ESTIMATION OF PEDERSTRIAN CIRCULATION FLOWS IN A TOURIST ZONE

Hiroshi TSUKAGUCHI

Department of Civil Engineering
Ritsumeikan University
Nozi-highashi Kusatsu, Shiga 525-8577, Japan
Phone/Fax 81-77-561-2735
e-mail: tsukaguc@sc.ritsumei.ac.jp

and

Upali VANDEBONA

School of Civil and Environmental Engineering
University of New South Wales
UNSW Sydney NSW 2052
Phone 02 9385 5056
Fax 02 9385 6139
e-mail: u.Vandebona@unsw.edu.au

Abstract

A methodology for estimation of pedestrian circulation patterns is proposed for application to a tourist area where there is a randomness of the sequence of sites visited by tourists. The simulation method is based on a traffic assignment technique applied in association with a trip chain concept that takes into account the behavior specific to leisure pedestrian activities. This method has been primarily designed to provide meaningful traffic estimates for those responsible for planning and development of pedestrian infrastructure. The methodology can also provide valuable information to third parties that may have commercial interests in such zones. Comparison of the simulation outcomes against flows revealed from a pedestrian survey is presented with the aid of a case study of a historical city in Japan.

1. Introduction

Even in motorized societies, walking as the means of mobility plays a major role in leisure travel where the visitor flows are high as could be observed in major expositions, sporting venues, large musical events as well as religious and cultural sites. Encouraging such pedestrian activity provides positive outcomes to planners and also in terms of system performance measures such as efficiency, safety and environmental friendliness. This project attempts to provide a traffic forecasting method suitable to estimate internal traffic within venues that contain many locations of interest while visitors can visit any number of these locations in different possible trip chains. Ability to make reliable traffic estimates in these venues is important in determination of placement of infrastructure and allocation traffic management resources in a useful manner.

The case study area presented here is a tourist zone that has evolved around a street network that contains number of religious and cultural sites within reasonable close proximity to number of major transport gateways. This research problem is of interest as the trip chain behavior in these leisure trips is free of certain constraints seen in trip chains in daily life.

The problem addressed here involves pedestrian route choice behavior as wells as sequencing of destinations. Number of research teams have already documented basic concepts useful for modeling pedestrian behavior in the context of network analysis (for example, Hoogendoorn and Bovy 2005; Kishita et al. 1999). Also, number of previous research projects has investigated the pedestrian route choice problems. Some of the early work in this area has been from the point of view of shopping trips (Borgers and Timmermans, 1986; Hagishima et al. 1987).

The destination sequence followed by a person is known as trip chains in transport literature. Newmark and Plaut (2005), Saito and Ishibashi (1992) and Saito et al. (2004) have already published their applications related to models developed to deal with pedestrian trip chains. In our work, the trip chain behavior of leisure travel has been considered to have less constraints than found in other trip chains where there is more emphasis on satisfying certain arrival and departure time windows.

In this research project we consider a tourist zone, and the route choice problem where travelers perform the destination search in an unfamiliar network maybe relevant to a portion of the traffic. This type of problems could be handled using a random choice technique as already presented in Vandebona and Yossyafra (1999). However, such choice techniques are insufficient here because of the trip chain that involves the pedestrian spending time at number of destinations. These trip chains that give rise to a pedestrian circulation pattern can arise in two situations where the route choice process could be different. The pedestrian may (a) have a good idea about the location of a particular destination and the way to get there or (b) the location is unknown or undecided at the commencement of the trip. Figure 1 attempts to identify this distinction. The key point in the diagram is that the route choice behavior is different depending on whether the destination locations are known or unknown to the person at the outset. Journey to work or school are generally in the first category where the person is familiar with the destination location and routes available. These trips however form predominantly one way trips with return home trip forming a mirror image. It is possible these trips to have short diversions referred to as the 'Starbuck's effect' in Richardson (2006) where one may attend an incidental activity near the origin or destination. Richardson (2006) has already shown that from traffic analysis point of view the effect of such incidental trips is relatively small when measured in terms of travel distance and travel time. Anyhow, in general these trips lack the circuitous appearance on a map we expect from a trip chain connecting number of different destinations of an individual. In some literature the term 'trip chain' is adopted to mean sequence of successive nodes passed through where the nodes could be relevant intermediate road intersections. In the current research work, the term node is adopted to mean destinations visited by the traveler. We use the term 'circulation trip' to mean a trip chain performed by an individual to visit a particular sequence of nodes.

Circulation trip patterns are likely to be observed in the examples identified in Figure 1, within the box marked by dashed lines. As mentioned before, early literature on circulation trips have addressed shopping trips. Shopping trips we have included here in the first category are those performed on a regular basis at familiar localities. Shopping trips that occur at unfamiliar localities when the consumer is away from his or her usual locations or when searching for an infrequent purchase are classified under the second category in the diagram as the destination and route choice strategies are different from regular shopping trips.

Tourist trips could occur in both familiar and unfamiliar context as indicated in Figure 1. A person going overseas on a holiday may perform the trip chain using behavioral strategies of a person unfamiliar with the locality. On the other hand, a local or a regular visitor to a tourist zone can perform the trip chain with the advantage of the familiarity. For the purpose of this study, trip chains we consider are in this familiar tourist category.

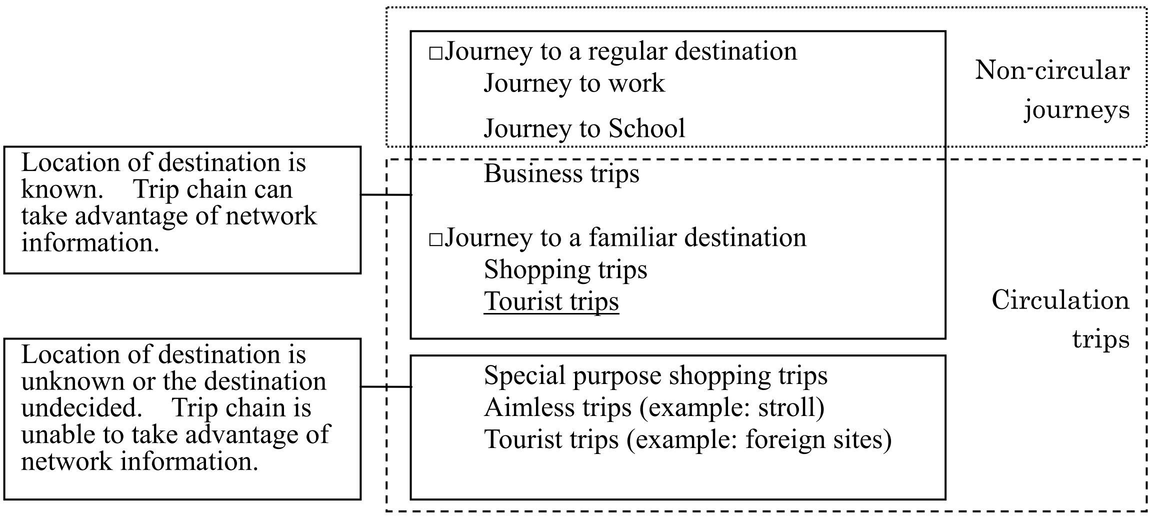


Figure 1 Classification of trip types

2. Data collection

The model developed has been applied to study pedestrian circulation within a well known tourist area in Japan. This area known as Saga-Arashiyama is located in the historical city of Kyoto. This is a well known tourist destination in the country. There are more than 50 nodes of interests to holiday makers in the network considered in this area. Figure 2 shows the locality map.

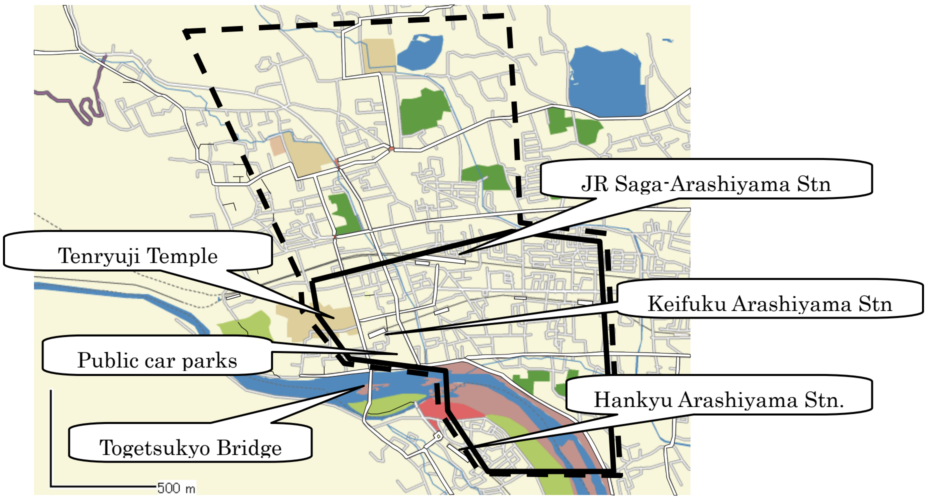
A survey has been carried out at gateways to this area using personal interview technique to obtain trip chains of nearly 100 pedestrians. Specifically, surveys were carried out at three railway stations and a nearby car-park, identified in Figure 2. Survey was administered at the completion of the tourist activity, when the respondent is about to leave the tourist zone. The survey was conducted in November 2007.

The field survey recorded the recollection of tourists about the sequence of locations visited and routes taken within the tourist zone. The respondent demographic information was recorded and locations visited that day within the zone have been noted by the interviewers. It is acknowledged that travel surveys related to leisure trips can have inherent problems due to lapses of respondent recollection. To minimize such problems, the respondent was also requested to sketch his or her travel path on the locality map. Key features of survey administration is provided in Table 1.

There are two zones of interest shown in Figure 2. The smaller zone within the thick solid line boundary identifies the potential coverage area of tourists who spend a relatively short time, perhaps spending less than half a day in the area. The zone bounded by the dashed line is the area applicable for long duration visitors. Tourists who spend more than half a day in this tourist area may have time to venture out of the smaller zone to sites in the greater zone. The locality map given to subjects to mark their routes contained the larger coverage area, shown by the dashed line boundary in Figure 2.

Table 1 Survey administration summary

Surveyed area	Saga-Arashiyama area (map shown in Figure 1)
Date of survey	Saturday, November 10, 2007
Time	Between 1 and 6 pm
Subject requirement	Pedestrians who have completed sightseeing
Number of subjects	98
	43 Males + 55 Females
Items recorded	Sites Visited Sequence of journey Route followed Reasons of route selection



Note: Extent of the tourist zone is indicated by the dashed line. The inner zone bounded by the thick solid line is applicable to short stay tourists.

Figure 2 Locality map of the survey area

3. Pedestrian transition behavior among facilities

Respondents have identified 54 nodes of interest within the area. These could be classified into five broad types, namely, tourist attractions (religious and cultural sites), shops (souvenirs, specialty shops), eateries (food and drink outlets), transport terminals (railway stations, parking facilities) and others (small parks, bus stops). There are twenty tourist attractions, twelve eateries, four transport terminals and eleven other facilities. Here two facilities are double counted within shops and eateries categories.

Survey data could be utilized to produce a transition matrix using the above classification scheme. This type of matrix can be useful in production of models using Markov chain concept for simulation of node choice behavior of pedestrians. The transition matrix shown in Table 2 provides the probability of walking to a node of particular type from a node of a given type. In this tabulation, the origin and destination both refers to the node type of transport terminals.

Table 2 Transition matrix for travel among facilities in the survey area

	Origin	Tourist attractions	Shops	Eateries	Others	Destination
(a) Origin	0.00	0.738	0.048	0.143	0.071	0.000
(b)Tourist Attractions	0.00	0.556	0.113	0.117	0.046	0.167
(c) Shops	0.00	0.273	0.145	0.091	0.036	0.455
(d) Eateries	0.00	0.326	0.217	0.022	0.065	0.370
(e) Others	0.00	0.350	0.300	0.050	0.150	0.150
(f) Destination	0.00	0.000	0.000	0.000	0.000	1.000

Table 2 shows that most tourists (about 74%) walk to a tourist attraction as their first destination. Once a person is at a tourist attraction, the dominant probability for next node is also a tourist attraction. About 56% of trips starting from a tourist attraction terminate at another tourist attraction. This highlights the tourism focus of the area.

When a person is at a node classified as shops, the dominant destination from there is a transport interchange. This indicates that persons at shops have a reasonable likelihood of completing their trip chains at the next destination. Another way to interpret this is to say that tourists in this area leave the shopping activities to latter part of their trip chains.

Table 3 shows average count of nodes visited by a respondent. There were a total of 4.7 nodes visited by the average person. The first two rows of results in Table 3 shows values related to those who can be classified as short term or long term tourists according the area of geographical coverage shown in Figure 2. The nature of the area as a tourist zone is evident in Table 3 that shows the average number of visits to tourist attractions in the form of historical and religious locations is 2.5 for the whole area. Visitors that maybe termed as short term tourists averaged almost two tourist attractions per person during their visit whereas the average long term tourist visited twice as many tourist attractions. Shops and refreshment facilities are generally congregated around the tourist attractions or along links between such locations to take advantage of their pulling power. For example, main shopping streets are focused around sightseeing sites such as Tenryuji Temple and Togetsukyo Bridge.

Table 3 Average number of visits

	Transport terminals	Tourist attractions	Shops	Eateries	Others	Total
Short term zone tourists	0.9	1.9	0.6	0.5	0.4	4.3
Long term zone tourists	0.9	3.8	0.6	0.4	0.2	5.8
Total	0.9	2.5	0.6	0.5	0.3	4.7

This study applied an Absorbed Markov Chain method to model the pedestrian movement among nodes within the tourist zone using the transition matrix shown in Table 2. It was possible to recreate the average counts shown in the last row of Table 3.

Because sightseeing is the main activity in this tourist zone a decision was made to ignore the other types of nodes for the purpose of producing trip chains in the simulation model. It is acknowledged that this simplification can give rise to some forecasting error. A comparison of model predictions with observed flow estimates will be presented later to show that this simplification is acceptable. Anyhow, as mentioned in the introduction, Richardson (2006) has shown that there is only little loss of accuracy in terms of travel distance and travel time by not accounting for short diversions made by travelers to incidental activities. Although work by Richardson (2006) relates to a city wide travel survey of trips by different transport modes, the behavior explained for this 'Starbucks effect' appears to be relevant in the context of pedestrian travel as well. He explained four measures to compute trip incidentality, if required. It is not necessary to quantify those measures in the present context as the location of such nodes clearly relied on the ability of anchor nodes (tourist attractions) to deliver tourists to doorsteps of these incidental nodes.

At the conclusion of this preliminary analysis, it was decided to focus on anchor nodes (tourist attractions) and ignore incidental nodes for the purpose of construction of trip chains.

4. Impact of distance on trip chain development

Routes marked by respondents on locality maps were inspected to obtain an initial view of the trip chain behavior. As a result it was hypothesized that visitors in this tourist zone walk from one anchor node (tourist attraction) to the nearest anchor node. Computation of probabilities of walking to the n-th nearest anchor node was carried out from assessment of trip chains in route maps produced by respondents. These results are shown as a probability distribution in Figure 3. An overwhelming proportion, an 83%, walked to the nearest anchor node from the current anchor site. There is a small proportion of tourists who elected to walk to an anchor node that is not the closest. However, there is some evidence from reasons respondents have provided to their route choice behavior to suggest that this departure from the nearest node selection is a result of forward planning to direct the trip chain to go through particular tourist attractions of their choice.

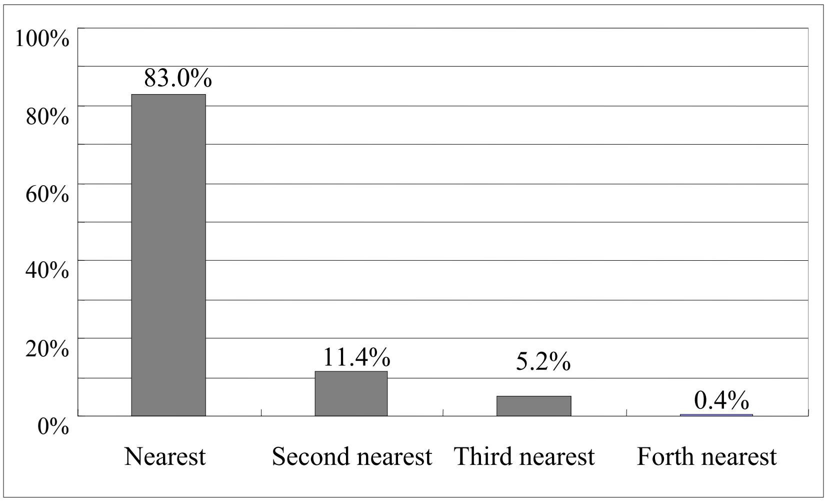


Figure 3 Percentage distribution of the next location visited

5. Simulation approach to generate trip chains

It is now possible to develop a simulation model that accounts for the observed pedestrian behavior explained in previous sections. The transition matrix (Table 2) provides information required about demand and destination choice behavior. The absorbed Markov chain method applied to the above transition matrix can generate counts for number of nodes visited. Then specific sites can be assigned and a trial trip chain can be produced. A simple circuit optimization can be applied to improve the route according to travel distance and find a feasible trip chain for the individual tourist.

Specifically, there are six steps in the pedestrian simulation process as follows:

(1) The first step involves estimation of the transition matrix, similar to Table 2. In this project, the transition matrix for movements between pairs of nodes was obtained from route details revealed by respondents during the field survey. It may be possible to develop the transition matrix from a simpler origin destination type survey. This project identified two types of pedestrians (short stay or half day tourists and long stay or full day tourists) and it is necessary to generate pedestrians in both categories. However, in view of the smallness of the sample size of the field survey, a common transition matrix was applied for both types of tourists at this initial step.

(2) The second step involves estimation of the number of nodes visited by each generated tourist, using an absorbed Markov chain method applied to the transition matrix. At this step the focus is on the count of nodes, as the location of nodes corresponding to that count will be determined in a later step. Also, the generated tourist is classified stochastically to short or long term category according to the percentage breakdown of these two types of tourists observed during the field survey for a given count of nodes visited. In a later step, this classification to long and short term types aids the identification of the geographic area covered by the tourist.

(3) The third step involves development of an array of frequency distribution of tourist arrivals at anchor nodes. In this project, there were 20 tourist attractions and 4 transport terminals that form the role of anchor nodes. Frequency distribution for tourist arrivals at these nodes was obtained from the field survey. It may be also

possible to obtain this information from a head count at turnstiles or entrances of these locations.

(4) The fourth step assigns anchor nodes according to the arrival probability array developed in the previous step to individual generated tourist. Recall that incidental nodes are ignored in this study from this step onward. Long stay tourists have been assigned nodes from all 20 tourist attractions whereas short stay tourists have been allocated from a subset consisting of 10 attractions, those sites that lie within the smaller area shown in Figure 2. At the completion of this step, each generated tourist has the origin and the list of tourist attractions to be visited assigned to the individual.

(5) The fifth step makes a trial trip chain to satisfy the assigned origin and tourist attractions. The method adopted here is a nearest neighbor method. In other words, the trip chain starts from the assigned origin node and then the first link of the trip chain is formed to an assigned node nearest to the origin. The next link of the trial trip chain is formed to nearest of the remaining assigned nodes.

(6) The sixth step searches for an optimum solution for the trail trip chain for individual generated pedestrians. An arc exchange method (Example: Tsukaguchi et al. 1998) has been adopted in this step to arrive at satisfactory optimal solutions. At the completion of this step the node sequence is known for generated passengers. However, the exact path is still not concluded as there are more than one possible path between each pair of nodes.

(7) The step seven applies the pedestrian route choice model to solve the traffic assignment problem and identify the pedestrian paths between a given pair of nodes in both directions. These paths between nodes allow the model to complete path details of the complete circuit of each simulated tourist. Overlaying these circuits of all simulated tourists provides link flow pattern of the complete road network in this tourist zone. The route choice model applied here is described in the next section.

6. Pedestrian route choice behavior

The pedestrian route choice behavior concept presented here is applicable when there are multiple routes of almost equal distance between an origin and destination pair because of the grid layout of the road network. For the purpose of this study, routes with distance less than 1.2 times the shortest route are considered as potential pedestrian routes. Step 7 in the previous section applies only when there are different walking links between the origin destination pair. If there are no paths shorter than 1.2 times the distance of the shortest path between the origin and destination, the pedestrian is assigned to the shortest path. However, when there are two or more potential paths, as found in networks with curvi-linear grid patterns, the pedestrian assignment to paths depends on a choice probability concept.

The method applied is based on two properties of pedestrian route choice behavior:

1) The tendency to maintain a straight through movement: The method applied considers that pedestrians tend to choose a straight route over a branched route of similar distance. This behavioral tendency is similar to inertia or momentum in physics. The relevance of this choice behavior is pronounced when the pedestrian lacks orientation information. In other words, if there is insufficient route markings, majority of pedestrians will elect

to continue on the same vector until guidance information or other visual cues encourage the pedestrian to change the direction. For unfamiliar pedestrians, the left and right turn probabilities would be low and straight through movement would have a relatively large probability.

2) The tendency to minimize the angle of orientation: This behavior applies to familiar pedestrians who are aware of their orientation relative to the destination. Here the pedestrian is aware of the approximate orientation of the next destination relative to the direction the person is currently walking. In this situation the pedestrian may attempt to minimize the geometric angle between the current movement vector and the imaginary vector that connects the present location to the destination.

Figure 4 shows the angle measurements required to develop a model using the above concept. In the layout diagram shown at top (in Figure 4), the dashed line indicates the current direction of progress. Angle measurements are taken from the two available choices (assuming the total travel distance is nearly equal) of paths to the dashed line. In the second layout diagram in Figure 4, the dashed line is the vector connecting current location and the next destination. As before, angle measurements are taken from the two choice directions.

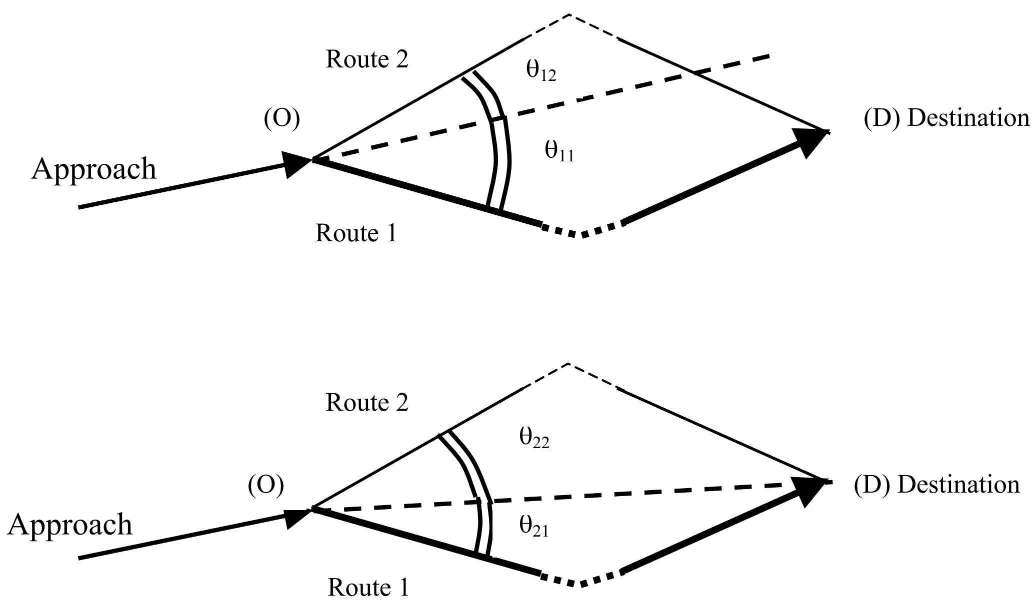


Figure 4 Angles related to pedestrian movement at an intersection.

Using measurement of angles θ_{11}, θ_{12}, θ_{21}, and θ_{22} as shown in Figure 4, a disaggregate route choice model can be constructed. Equation 1 shows the form of the utility function that include the route choice concept described above.

$$V_i = \sum_{j=1}^{2} \omega_j \theta_{ij} \qquad (i=1, 2) \tag{1}$$

where ω_1 and ω_2 are calibration parameters.

Now the binary logit model can be applied to estimate the choice rates for routes 1 and 2 expressed as:

$$P_1 = \frac{e^{V_1}}{e^{V_1} + e^{V_2}} \quad (2)$$

$$P_2 = \frac{e^{V_2}}{e^{V_1} + e^{V_2}} \quad (3)$$

Pedestrian route details obtained from the field survey allow us to compute the calibration parameters ω_1 and ω_2. The estimated parameter values are shown in Table 4. Table 4 also shows model properties such as t values, likelihood ratio ρ^2, and reproducibility of the model. It is observed that the parameter for the straight through movement is larger than that of the destination orientation. This may suggest that many tourists were not familiar with the travel area.

Table 4 Statistical Properties of the pedestrian route choice model

	Parameter	t value
$\omega 1$ parameter related to straight movement	-2.21×10^{-2}	-10.95*
ω_2 parameter related to destination orientation	-1.61×10^{-2}	-4.56*
Likelihood ratio ρ^2	0.36	
Reproducibility of the model	310/386 = 0.803	

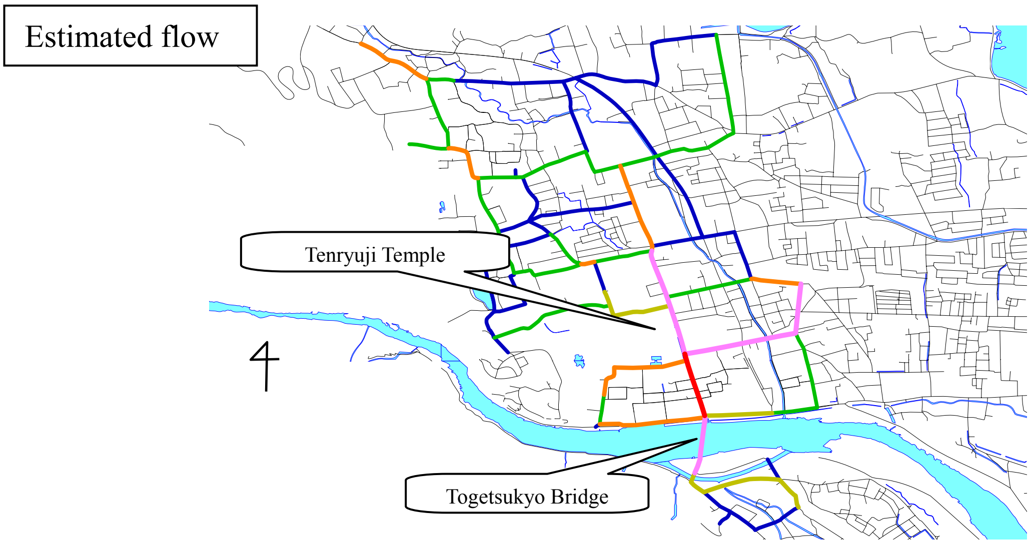
*1% significance

7. Estimation of pedestrian flows

As indicated in the last step of the description of the simulation methodology, overlaying routes of individual simulated pedestrians allows the model to estimate the flow intensity at the link level of the road network in the tourist zone. As we have individual travel paths of respondents from the field survey, it is possible to use this step to compare the pedestrian flow at link level using the model against the real data. It is relatively convenient to do the comparison using visual observation of network layouts, and that method is presented first. A numerical comparison will be presented later.

As there were 98 respondents for the field survey, the comparison will be made against the outcome from 98 simulated pedestrians. Figure 5 shows the link flow due to tourist behavior for the simulated sample (the top figure) and the field data sample (the bottom figure). There is a reasonable similarity between the simulated and observed link flow diagrams. Both diagrams agree that pedestrian flow on links between Tenryuji Temple and Togetsukyo Bridge are large. Also, the intensity of flow gradually decreases with distance radiating from the central area that contained the transport gateways.

A numerical comparison of flow values could be made by plotting the simulated and observed flow values in a graphical manner as shown in Figure 6. The figure shows that there are two dominant links from the point of view of pedestrian flow (between Tenryuji Temple and Togetsukyo Bridge). Considering this flow value of about 130 pedestrians was a result of activities of 98 tourists, the pedestrian flow on those two links is equivalent



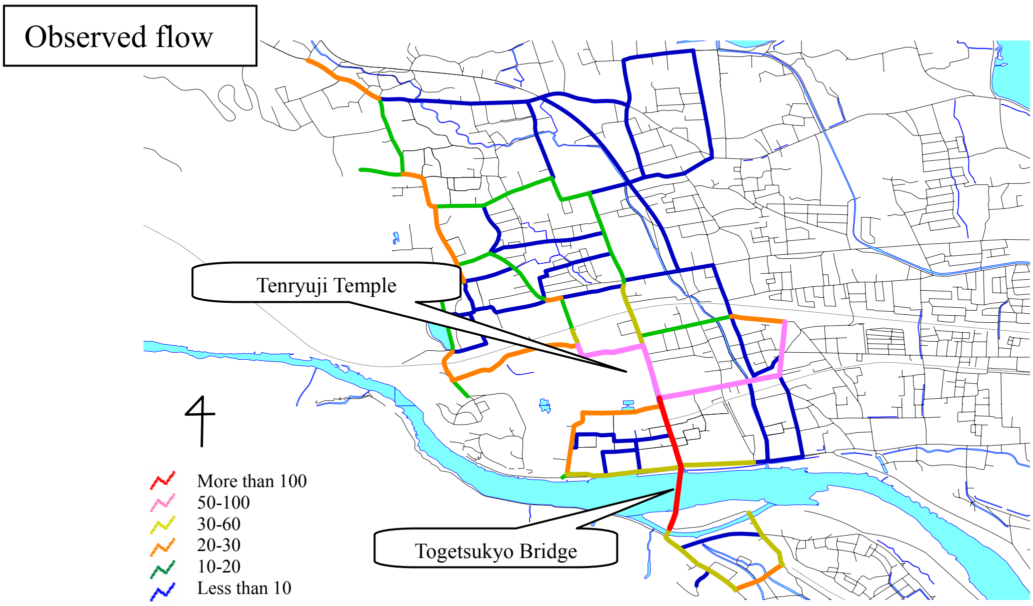


Figure 5 Estimated and observed Pedestrian Flow

to about 1.3 pedestrian trips per tourist arrival to this zone. In other words, one in three tourists appears to use these links two times in their trip chains. In general, estimates from the simulation are about 7% lower than the observed value according to a regression analysis performed on values shown on Figure 6. It is speculated that this maybe due to real pedestrians following the crowd (a 'herd effect') when alternatives are available and positive qualities of certain paths not being quantified into the distance oriented utility function adopted here. R squared value of 0.87 observed can be considered reasonable.

There are about 5 other links that shows relatively high pedestrian flows. The simulation and field observations generally agree on links where these high flows occur. And there is a reasonable agreement about the magnitude of the flows.

There is a large cluster of links with small flow values at the lower left corner of the diagram. This area is responsible for links that produce pedestrian flows less than half trip per visitor to this tourist zone. There is dispersion of data points in this area indicating some loss of estimation accuracy for links that has low pedestrian flows. Nevertheless, in general, there is a good correlation between model estimates and field observations.

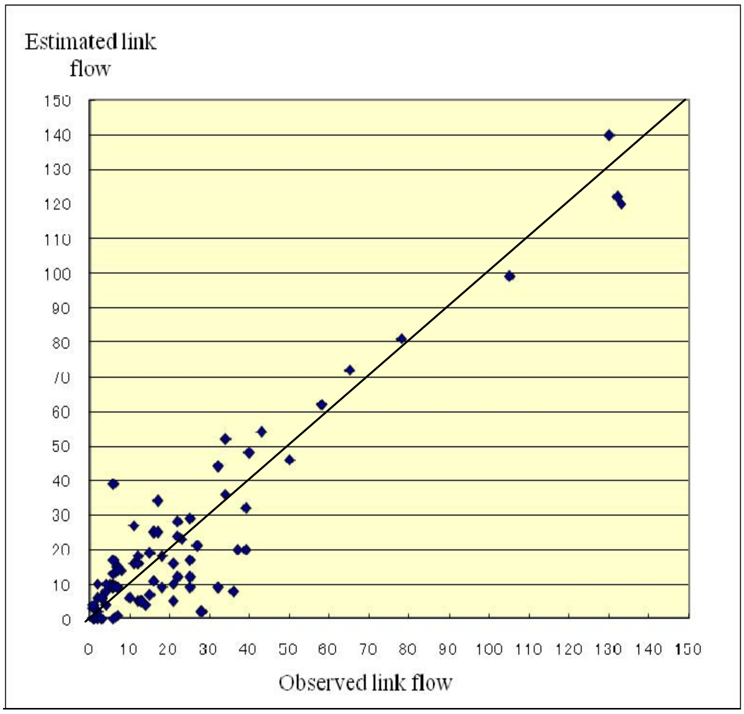


Figure 6 Comparison of simulated and observed flows

5. Conclusions

This study has proposed a methodology to forecast pedestrian circulation behavior in a tourist zone. The methodology follows a sequence of determining the destination choice process, trip chain construction and a probabilistic route choice process to allocate passengers to potential alternative paths. Development of the model has relied on number of properties of pedestrian behavior.

It is shown that a short field survey is able to provide information to construct the transition matrix for movement among nodes, average number of visits to a given type of node and properties required for logit model application for pedestrian route choice. This methodology has been explained with the aid of a field survey conducted at a tourist zone in Kyoto. There were 54 nodes tourists could include in their trip chain in this area.

The proposed model first determined the number of nodes a pedestrian may visit using the transition matrix and arrival count distribution revealed by the field survey. The case study presented had to account for the existence of two types of tourists classified according to their coverage area. The next step stochastically allocated the list of tourist attractions to visit for each simulated tourist. It was then possible to determine the trip chains by applying a walking distance minimization condition. As a further refinement, exact paths between nodes were assigned using the behavior choice theory. This process provided a detailed route map for each pedestrian and these paths could be combined to estimate pedestrian flow properties on each road link.

Estimated pedestrian flows on individual walking paths were compared against field observations. Results indicate that the proposed model structure is able to provide forecasts of link flows of pedestrians of the tourist zone network with sufficient accuracy for planning purposes.

The methodology developed is useful for estimation of traffic flows in areas where journeys are predominantly circulation trips formed by trip chains. Performing the analysis based on anchor nodes and ignoring incidental nodes for the construction of trip chains as done in this case study may not be suitable in other applications where incidental nodes have a high degree of independence about their location selection. In such situations, all nodes have to be considered in the formation of trip chains and an increased amount of computation effort is required to arrive at the solution. On the other hand, this study area was divided to two coverage zones to account for the circulation space possible by half day and full day tourists. In other applications it may be acceptable to consider only one coverage zone particularly when there is a clear area boundary and relatively small coverage space, such as in an evening leisure park.

The ability to forecast link flows using the proposed methodology is valuable for transport infrastructure management purposes, particularly for resource allocation in areas of signage, street beautification, lighting, shelters, policing and street cleaning. Established tourist zones such as the case study area already have much spent on such elements. Fine tuning and making better use of the limited resources is feasible when link flow estimates are available.

References

Kishita M., Tazo T. and Makimura K. (1999) Methodology of Data Collection for Pedestrian Mobility and its Application to Downtowns, Proceedings of JSCE, No. 625: 161-170.

Hagishima S., Mitsuyoshi K. and Kurose S. (1987) Estimation of pedestrian shopping trips in a neighborhood by using a spatial interaction model, Environment and Planning A 19 (9) 1139 – 1152.

Newmark G. L., Plaut P. O. (2005) Shopping Trip-Chaining Behavior at Malls in a Transitional Economy, Transportation Research Record 1938: 174-183

Hoogendoorn S.P., Piet H.L. and Bovy P.H.L. (2005) Pedestrian Travel Behavior Modeling, Networks and Spatial Economics 5(2): 193-216.

Borgers A. and Timmermans H.J.P. (1986) A model of pedestrian route choice and demand for retail facilities within inner-city shopping areas, Geographical Analysis 18: 115 – 128

Saito S. and Ishibashi K. (1992) A Markov chain model with covariates to forecast consumer's shopping trip chain within a central commercial district, 4th World Congress of

RSAI (Regional Science Association International), Mallorca, 216-217.

Saito S., Yamashiro K. and Nakashima T. (2004) A hidden Markov model to estimate time-varying pedestrian flows within a city center retail district, RSAI World Congress, Port Elizabeth, South Africa.

Richardson A.J. (2006) Fandangles and other Measures of Incidental Trips, Transportation research record 1985: 106-114.

Vandebona, U. and Yossyafra (1999) Analysis of Signage Requirements for Pedestrian Movements", Roads and Transport Research, Journal of the Australian Road Research Board Transport Research, Vol. 8(4): 55-67.

Tsukaguchi H., Jung H.Y. and Vandebona U. (1998) Modelling of Delivery and Pick-up Truck Movement to Improve Goods Transportation System in Central Business Districts, World Conference of Transport Research (WCTR8).

Tsukaguchi H., Vandebona U. and Matsuda K. (2003) Modelling of Pedestrian Route Choice Behaviour for Development of Information Systems Architecture, The Selected Proceedings of World Conference of Transport Research (WCTR9), Eds Park, Cho, Oh, Hayashi, Viegas.