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Road Sign System with Course Restoration Function

by

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Abstract

In this paper we proposed a mathematical model and its algorithm to build the optimum road sign system, which kept the drivers in the original course.

We assumed that the guide sign elements were classified into place name, route number and their combination types, and that these signs were posted only at the entrance of intersections.

Furthermore we defined the Straying Index as an expression of drivers straying, and proposed a method for minimizing the total Straying Index of all OD (Origin and Destination) travel. In this method, the total Straying Index of drivers was taken as the objective function, and the number of links, where signs were to be posted, and the number of displays for one direction on the signboard were treated as the restrictions.

Finally, we solved this problem using dynamic programming, and extracted some properties of the sign type, regarding such as place name, route number and their combination through the analysis of a small network example.

Keywords : Straying, Road sign system, Traffic control, Traffic information, Network analysis, Optimization

1. Introduction

Basic road traffic information is obtained from guide information on place names and route numbers[1]. The purpose of installation of road signs is to lead the unfamiliar drivers with the area without straying or anxiety. Also, by reducing the straying of drivers, road guide signs are expected to bring a number of effects such as alleviation of traffic congestion, travel time reduction, prevention of traffic accidents and reductions in energy consumption and gas emission.

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Generally, the contents of guidance are thought to be the location of road signs in the road network and the display contents so as to minimize straying of drivers. This idea is effective from a viewpoint of constructing a rational road sign system on the road network, and it also plays an important role in studying the relationship between road signs and car navigation systems.

Now we review the existing studies on the course guide using road signs.

Firstly, the studies on the evaluation of road sign system are as the following:

Mitsuda[1] introduced a theory of a continuous guide network to establish the rules for the consistency of display contents. Kurimoto[2] proposed a method for evaluating the effects of guide signs installed at the entrance of intersection over the entire road network. Wakabayashi[3),4] proposed a mathematical model for evaluating the ease of reaching the destination.

The findings from studies on visual recognition of signs are as follows:

Okura et al.[5] analyzed the relationship between the amount of information on the number of place names displayed for each direction and the readability. Nosaku et al.[6] numerically evaluated the degree of visual recognition effects of some types of road sign and reflection plates based on the actual driving investigations. Ishiwatari et al.[7] developed the travel simulator which enables drivers to evaluate course guide sign, and compared the level of drivers' anxiety between on the experiment and on actual driving. Takamatsu et al.[8] proposed the utilization of pulse numbers and "secondary task results" as indexes instead of questionnaires, and they verified the effect of the method using the travel simulator and actual driving experiments. Furthermore, Kimura et al.[9] verified the distance and time required for reading road signs using CG images to evaluate the readability of the signs, and they studied the relationship between distances and time.

Toi[10,11] proposed an optimization technique for minimizing the straying or the number of road signs to be installed using information entropy, only based on the place name guide, in order to study the optimum arrangement of road signs on the road network.

In addition to Toi's method, we[12] introduced a new objective function to equalize the straying in each OD (Origin and Destination) and expanded the Toi's method regarding the guide system using only route numbers. However, we could not introduce place names and routes at the same time in this model. We[13] also proposed an optimization technique assuming the route guide as primary problem and the place name guide as secondary one.

Incidentally, almost all of these studies aim only to allow drivers to reach the destination without straying, and no study takes any measures for assisting lost drivers into consideration.

Originally, it is impossible to guide the actual course for each OD completely. Therefore, it is preferable to provide a function to show an alternative course for the drivers to whom the shortest course is not guided due to various restrictions. Furthermore, since drivers unfamiliar with the area tend to miss the guide information, and the straying of drivers can occur even on the road network where the guide system is theoretically completed. The desired guide system should be the one that takes measures to assist lost drivers. That is to say, the guide system must be programmed to have the function to lead the straying drivers to the planned course or its alternatives, namely "Course restoration function." In order to study this problem, it is necessary to clarify the effect of road signs on the prevention of straying and to construct a guide system by optimizing the system.

From this viewpoint, in this study we defined the Straying Index of drivers, and proposed a mathematical model to obtain a guide system that minimized the total Straying Index on the road network, corresponding to the road sign arrangement and information contents. Furthermore, this model is improved as a mathematical model that adopted both place names and route numbers and used the simulation method in comparison with the fore-mentioned model[12),13)].

2. Optimization technique of road signs

Generally speaking, the primary purpose of road signs is to lead drivers to their destination through the shortest course, and the secondary purpose is minimization of drivers straying. However, if the secondary purpose is achieved, the primary one can be sufficiently achieved in almost all the cases. Furthermore, from the social viewpoint, it is considered that the guide system, which minimizes driver's straying, has a higher value than the one, which leads drivers just through the shortest course.

From this viewpoint, we consider the ideal feature of the guide system aiming to minimize the drivers straying in this study.

2.1 Method for guiding

As for methods for guiding to the destination, there is an opinion that the route guide system is more useful than the place name guide owing to the consistency of course guide[1)]. On the other hand, the place name guide system has three roles. The first of them is to lead the drivers to the destination and objective facility in an urban road network, the second is to check the traveling direction and the current place, and the third is to lead the strayed drivers to the original course or to the right destination even if they fail to return to the original course.

The contents of information needed for the route guide are i) the current location, ii) the traveling route, iii) the district traveling toward, and iv) the direction to be taken at the intersection. However, there are two types of information, namely the one is essential to determine the direction to be taken and the other is needed for confirmation. Although it is desirable to consider both of these types at the same time, we decided to express the model of a course guide at a first step using the above iv) that is needed as basic guide information on the road network.

From the viewpoint of road users, it is desirable that all the necessary route numbers and destination are displayed. However, a sign plate does not have enough space to display many destination names, and the drivers do not have enough time to read all the information. And, it is necessary to express the displayed contents as simply and appropriately as possible in order to improve visual recognition. Therefore, in this study we propose a method for constructing a guide system, in which the place names are displayed in combination with the route numbers at the appropriate location in order to utilize the advantages of both place names and route numbers as much as possible.

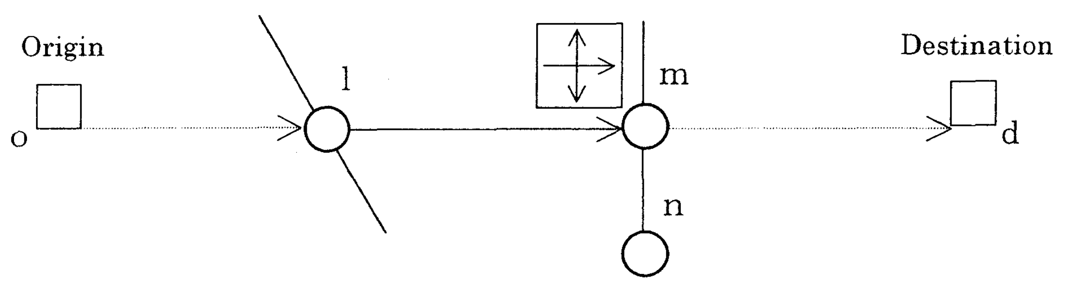

Fig. 1 Sign location on links

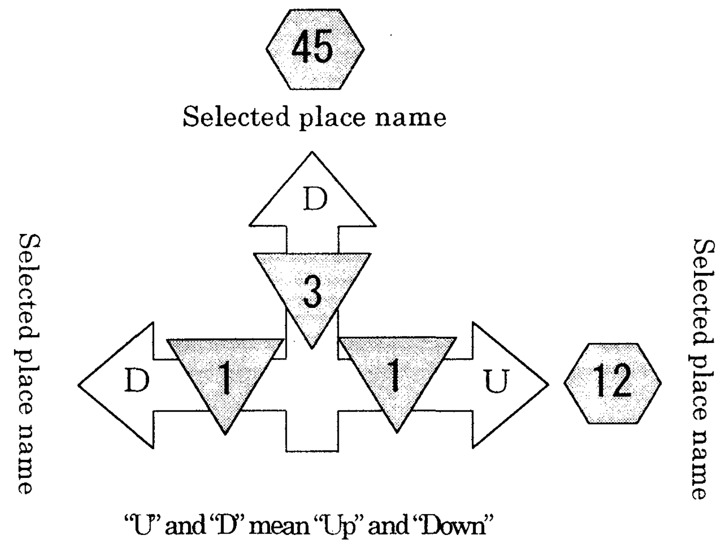

Fig. 2 Proposal of guide signs

2.2 Assumption for modeling

The routes guided by the road signs are set for each combination of OD. And the shortest courses obtained for each OD combination are taken as the basic guide routes. The location of guide sign installation is assumed to be at the entrance of the intersection as shown in **Fig. 1**. The candidate group S_{mn} for the place names and route numbers in the direction from m to n on the link lm, consists of the destination of each OD and the route numbers that pass through the destination. The information on the planned route is assumed to be the place names, the route numbers, "Up" or "Down" as the direction, and the order of the route guide. The display "Up" or "Down" is introduced here, because it is considered that the displayed "Up" or "Down" in addition to the route numbers is effective for the drivers who cannot obtain appropriate information from the displayed place names.

As shown in **Fig. 2**, the contents to be displayed will be the route number and its "up" or "down" of diverging or crossing routes, and the place name or the route number is selected without overlapping among the directions. The number of place names and route numbers is limited by constant value n_a for each direction. In an example shown in **Fig. 2**, n_a equals to 2.

2.3 Expression for installation of signs and displayed contents

Firstly, several symbols are introduced to express the installation of signs and the contents to be displayed. In the section shown in **Fig. 1**, $x_{lm}=1$ means that a guide sign is installed at the entrance of the intersection of node m on the link lm, and $x_{lm}=0$ means that it is not installed. And, $\xi_{lmnj}=1$ means that the place name or route number j is guided to the direction of the node n, adjacent to the node m on the link lm, and $\xi_{lmnj}=0$ means that it is not guided.

By using these symbols, the policy $\boldsymbol{x}$ showing presence or absence of sign installation on a link and the policy $\Xi(\boldsymbol{x})$ of the place name or route guide based on $\boldsymbol{x}$ can be expressed by the following formula:

$$\boldsymbol{x}=\{\cdots x_{lm}\cdots\} \tag{1}$$

$$\Xi(\boldsymbol{x})=\{\cdots \boldsymbol{C}_{lm}\cdots\},\quad lm\in \boldsymbol{M}_{od} \tag{2}$$

$$\boldsymbol{C}_{lm} = {}_{n}\begin{bmatrix} \cdot & \overset{j}{\cdot} & \cdot \\ \cdot & \xi_{lmn} & \cdot \\ \cdot & \cdot & \cdot \end{bmatrix}, \quad n \in \boldsymbol{N}_m \tag{3}$$

where, $\boldsymbol{M}_{od}$ is a set of links in the route between the nodes o and d, and $\boldsymbol{N}_m$ is a set of the adjacent nodes around the node m.

2.4 Expression of restrictions

The place name or its route number to be guided to each direction is selected from the set $\boldsymbol{S}_{mn}$ of the candidates.

$$\boldsymbol{C}_{lm} \leqq x_{lm} \cdot \boldsymbol{\omega}_m \tag{4}$$

$$\boldsymbol{\omega}_m = {}_{n}\begin{bmatrix} \cdot & \overset{j}{\cdot} & \cdot \\ \cdot & \omega_{mnj} & \cdot \\ \cdot & \cdot & \cdot \end{bmatrix} \tag{5}$$

or

$$\xi_{lmnj} \leqq x_{lm} \cdot \omega_{mnj} \tag{6}$$

where, $\omega_{mnj}=1$ means that the place name or route number j is included in $\boldsymbol{S}_{mn}$, and $\omega_{mnj}=0$ means that it is not included.

The restricted number of place names or route numbers to be guided to each direction is n_a.

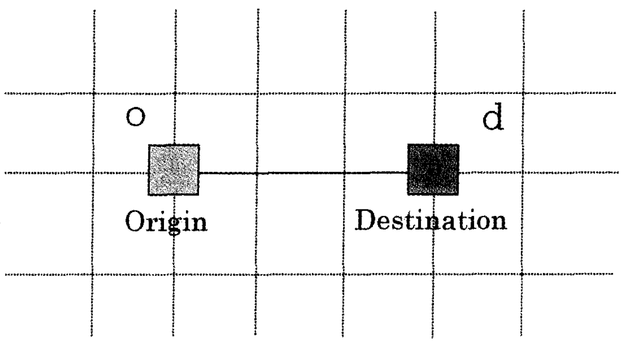

Fig. 3 Example of network

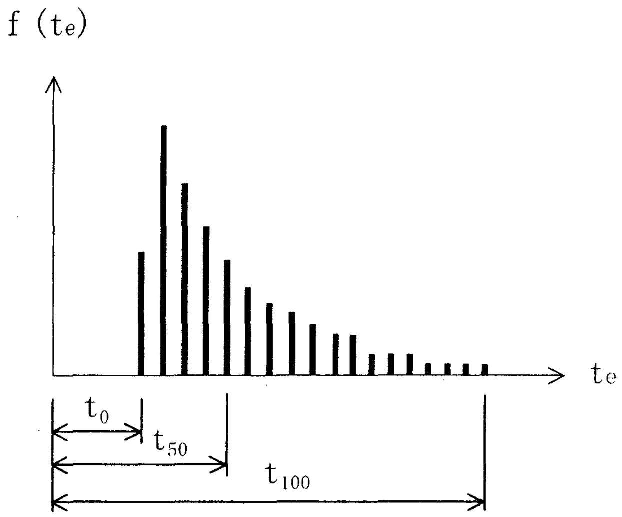

Fig. 4 Concept of reaching frequency distribution

$$\sum_j \xi_{lmnj} \leqq n_a \tag{7}$$

Furthermore, when the upper limit of the number of sign installation is assumed to be n_s.

$$\sum_{lm \in L} x_{lm} \leqq n_s \tag{8}$$

where, $\boldsymbol{L}$ is a set of link candidates where signs are installed.

2.5 Expression of Straying Index

If there is effective guidance successively at the entrance of the intersections on each route, fuzziness of route guide information becomes 0. Now, let us consider an infinite network having various link lengths (**Fig. 3**). When a person unfamiliar with the area drives to the destination without guidance on this network, it is considered that the time or distance to reach the destination follows a probability distribution. This reaching frequency distribution is likely illustrated in **Fig. 4**, where t_o is the time or distance until the first wave, namely the minimum course length of OD, and t_e is the time or distance in which e % of drivers reach the destination. At this time it is considered that the larger the ratio of t_e to t_o becomes, the more the straying is. Therefore, the evaluation function called "Straying Index" shall be defined as follows:

$$H(\Xi(\boldsymbol{x})) = \sum_e \left(\frac{t_e(\Xi(\boldsymbol{x}))}{t_o(\Xi(\boldsymbol{x}))} - 1 \right) \tag{9}$$

where, $H(\Xi(\boldsymbol{x}))$, $t_e(\Xi(\boldsymbol{x}))$ and $t_o(\Xi(\boldsymbol{x}))$ are the values under the policy $\Xi(\boldsymbol{x})$.

The Straying Index $H(\cdot)$ is non-negative, and when the distribution form shown in **Fig. 4** shifts to the left, the Straying Index tends to decrease. And it means the desirable change of conditions. Further, $H(\cdot)=0$ means the case that all the drivers of a certain OD ride on the first wave shown in **Fig. 4**, and no straying is found. Since the Straying Index represents the degree of drivers straying, it is possible to clarify guide effects, namely the ability to lead the drivers to the destination, by observing the change of the Straying Index based on the policy $\Xi(\boldsymbol{x})$.

2.6 Concept of optimization

It is desirable for drivers to lower the possibility of straying, while it is desirable for the road administrator to lessen the number of guide signs as small as possible from the viewpoint of budget restrictions, administration time and landscape. Therefore, the following two ideas can be taken for optimization:

i) An index regarding the degree of straying of drivers is adopted as the objective function and it is minimized. At this time the restraints regarding the upper limit on the number of guide sign installation and displays in each direction, the amount of information on planed route and the contents to be displayed must be considered.

ii) The number of guide sign installation is adopted as the objective function and it is minimized. At this time it is necessary to establish the restraints regarding the allowable degree of straying as the result of guide service level to each OD, the upper limit of the number of displays in each direction, the amount of information on planed route and the contents to be displayed.

If the objective function and one of the restraints are exchanged with each other, i) and ii) become the same problems. However, if the installation of guide signs on all links is allowed, i) becomes the problem to determine the contents to be displayed, while ii) is not handled as a problem. And, it can be said that i) is more general because it is difficult to set the upper limit of Straying Index. Therefore, in this study, we decided to use the total Straying Index of all drivers as the objective function and to minimize it based on the concept of i).

This is an optimal problem to minimize the function Z subject to the restraints relating to the number of guide sign installations and the number of displays in each direction. In other words, if we assume the policy set of guide contents in each direction, including sign installation points to be $\Xi(\boldsymbol{x})$, and make a optimization problem formula, we obtain

$$\underset{x,\Xi(x)}{\text{minimize}}\, Z(\Xi(\boldsymbol{x})) \tag{10}$$

$$Z(\Xi(\boldsymbol{x})) = \sum_k H_k(\Xi(\boldsymbol{x})) \tag{11}$$

where, the fore-mentioned formulas (1), (2), (5), (7) and (8) are omitted, and k is the OD number.

Furthermore, the decision variables for the optimization model shown in the formulas (10) and (11) are x_{lm} and ξ_{lmnj}.

3. Solution

3.1 Application of dynamic programming

This problem is an optimum resource allocation problem with a nested structure assuming the sign installed links, guide directions and guide contents as finite resources. Taking these points into consideration, the dynamic programming is useful to obtain a solution, because it is helpful to modify complex structure of non-linear problem to obtain a simple formula and to reduce calculation time reasonably.

Here, OD or the link is able to be adopted a stage variable[12]. If the number of sign installed location increases, the problem becomes a high dimensional one and it is difficult to solve, in case that links are adopted as the stage variable.

On the other hand, if OD is assumed to be the stage variable, it becomes a multi-step one-dimensional problem that can be solved with a small amount of calculation. Thus, OD should be adopted as the stage variable.

Now, the policy of guide sign installation, which shows the condition at k-th stage satisfying the restrictions (4)~(8), is represented by $\boldsymbol{x}^k$ and the guide contents policy by $\Xi(\boldsymbol{x}^k)$. Then the minimum of total Straying Index for each OD, corresponding to $\boldsymbol{x}_{lm} \in \boldsymbol{x}^k$ and $\xi_{lmnj} \in \Xi_k(\boldsymbol{x}^k)$, can be obtained by the following formulas based on the dynamic programming.

$$Z_k(\Xi_k(\boldsymbol{x}^k)) = \min_{\Xi_{k-1}(x^{k-1}) \in \Xi_k(x^k)} [H_k(\Xi_k(\boldsymbol{x}^k) - \Xi_{k-1}(\boldsymbol{x}^{k-1})) + Z_{k-1}(\Xi_{k-1}(\boldsymbol{x}^{k-1}))] \tag{12}$$

$$i.c. \qquad Z_1(\Xi_1(\boldsymbol{x}^1)) = H_1(\Xi_1(\boldsymbol{x}^1)) \tag{13}$$

where, $Z_k(\Xi(\boldsymbol{x}^k))$ is the minimum of the total Straying Index for each OD at k-th stage. The flow diagram of solution is shown in **Fig. 5**.

3.2 Simulation of Straying Index

The link length and the number of branches at one intersection vary in the actual network. And it is so difficult to obtain the Straying Index analytically considering the second and successive waves in **Fig. 4** that the value of the formula (9) must be obtained by simulation.

Firstly, we assume that the direction from the origin is that for the first node on the

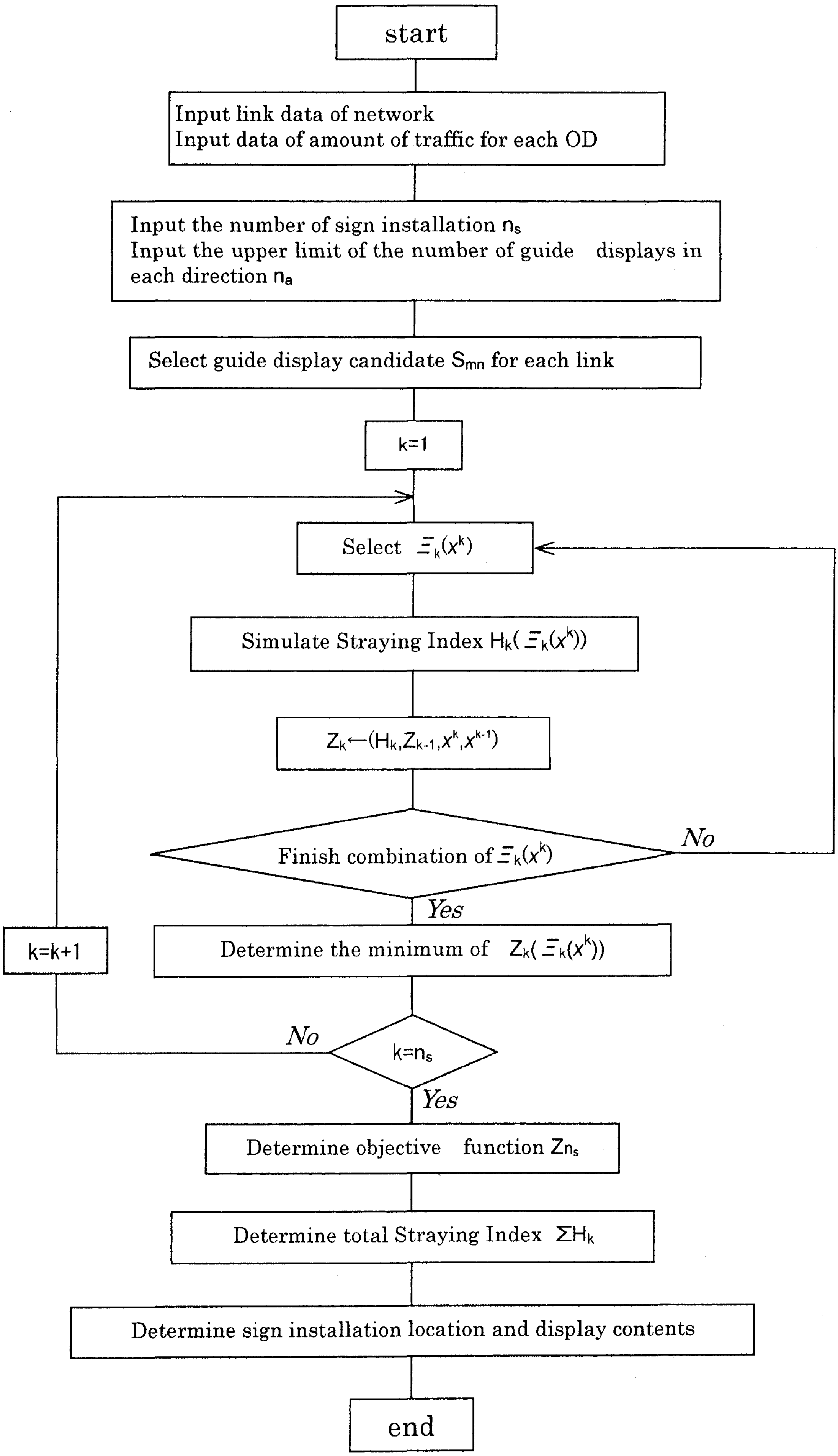

Fig. 5 Flow diagram of solution

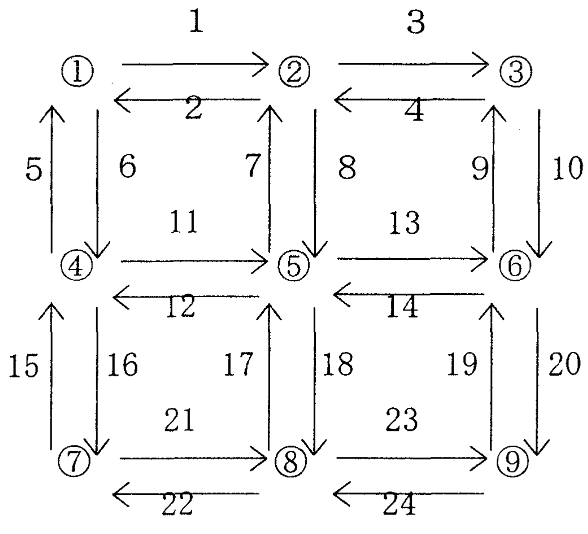

Fig. 6 Road network for example (Link and node numbers)

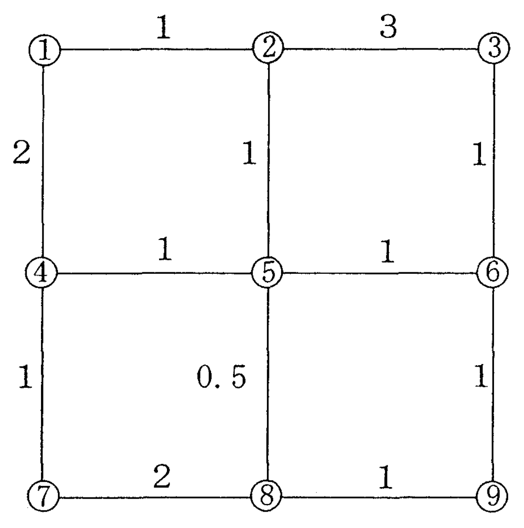

Fig. 7 Link length between adjacent nodes

shortest course and that this is same after a straying driver returns to the origin. Therefore, the link length from the origin to the next node is subtracted from the straying distance.

Secondly, the traveling drivers select one direction from among four directions, namely straight, right turn, left turn and return at random in case of no guide sign. If there are no guide signs at the intersection where a driver entered according to the former guide sign, it is selected from three directions, straight, right turn and left turn. Regarding the direction from the origin to the next node, it is the same, namely without the return. Moreover, when a driver who has traveled on a link with a route number that crosses a link without route number, the crossing road shall not be selected as the course.

As for the guide contents, we firstly assume that the same place name or route number is not displayed in multiple directions on the same guide plate. Secondly, if the Straying Index is identical when either the place name or route number is used for the same OD, the priority is given to the place name guide.

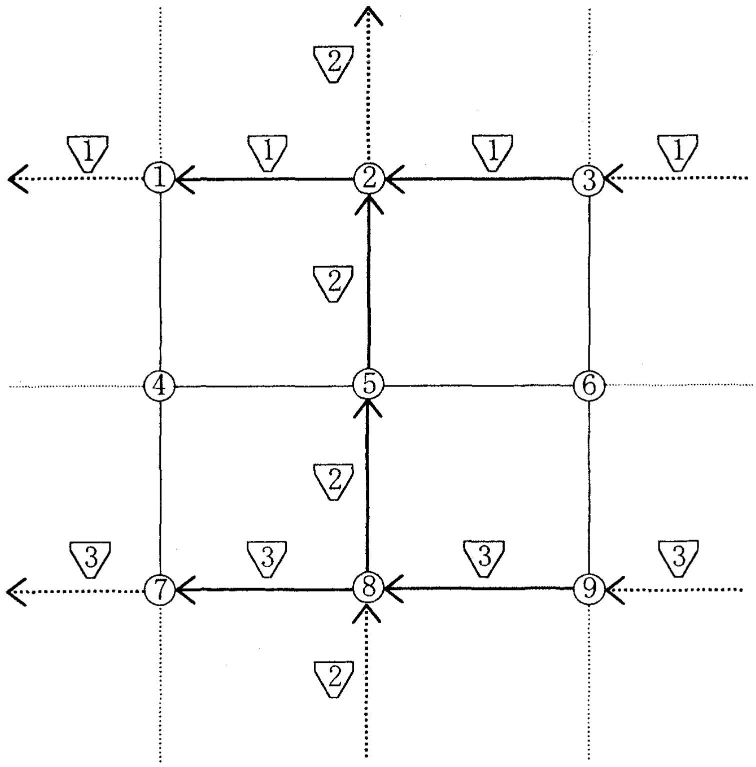

Fig. 8 Route number and its direction

Table 1 Guide candidates

	Starting point	Destination	Guide candidate	
			Place name	Route number
OD1	⑦	②	④,⑤,②	▽2
OD2	④	③	⑤,⑥,③	–
OD3	①	⑨	②,⑤,⑧,⑨	▽1, ▽2, ▽3

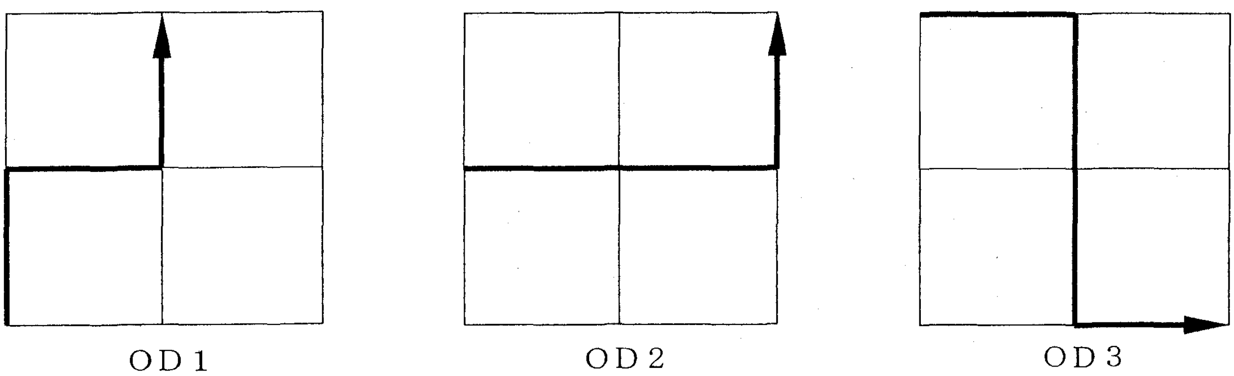

Fig. 9 Basic guide courses

4. Calculation Example

4.1 Example

Let us solve the problem of guide sign installation in the road network with 24 links (two-way) and 9 nodes as shown in **Fig. 6**. We assume that the whole network with four-branch intersections uniformly expands around **Fig. 6**.

The link lengths representing time or distance are shown in **Fig. 7**, and all the link lengths out of this area is assumed to be 1. The route number and its direction are shown in **Fig. 8** where a node number in the circle represents a place name. A number in the triangle shows a route number. A broken line represents an adjacent link out of the area of **Fig. 6**, while a broken arrow line shows the link direction of a route when the link has a route number. Furthermore, the left or upward direction is assumed to be "Up" . And, it is assumed that the amount of traffic of every OD volume is equal; the both of upper limit n_s (the number of sign installation) and n_a (the place names or route numbers) are 2.

The set of guide candidate S_{mn} should be found for each link originally. However, all the place names, all the route numbers and the destination name on the shortest course shown in **Fig. 9** are taken as the candidates because the area is small. **Table 1** shows these guide candidates.

The calculation of the evaluation function is useless in the case where the travel time ratio t_e/t_0 in the formula (9) is extremely large because the calculation time is enormous. Therefore, we adopted the value e in t_e by the intervals of 10%, and up to the value of 50%.

Table 2 Straying Index in the example

	OD1	OD2	OD3	Total
Without	30.25	29.75	171.12	231.12
Only place	23.00	2.50	4.00	29.50
Only district	2.50	29.75	8.60	40.85
Combination type	2.50	6.00	8.60	17.10

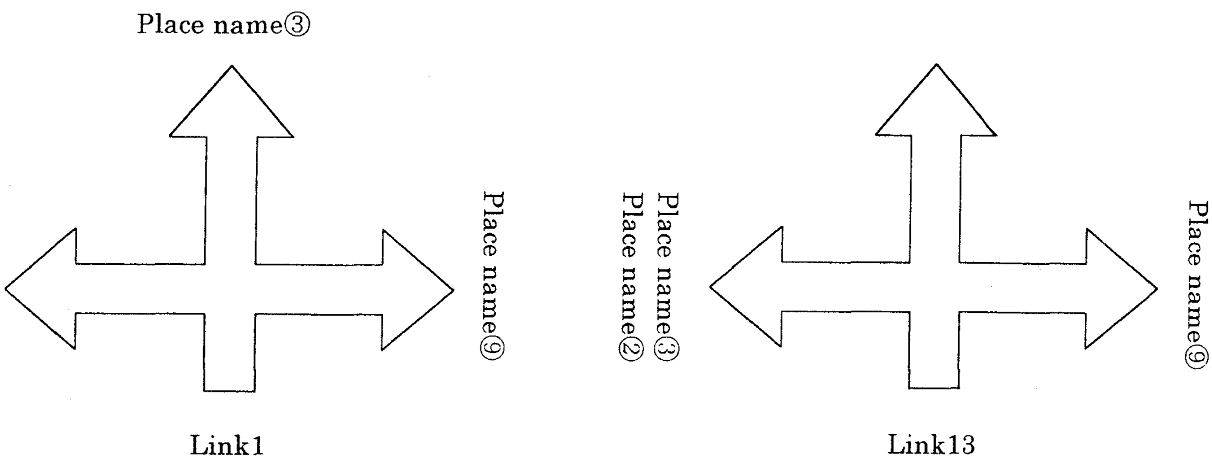

Fig.10 Guide display only by place names

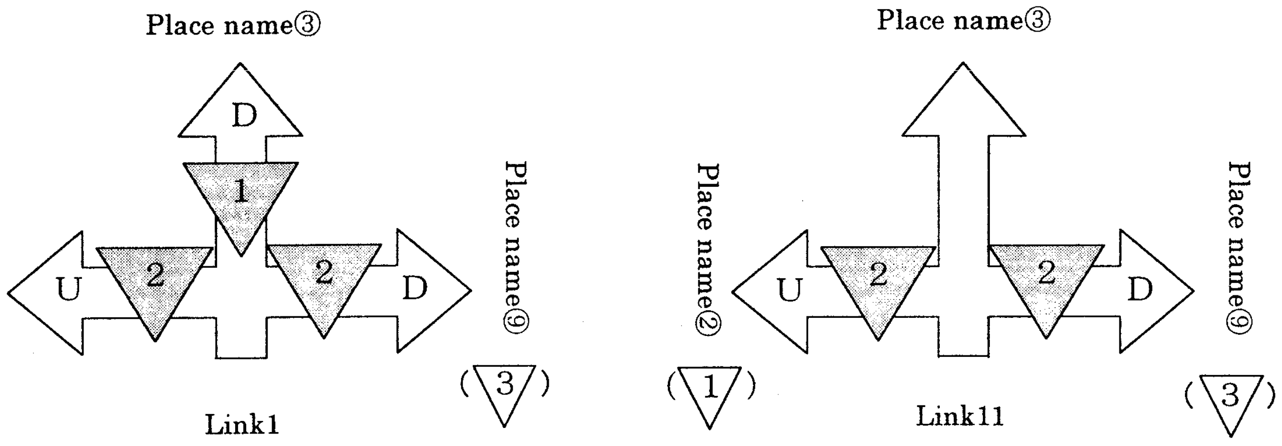

Fig.11 Guide display of combination type

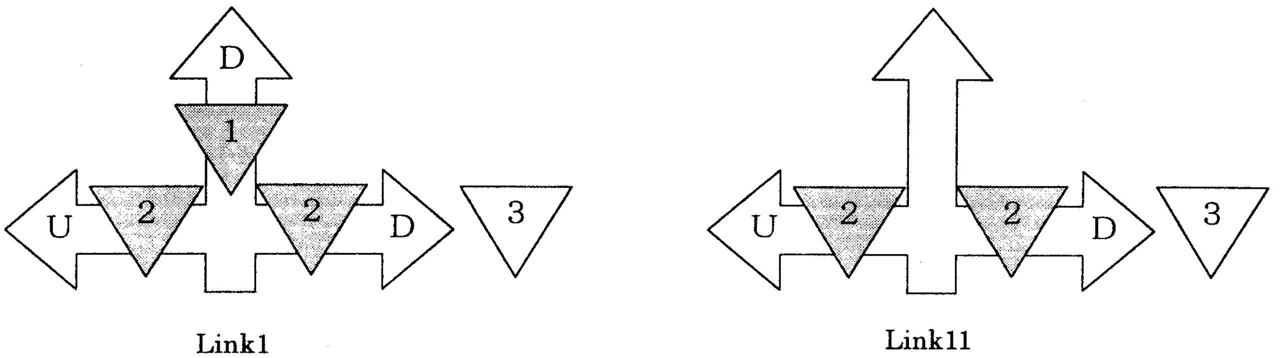

Fig.12 Guide display only by route number

4.2 Calculation results

The calculation results of the Straying Index in each guide direction in the example are shown in **Table 2**. The links where the signs are installed and their display contents are shown in from **Fig.10** to **Fig.12**.

4.2.1 Location of signs

i) Regarding the location where the signs are installed, there are the tendencies as follows. The signs are likely installed on the links in the shortest course with many links or many branches.

ii) The signs are likely installed on the links just before a long link.

iii) The signs are likely installed on the links with a large traffic volume including other OD volumes, even if they are not on the shortest course but on the relatively short route.

Taking the OD 3 as an example hereafter, the links on the shortest course of OD 3 corresponds to i). It can be said that a link just before a short link is ineffective contrary to ii). The link 8 corresponds to this, and the sign is not installed in link 8 if n_s is small. Link 13 shown in **Fig.10** corresponds to the case of iii). Although this link is on the shortest course of OD 2, and not on the shortest course of OD 3, the destination name ⑨ is displayed for the right turn.

It is desirable for drivers that they are guided to the destination in the shortest distance. However the drivers are not guided to the shortest course in some cases, when we attempt to minimize the total Straying Index. This case corresponds to drivers introduced to the course of the second or after the second wave in **Fig. 4**.

4.2.2 Display system

As shown in **Table 2**, the values of Straying Index by the place name guide, by the route number guide and by combination of them for all pairs of OD are 29.50, 40.85 and 17.1 respectively. The guide effect by the combination of place name and route number is significantly high. Furthermore, links 1 and 11 are selected in the calculation result using the combination type guide, and their display contents are shown in **Fig.11**. The place name ⑨ is selected for the right turn at the link 1 and links 11 rather than the route number ▽3. And the place names ② is selected for the left turn at the link 11 rather than the route number ▽1. This is because we gave the place name a priority in cases where the place name and route number have equal effect.

Now we describe the effect of displaying Up and Down.

Since the route number of link 8 and link 18 on the shortest course of OD 3 is same and this course does not cross any routes with the number, it becomes possible to continuously lead to intersection ⑧ by displaying [▽2 Down] for the right turn on the link 1 as shown in **Fig.12**. Furthermore, this display performs an effective guide linkage with route number after branching.

4.3 Discussion

Described above, the drivers are sometimes guided to the links that is not on the shortest course. The reason is as follows:

In cases where continuous guides exist on all the intersections, drivers are introduced to the shortest course, and the Straying Index becomes zero. However, some links except on the shortest course are effective, owing to the restrictions on sign installation and guide displays.

Major small values among the Straying Index for OD 3 are shown in **Fig.13**. They are obtained if the number of sign installation n_s is 1 and only the place name guide is used. The numeral in the box is the link number, the start of an arrow shows the link where the sign is installed, and the direction of an arrow shows the guide direction.

The minimum Straying Index in cases where signs are installed on the link of the shortest course is 25.5 (link 1). And as for the links other than those on the shortest course,

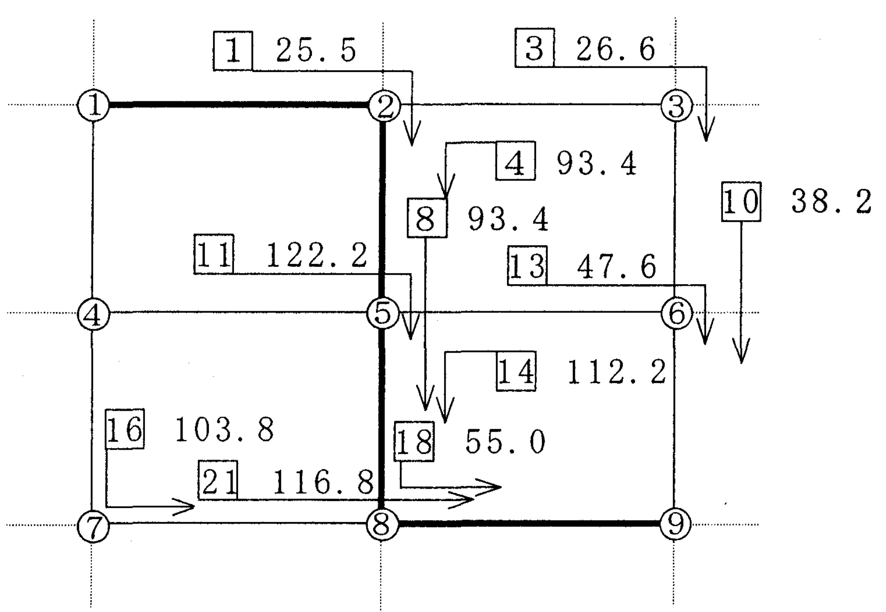

Fig.13 Straying Index of OD3 (n_s=1)

link 3, 10 and 13 show smaller indexes than link 8 (93.4) and link 18 (55.0). This means a number of links are more effective than the links on the shortest course unexpectedly.

Furthermore, the effective combinations obtained are as follows in the order from high effect to low assuming n_s to be 2 :

H_3(link 1 right turn and link 18 left turn) =2.75
H_3(link 1 right turn and link 13 right turn) =4.0
H_3(link 1 straight and link 10 straight) =13.5
H_3(link 1 right turn and link 8 straight) =23.75
…

The most effective combination is link 1 and 18 on the shortest course. Among these combinations, the second and the third include the links other than the links on the shortest course. These combinations are more effective than the fourth combination (link 1 and 8) on the shortest course.

In the example, since the total Straying Index for each OD was minimized, the second combination of links 1 and 13 (**Fig.10**) was selected. On the link 13 the right turn with the place name ⑨ and the left turn with the place name ② are displayed, but these guides do not lead any OD to these shortest course.

This is because the evaluation value of the formula (9) is fundamentally reduced by leading drivers who are traveling out of the shortest course to the destination. In other words, the evaluation value is not necessarily reduced by leading drivers to the shortest course, when the drivers who cannot reach the destination through the shortest course are few, or when the length of the alternative route is relatively short. Thus, this model enables to construct the guide system that allows a driver who deviates to return to the original course or leads him to the alternative ones.

5. Summary

This study was performed to build a mathematical model and an algorithm calculating the Straying Index and minimizing it for the optimum arrangement of guide signs in the road network.

The equation was formulated successfully in the efficient solution using dynamic programming. The calculation results of the small road network show the following properties:
i) Among the place name guide, route number and combination types, the last one brings the highest effect.
ii) There is a tendency that the links on the shortest course, the links on the course having numerous branches or the links just before the long one are selected as the effective links. And, some links are effective even if they are not in the shortest course.
iii) If the links of the same route number exist continuously on the shortest course and they can be distinguished from the crossing links on the way, the route number guide is very effective. If it is a continuous guide, the effect increases further.

It was confirmed that the guide sign system optimized in this study has functions not only for allowing drivers out of the shortest course to return to the original one, but for leading the drivers, who are not guided on the shortest course due to the restriction of the guide sign installation, to an alternative course. And it was also comfirmed that the system optimization can provide an alternative route guide by minimizing the total Straying Index.

It is considered that this model is very effective to optimize the guide sign system in the road network. Now, we have begun to analyze the information of planned course, and the allocation of role between guide sign system and navigation system regarding static information.

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