Modelling of Pedestrian Sign Locations in a Large Transport Hub

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Abstract: Lack of suitable signs in pedestrian intensive networks similar to those found in certain transport interchanges degrades the quality of service of such systems by increasing walking distances, journey times and stressful conditions caused to people getting lost. An Entropy based model for determination of direction signs in a pedestrian flow network has been presented in the paper. Pedestrian route choice behavior has been built into the model to evaluate the selection process for travel paths. A demonstration of the computation procedure to propose a sign system for the underground pedestrian corridor network of a large transport interchange, Osaka Transport Hub, has been included.

Keywords: Pedestrian Signs, Large Transport Hub, Entropy, Route Choice Behavior

1. INTRODUCTION

Recent innovations in communication technology have given rise to a range of navigation tools to assist the general public and system providers. This is much different from historical times when pilgrims had to rely on word of mouth or follow knowledgeable guides (for example to Santiago de Compostela in Europe; Mecca in Middle East and Ise-mairi in Japan). Some of these sites are even more popular and accessible now and there are many who elect to perform the pilgrimage the old-fashioned way. In essence, providing an adequate system of signs to manage pedestrian flows are important for users as well as administrators of large crowd attractors such as recreational parks and cultural venues. Similarly, sign systems are an integral part of management of pedestrian flows in localized properties including shopping complexes, employment hubs, educational centers and, hospitals.

Lack of signs in pedestrian intensive networks degrades the quality of service of such systems by increasing walking distances, journey times and stressful conditions caused to users. Facility operators also suffer from having to place extra resources to handle lost and delayed users of the facility in addition to extra congestion caused by those who were unable to find an efficient path through the network of corridors.

The approach followed in the proposed methodology attempts to make use of the static sign system to minimize the randomness of walking paths through the network for all passengers walking between a given origin and destination pair. This methodology is particularly helpful when there are number of minimum distance paths between the origin and destination pair, as often found in built environments. The methodology also makes a conscious attempt to make the guide paths be similar to the one selected by most users who are well familiar with the network layout and make route choice decisions at intersections according to observed pedestrian choice probabilities.

Previous attempts to identify characteristics of pedestrian route choice behavior have been reported by Takegami and Tsukaguchi (2006). Hoogendoorn and Bovy (2004) analyzed route choice behavior by minimizing the activity load of pedestrians. Zacharias et.al. (2005) and Zacharias (2006) analyzed pedestrian route choice behavior in a shopping center. Also, they have analyzed pedestrian route choice behavior in street networks located on the ground and underground.

In a large transport hub located in the city center of a metropolitan area, there are railway terminals, commercial establishments and public facilities on different floors of multistory layout. Transport hubs rely on the sign system to provide directions in an understandable and convenient way for users. Continuity and standardization are important factors of an effective sign system. Also, clarity of contents of signs is an important factor for user comprehension of the directions.

As for pedestrian route choice behavior in transport hubs, Cheung (1998) studied pedestrian route choice behavior related to escalators and stairways in stations. Zacharias *et al.* (2005) have simulated pedestrian behavior in a retail shopping environment. Earlier, Tsukaguchi *et al.* (2013) have developed a model for route choice behavior in a three dimensional pedestrian space of a large transport hub.

Previously, sign systems have been studied with the focus on analyzing the relationship with destination and/or route choice behavior. For example, Yokota *et al.* (1997) studied basic characteristics of sign system from a viewpoint of spatial recognition in order to plan an easily understandable underground shopping arcade, because space recognition should be studied in advance. Kim *et al.* (1990) discussed sign planning including arrangement, design and management of pedestrian signs. Ogata *et al.* (1995) also discussed arrangement of pedestrian signs. Vandebona and Yossyafra (1999) studied the efficiency of a pedestrian sign system using simulation approach for a grid type network. On the other hand, Mori and Iida (1997) have analyzed pedestrian behavior in order to construct pedestrian sign system.

As mentioned above, there are many studies on pedestrian movements and signs for pedestrians. However, there is still a room to improve methodology followed in the planning process to determine the best way to arrange signs for pedestrians in large transport hubs based on analysis of pedestrian characteristics.

Since Entropy has been mainly studied in information science field, there are few studies in transportation field. Prochazka et al (2015), Nurwulan(2016), and Huerta (2017) studied pedestrian movements using Entropy concept. However, these studies are different from those of pedestrian sign system.

2. ANALYTICAL METHODS

2.1 Path Selection to Achieve Minimization of Randomness of Flows

Suppose pedestrians are unaware of the location of the desired destination. If there are no signs, pedestrians have to determine the suitable direction at each intersection without guidance information. The route selection from the origin to destination consists of a series of turns at each intersection in the network. If the pedestrian does not have network spatial information, the person has to select direction at random. On the other hand, if the approximate direction to the destination is known, number of alternative directions to select can be reduced. Previous studies have indicated that a route longer than 1.2 times than the shortest route is rarely considered by pedestrians (Takeuchi(1977), Takegami and Tsukaguchi (2006)). Considering these findings, this study selects these nearly shortest passes for modelling.

Suppose that there are n alternative links, namely Ai (i=1, n), potentially going to the destination at an intersection. Then the probability P_i of selection of A_i is, can be applied to express the uncertainty measure known as Entropy (H) in information theory. Entropy (H) is formulated by the following equation.

$$H = \sum_{i=1}^{n} P_i \times \log\frac{1}{P_i} = -\sum_{i=1}^{n} P_i \times \log P_i \qquad (1)$$

2.2 Probability of Link Selection at Each Node

Assume that a pedestrian is approaching node O illustrated in Figure 2-1. His/her destination is node D. Assuming the pedestrian knows approximate direction of the destination, alternative links at each node may be two in most cases, when U-Turn movement is ignored. Takegami and Tsukaguchi (2006) developed route choice models successfully which follow the situation mentioned above. The models are based on observation surveys in twenty districts with deferent street networks in Keihanshin (Kyoto, Osaka and Kobe) area, Japan. Therefore, the modeling concept, allowing two alternative links to select at the node is reasonable, if the pedestrian can guess the approximate direction of the destination.

At the node O in Figure 2-1, there are two links, on left side (S_L) and right side (S_R). We can also identify two vectors, named origin vector and destination vectors. The origin vector is the extension of approach vector, and the destination vector formed by the straight line connecting node O and destination D. Considering the two links and two vectors, the following angles can be defined:

Θ_{OL}: angle between the origin vector and the left side link,
Θ_{OR}: angle between the origin vector and the right side link,
Θ_{DL}: angle between the destination vector and the left side link, and
Θ_{DR}: angle between the destination vector and the right side link.

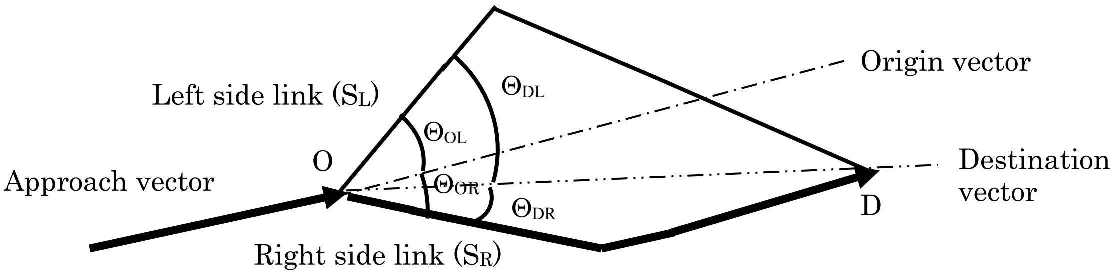


Figure 2-1 Angles related to pedestrian turning movement at an intersection

Route choice of pedestrians often depends on two behavioral intentions. Pedestrians tend to choose a straight route over a branched route of similar distance. It may be said that there is somewhat similarity between such pedestrian behavioral tendency and inertia in physics. For example, if Θ_{OR} is smaller than Θ_{OL}, the pedestrian is likely to selects the right side link drawn by thick lines. Also pedestrians prefer to minimize the geometric angle (Θ_{OR}, Θ_{OL}) between the origin vector and the destination vector that connects the present location to the destination. For example, when Θ_{DR} is smaller than Θ_{DL}, pedestrians are likely to select the right side link.

Considering these characteristics, authors developed the following route choice model. The choice probabilities of the left side link and right side link are expressed as:

$$P_L = \frac{e^{V_L}}{e^{V_L}+e^{V_R}}, \; P_R = \frac{e^{VR}}{e^{VL}+e^{VR}} \tag{2}$$

where,

$$V_L = \omega_L \Theta_{OL} + \omega_R \Theta_{DL}, \text{ and } V_R = \omega_L \Theta_{OR} + \omega_R \Theta_{DR} \tag{3}$$

ω_L and ω_R are coefficients associated with Θ_{OL} or Θ_{OR}, and Θ_{DL} or Θ_{DR}.

Based on field observations, the following route choice model (see Table 2-1) has been developed earlier [Tsukaguchi, Shibata, and et al (2013)]. The coefficients ω_L and ω_R show the relationship between (A) Angle of orientation and (B) Angle related to turning movement. Using the two coefficients, coefficient ratio can be calculated that indicates which tendency (a) or (b) has more effect on pedestrian route choice behavior.

Table 2-1 Route choice model

Coefficients		Likelihood ratio	Reproducibility of the model	Coefficient ratio (A/B)
(A) Angle of orientation (degree)	(B) Angle related to turning movement (degree)			
-1.5802×10^{-2} (-14.03*)	-8.9417×10^{-3} (-17.06*)	0.1604	69.4 %	1.767

Note: values within parentheses are t values and * indicates 1 % significance level.

Substituting P_L and P_R, shown in equation (2), to Pi values of equation (1), entropy measure H can be calculated. The next section explains the sign location selection process in a step by step manner.

2.3 Method for determination of sign locations

Pedestrians want to decrease uncertainty in general when navigating toward their destination. Therefore, the search process looks for the location where a sign can deliver the highest reduction of uncertainty and installs the next sign there. The search process can then be repeated until the complete path can be defined with all turns are sign posted to a given destination. The computation process can be summarized as follows:

1) Select an origin destination pair and a suitable cut-set arrangement.
2) Measure Θ_{OL}, Θ_{OR}, Θ_{DL}, and Θ_{DR} at all nodes.
3) Compute all turning movement probabilities at nodes (using the choice model) assuming there are no pedestrian signs provided yet in the network.
4) Calculate the initial Entropy (E_0) for the movement between particular origin destination pair without any signs.
5) Select a node as a potential sign location, recalculate Entropy (E_1) assuming all pedestrians relevant to the particular origin destination pair obey the sign.
6) Repeat Step 5 for all other nodes of the network.
7) Find the node i that maximizes $E_0 - E_i$. Locate the next sign at that node i facing the direction of the approach vector of pedestrian flow.
8) Repeat the process until the Entropy is zero.

It can be seen that this process follows a greedy algorithm character.

Route choice model presented in Section 2 combined with the entropy concept presented in Section 1 have been applied here to evaluate sign systems. The route choice model gives probability of route choice at each node using Equations (2) and (3). Substituting those probability values to Equation (1), the Entropy H in the network responding to the sign installment is easily calculated. Entropy minimization is then carried out to determine best locations for signs. The process is illustrated in Figure 2-2.

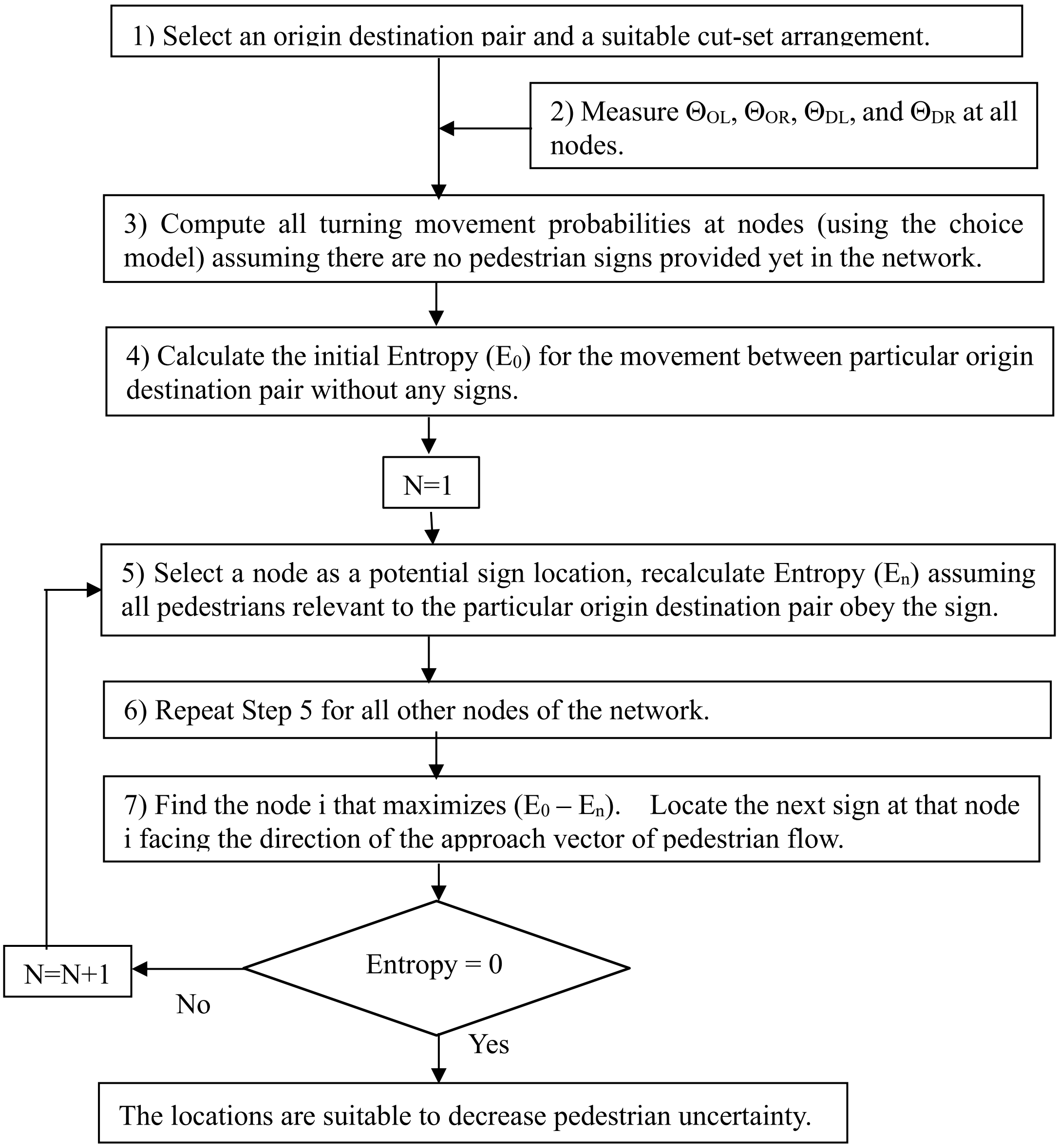


Figure 2-2 Flowchart of the computational steps

2.4 Simplification of Sign Location

As a result of the procedure mentioned above, the suggested plan of signs can be excessive and complicated. It could be simplified by the following manner. As mentioned earlier, pedestrians tend to choose a straight route over a branch route of similar distance, a behavioral tendency similar to inertia in physics. Hirata (2012) conducted a survey at grid-type network where subjects had no information of the destination location and that survey indicated that the percentage of going straight is 56%, and the percentages of turning right and left are 20% and 23%. The result supports the validity of characteristics mentioned above. Considering this tendency, the signs placed on the nodes where pedestrians will go straight can be removed.

3. SIGN ARRANGEMENT EXAMPLE FOR A GRID NETWORK

For ease of understanding the model application is shown for a grid network in the following section. All links are of equal length in the selected network (See Figure 3-1). However, the proposed sign allocation methodology can be applied to other types of street networks as well.

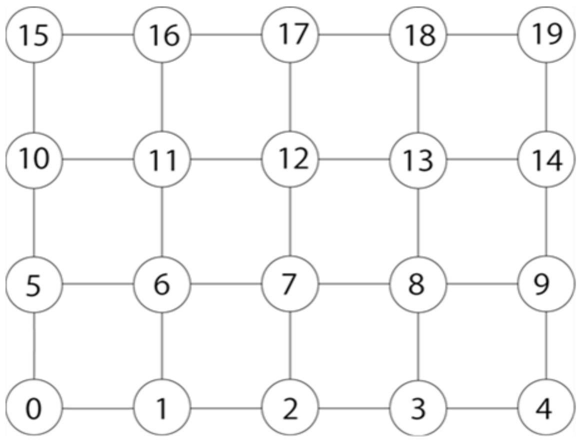


Figure 3-1 Example 4 x 5 grid network selected for the application.

At the beginning, there is no sign nominated for any node in the network shown in Figure 3-1. We assume that the origin is node 0 and the destination is node 19, when the passenger approaches the node 0 from the left side. Following conditions relate to the calculation performed:

a) Passengers do not know the route to the destination, but they know approximate direction to the destination, even if there is no sign in the network. Therefore, U-turns are not considered,
b) The two angles shown in Figure 2.1 are measured at all nodes (forks) in the network,
c) If a sign exists, all passengers obey the direction sign, and
d) If there is no sign at a node, passengers select their link according to the route choice model (equations (2) and (3)).

In the network shown Figure 3-1, a sign is added systematically, one by one. In each situation, entropy is calculated. The most suitable location for the next sign is determined by looking for the location that creates the largest amount of entropy reduction. This process repeats until the entropy becomes zero.

3.1 Calculation of the Initial Entropy

In this case, there is no sign installed in the network, therefore passengers have to rely on their own route choice behavior. Link choice probabilities obtained from Equation (2) and (3) are applied in the calculations.

As mentioned before, passengers approach node 0 from left side. Therefore, at the beginning, such passengers select link 0-5 with probability of 0.26 and link 0-1 with probability of 0.74[(1)]. Probability values calculated at each node using the route choice model provides the link choice probability of all links as illustrated in Figure 3-2.

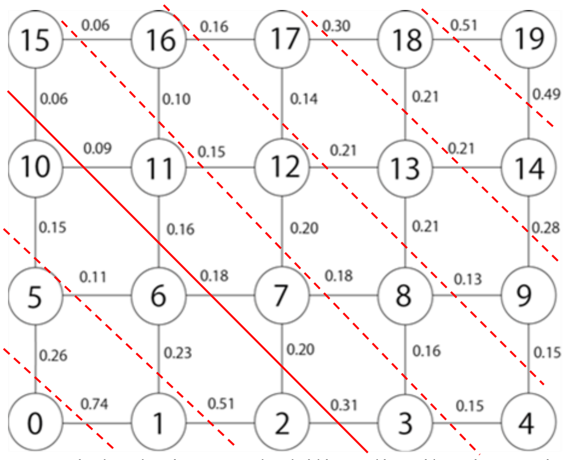


Figure 3-2 Link choice probability distribution without any sign

The obscurity of the network for unfamiliar persons can be expressed by the entropy concept. To obtain the value of entropy, cut sets as shown in Figure 3-2 has been selected. There are seven cuts in this network.

The entropy value for the cut set drawn by red solid line is calculated using Equation (1)

$$H = 0.31 \times \log\frac{1}{0.31} + 0.20 \times \log\frac{1}{0.20} + 0.18 \times \log\frac{1}{0.18} + 0.16 \times \log\frac{1}{0.16}$$
$$+0.09 \times \log\frac{1}{0.09} + 0.06 \times \log\frac{1}{0.06} = 1.67$$

Entropy for the each cut set of the network is calculated by the same way mentioned above, and the results are shown in Table 3-1. Adding these values, the initial Entropy (E_0) of the network is obtained as 9.18.

Note (1): When a pedestrian approaches to node 0 from left side, the angles in Figure 2-1 are: $\Theta_{OL} = 90$, $\Theta_{OR} = 0$, $\Theta_{DL} = 53$, and $\Theta_{DR} = 37$. Substituting these values and the coefficients shown in Table 2-1 to equation (2) and (3), the probabilities of going to node 1 and node 5 are calculated as 0.74 and 0.26.

Table 3-1 Calculation of network Entropy value

Cut	Entropy value
[0-5, 0-1]	0.57
[5-10, 5-6, 1-6, 1-2]	1.21
[10-15, 6-11, 6-7, 2-7, 2-3]	1.67
[15-16, 11-16, 11-12, 7-12, 7-8, 3-8, 3-4]	1.89
[16-17, 12-17, 12-13, 8-13, 8-9, 4-9]	1.78
[17-18, 13-18, 13-14, 9-14]	1.37
[18-19, 14-19]	0.69
Entropy of the whole network: 9.18	

3.2 Entropy Minimization to Determine Sign Locations

The objective here is to minimize randomness of pedestrian flows caused with the planned sign system. Randomness is reduced when a sign is introduced at any node in the network. The greedy optimization strategy adopted here is based on identifying the largest reduction of the entropy measure feasibly by introducing a sign at a single node. That node becomes most effective location for the next ideal sign.

1) Network with a single OD pair

First example presented is for a one to one flow condition. Origin node is node 0 and destination node is node 19. At the node 0, passengers approach from the left side.

Firstly, let's find the most effective location when one sign is installed. If a sign is at a node, all pedestrians who pass the node follow the direction which the sign indicates. On the other hand, if there is no sign at a node, pedestrian movement is estimated by the route choice model in the same way as former section. Table 3-2 shows entropy values and reduction from the condition without any sign (here, Entropy is 9.18 calculated in Table 3-1), when one sign is installed. Since the entropy reduction is largest when sign is installed at node 0, the first sign is determined to install at node 0 as illustrated in Figure 3-3.

Table 3-2 Entropy calculation to select the guidance

Node	Entropy	Reduction from E_0
0	7.44	1.74
1	8.27	0.91
2	8.63	0.55
3	8.71	0.47
5	9.03	0.15
6	8.68	0.50
7	8.74	0.44
8	8.91	0.27
10	8.94	0.24
11	8.68	0.50
12	8.92	0.26
13	8.80	0.38
Node selected	0	
Sign direction	Right	

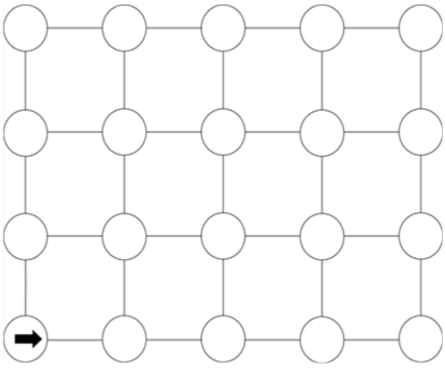


Figure 3-3 Sign location

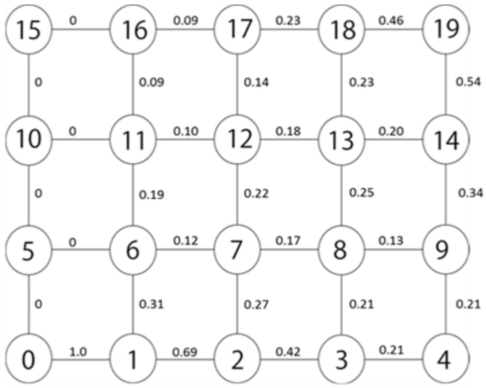


Figure 3-4 Link choice probability for Figure 3-3

Table 3-3 Effect of sign installation

Node	Entropy	Reduction from E_0
1	5.50	3.68
2	6.44	2.74
3	6.87	2.31
6	7.27	1.91
7	7.10	2.08
8	7.20	1.98
11	6.62	2.56
12	6.82	2.36
13	7.10	2.08
Node selected	0, 1	
Sign direction	Right	

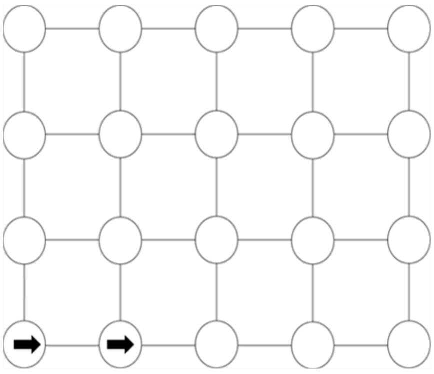


Figure 3-5 Sign locations

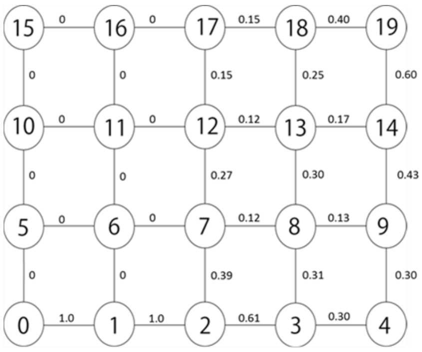


Figure 3-6 Link choice probability for Figure 3-5

Table 3-4 Effect of sign installation

Selected node for signs	Entropy
No sign	$H_0 = 9.18$
0	$H_1 = 7.44$
0, 1	$H_2 = 3.68$
0, 1, 2	$H_3 = 3.16$
0, 1, 2, 3	$H_4 = 2.18$
0, 1, 2, 3, 8	$H_5 = 1.24$
0, 1, 2, 3, 8, 13	$H_6 = 0.0$

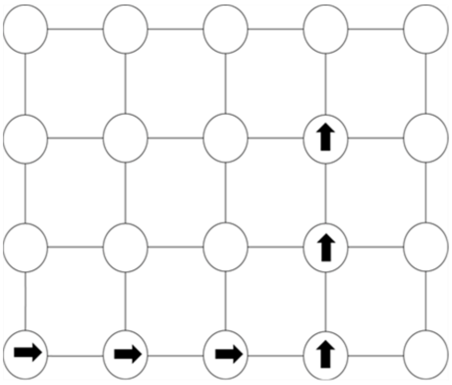


Figure 3-7 Sign locations

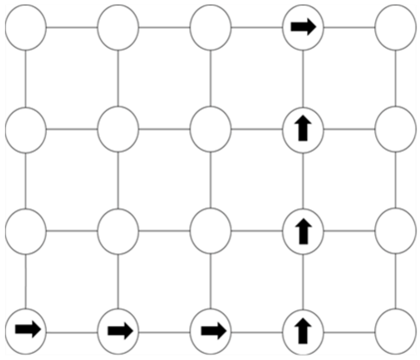


Figure 3-8 Final sign locations

When one sign is installed at node 0, the link choice probability is calculated as shown in Figure 3-4, using the same way we used in Figure 3-1. In this calculation, Entropy H_1 is 7.44. Since the entropy is not 0 at the sign location illustrated in Figure 3-3, we advance to the next step.

Figure 3-4 shows the new movement probability values when a direction sign is available at node 0. Table 3-3 shows the entropy calculation with trial signs introduced one at a time at the remaining nodes. The least entropy is observed when the next sign is added at node 1. Therefore, node 1 is selected as the second location for sign installation. Then Entropy H_2 is 5.50. Since the entropy is not 0 at the sign location illustrated in Figure 3-5, we will advance to the next step. With signs installed at nodes 0 and 1, the link utilization is calculated as shown in Figure 3-6.

We can repeat this process until the entropy value becomes zero. The results are indicated in Table 3-4. The sign location at this stage is shown in Figure 3-7.

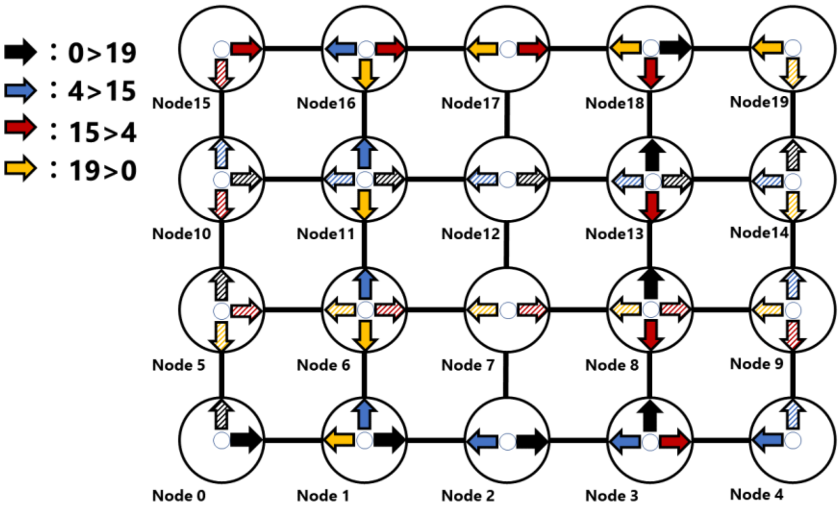


Figure 3-9 Sign locations for four OD pairs

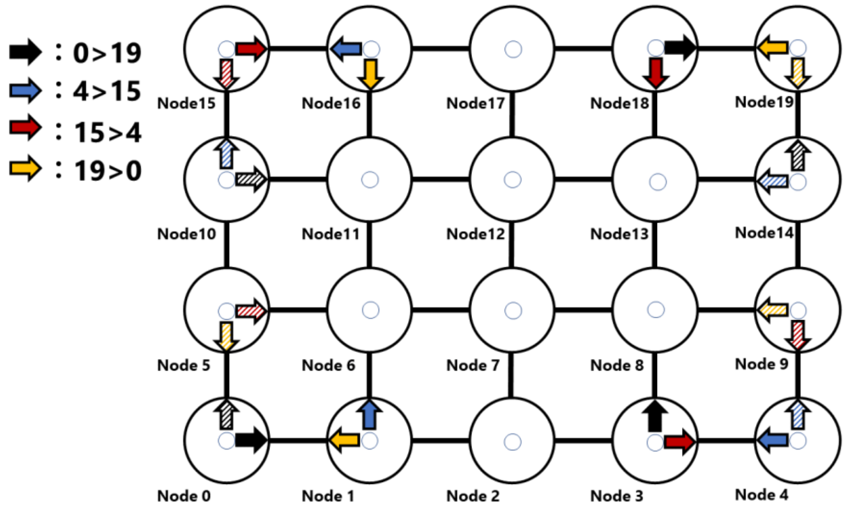


Figure 3-10 Simplified sign location for four OD pairs

As shown in Table 3-4, when signs are installed at nodes 0, 1, 2, 3, 8 and 13, the entropy becomes 0. As the Entropy H_6 reaches 0, the calculation has been completed. In this sign system, U-turn is not considered. Therefore when the sign is installed at node 13, the route from node 13 to node 19 are determined. But in order to make the sign system certainly, this study add a sign at node 18.

2) Multiple ODs

In a typical network there is a many to many origin destination pattern for the pedestrian flows. To recreate such a situation, it is possible to use following OD pairs for example. There are four origin destination pairs considered: from node 0 to 19, from node 4 to 15, from node 15 to 4, and from node 19 to 0. In each OD pair, there is two approach directions at the origin node as illustrated in Figure 3-9, such as horizontal and vertical directions.

Based on the methodology explained in the former section, suitable sign locations for the OD pairs described above are illustrated in Figure 3-9.

The plan of signs shown in Figure 3-9 is complicated. As mentioned in Section 2, pedestrians tend to choose a straight route over a branched route of similar distance, a behavioral tendency similar to inertia in physics. Hirata (2012) confirms that the percentage of going straight is 56%, and the percentages of turning right and left are 20% and 23% at grid-type network where subjects had no information of the destination location, based on an observation survey. Considering this tendency, Figure 3-9 may be simplified as shown in Figure 3-10.

4. CASE STUDY OF SIGN SYSTEM IMPROVEMENT IN OSAKA TRANSPORT HUB

Osaka Transport Hub is located in the central area of Osaka City. The population of Osaka, the third largest city in Japan, was 2.7 million in 2018. There are several large transport hubs in the CBD of Osaka City. The largest one is Osaka Transport Hub which consists of seven railway stations. JR Osaka Station, JR Kita-shinchi Station, Hankyu Railway Umeda Station, Hanshin

Railway Umeda Station, and three stations of Osaka Subway (Subway Umeda Station, Higashi-Umeda Station, and Nishi-Umeda Station) are included in this transport hub. About 2.5 million of passengers per day use this transport hub.

In the underground level of the transport hub, there is a large underground shopping arcade with several independent shopping centers. The underground street network poses numerous orientation difficulties for passengers to find their way. This study investigates this the underground street network in Osaka Transport Hub to recommend a suitable sign system.

This study selects the area surrounded by the dotted line oval shape in Figure 4-1. It is located in the central part of Osaka Transport Hub. The underground street network in this area is illustrated in Figure 4-2.

Ahn and Tsukaguchi (2015), and Nakamura (2018) have estimated the OD matrix in this area as shown in Table 4-1. Using the data authors observed pedestrian flows at different 24 points, OD matrix was estimated. Ahn and Tsukaguchi (2015) explains the detailed method of estimation. Table 4-1 shows the pedestrian flows per one hour in the morning peak.

Table 4-1 makes clear the major OD pairs in this area. The OD pairs selected to develop sign locations in this study are:

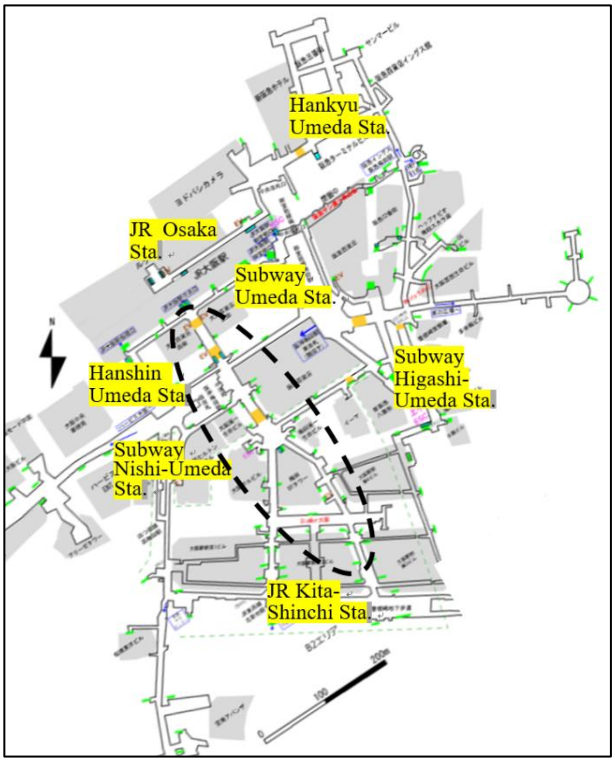


Figure 4-1 Main elements of the Osaka Transport Hub

from node 16 to nodes 18, 19, 21, and 22,
from node 18 to node 19 and 22
from node 19 to nodes 16 and 22
from node 22 to node 19.

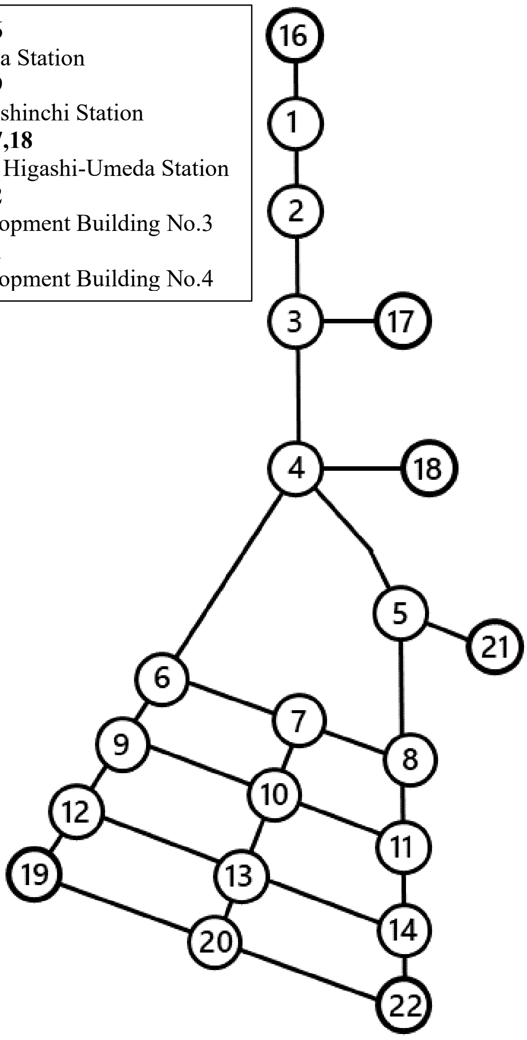
The traffic flows for these OD pairs are indicated by bold letters in Table 4-1.

The methodology described in the former sections can be applied to propose suitable sign locations for travelers among the OD pairs. For each OD, entropy values are calculated and the sign location in which ($E_0 - E_n$) are maximized is selected. Signs are added one by one until entropy value becomes zero. The results are illustrated in Figure 4-3.

Table 4-1 OD matrix in this area (Persons/hour)

O \ D	16 JR Osaka	17	18 Higashi Umeda	19 JR Kita-shinchi	20	21 Building No4	22 Building No3
16 JR Osaka	-	**526**	**564**	**2038**	166	**326**	**804**
17	9	-	8	29	2	5	11
18 Higashi Umeda	196	166	-	**642**	52	103	**253**
19 JR Kita-shinchi	**199**	168	180	-	53	104	**257**
20	43	37	39	142	-	23	56
21 Building No4	10	8	9	32	3	-	13
22 Building No3	87	74	79	**286**	23	46	-

Node 16
JR Osaka Station
Node 19
JR Kita-shinchi Station
Node 17,18
Subway Higashi-Umeda Station
Node 22
Redevelopment Building No.3
Node 21
Redevelopment Building No.4



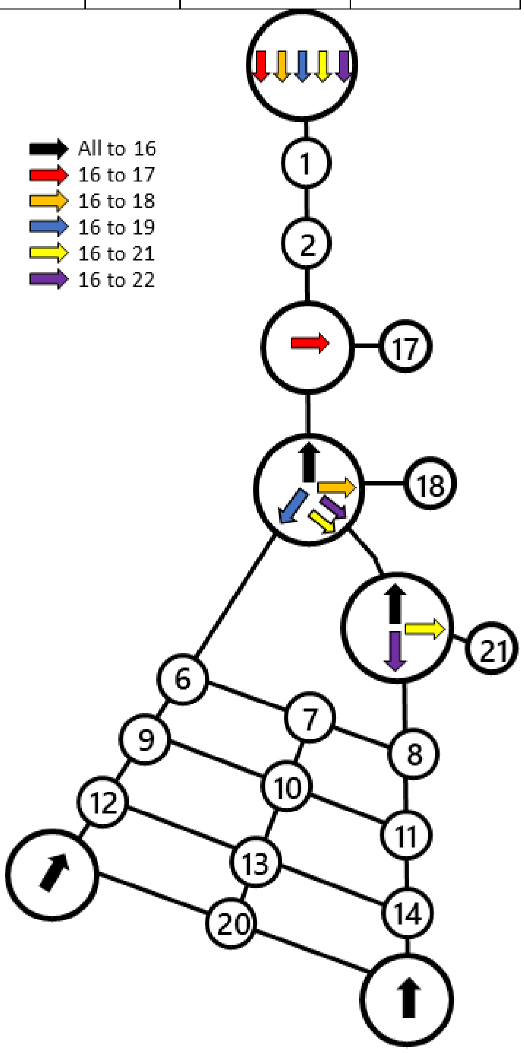


Figure 4-2 Network selected for analysis

Figure 4-3 Recommended direction sign locations

5. CONCLUSIONS

An entropy based model for determination of direction signs in a pedestrian flow network has been presented in the paper. Pedestrian route choice behavior has been built into the model to evaluate the selection process for paths.

Entropy calculation for a trial sign placement arrangement relies on network evaluation using the cut set technique. A greedy algorithm has been introduced to search for the minimum entropy condition that provides the best arrangement of signs. In addition to this, when the arrangement of signs is excessive and complicated, this study proposes a way to simplify the results based on pedestrian characteristics to choose a straight route, a behavioral tendency similar to inertia in physics.

The details of the methodology are as follows: First, this study tries to find suitable locations of signs, considering characteristics of pedestrian route choice behavior (Using Equations (1) on Entropy, Equations (2) through (4) and Table 2-1 on the route choice model). At this stage, signs are installed at all forks. But it may be a little complicated. Therefore, next some signs are removed as shown in Figures 3-10 and 4-3.

A demonstration of the computation procedure to propose a sign system for the underground pedestrian corridor network of a large transport interchange has been included. Many to many demand patterns have been considered for this problem. The example network shows the sign system required to efficiently direct pedestrian flow paths among major demand nodes, i.e. among train stations and common entry/exit nodes.

More clearly, an application of sign locations and guidance directions has been demonstrated using the proposed model. A significant section of the pedestrian network of the Osaka Transportation Hub has been selected for the demonstration. The network consisted of 21 nodes and 24 links where significant sites of origins and destinations such as stations and building entrances were spread over five nodes causing complex interactions among pedestrian flows. The model was able to limit sign locations to six nodes. The model also provided directions the signs should indicate to users.

Putting all matters described above, it can be said that the study can propose a new method to find suitable locations for sign boards based on theoretical background.

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