obviously, such information is very important for managing traffic in shopping malls and for the establishment of refuges in times of emergency. However, since underground shopping malls must connect to the ground level, the three-dimensional movements of pedestrians, including vertical movements using stairs, slopes, escalators, and/or elevators, must also be considered. In addition, in the case of multi-storey underground shopping malls, numerous three-dimensional (3-D) movements exist and 3-D analysis is therefore necessary to improve the route choice models so that they are suitable for planning underground shopping malls.

When there is only one point where pedestrians can transfer to the different level, and he/she knows the approximate direction, his/her route choice behaviour can be estimated by using the model developed in this study twice. As shown in Figure 4 (a), for example, the model is used twice to estimate the route from the point S to M, which is a temporary destination, and the route from M' to D. Thus, the route from S to D is estimated.

In instances where there are multiple transfer points between an OD pair, other considerations are necessary. For example, let us consider a scenario in which there are several transfer points between a major OD pair and also that there exist multiple paths of similar length corresponding to the transfer points M and N as shown in Figure 4 (b).

Fig. 4. Walking paths with transfer points to different levels.
Suppose that the most preferred path via point M is Route 1, that going to point N requires Route 2, and that stairs are installed at the transfer points. Using the model proposed in this study, we can estimate the probability that the paths are selected, which may be important information in order to identify which staircase has higher priority for being upgraded to an escalator, for example. At each transfer point, facilities including stairs, slopes, escalators, and/or elevators, are installed to assist pedestrians to move to a different level. These facilities have marked effects on pedestrian route choice behaviour, especially upon elderly or disabled pedestrians. Consequently, the route selection model developed in this study should be amended to consider the factors related to the walking environment including the status of these aforementioned facilities.

6. GENERAL CONCLUSIONS

This study developed a pedestrian route selection model for large underground shopping malls in the downtown areas of Osaka and Tokyo in Japan. Since the modelling concept was the same as the route choice model the authors developed for aboveground street networks, and since models are structurally similar to each other, the pedestrian route choice mechanisms for aboveground streets networks and underground shopping malls are similar. The relationship between the parameters employed in the Umeda and Yaesu models were found to differ slightly, with straight-through movements found to be more prevalent than the angle of orientation observed in the Umeda model. Conversely, the Yaesu model was found to have the opposite characteristics, with the angle of orientation being more prevalent. While the reason for this disparity has not yet been determined, differences in the structure of the networks in the districts may have some effect on the differences of pedestrian behaviour.

In order to apply the pedestrian route choice models effectively to the planning of underground shopping malls, as well as stimulating plans during peaceful times and as refuges for civilians in times emergency, 3-D movements should be analysed. Extending the findings of this study needs to be undertaken in future studies.

REFERENCES