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Traffic Flow on Urban Networks with Fuzzy Information

By

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Abstract

Many methods of analysis of traffic on transport networks have been proposed which assume crisp travel time. Most of them are based on Wardrop's principle which says in particular "The travel time on all routes actually used equal to and no greater than those which would be experienced by a single vehicle on any unused route." The principle represents a state of user equilibrium under the condition that drivers can get perfect traffic information. Though this principle reflects the definition of the crisp performance function used in traffic assignment, the drivers dynamically make decisions about route choice behaviour with their experience and given information. A method commonly used to represent such perception is stochastic traffic assignment.

In the real world, however, the driver can only use fuzzy traffic information even if several types of information are available. The objective of the study is to formulate the fuzzy user equilibrium with fuzzy travel time and show the application of the techniques to an actual problem.

First, a basic survey was carried out to ascertain the perception of drivers on an urban transportation network. The network includes the Hanshin Expressway and urban streets in the Osaka area. In the survey, the travel time for streets and expressways on the same O-D (Origin-Destination) are assumed to be Triangular Fuzzy Numbers (TFN). A TFN is simply defined as (T_l, T_o, T_r) which show the smallest value, centre of time values, and largest value respectively according to the perceived travel time T. Therefore, T_0 is recognized to be an informed and physical travel time. Typical features of perception of travel time are summarized from the survey results. The membership function of the fuzzy number on travel time can be displayed once this database is constructed from the empirical survey.

Second, the descriptive method of route choice behaviour is introduced to design the traffic assignment model. The crisp travel time for link a, T_a, is extended to fuzzy number T_{Fa} with the spread parameters described above. Two concepts of comparison among fuzzy travel times are introduced. They are the centre of gravity method and the generalized distance method based on compatibility. The former is the very simple concept that the centre of gravity point of a fuzzy number is adopted as a representative value of T_{Fa}. The latter method is based on the α-cut concept of fuzzy sets. The definition of generalized distance between fuzzy numbers is defined as the sum of successive intervals between numbers for each a value as it increases from zero to one. It is

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interesting that with TFNs, this can be carried out rapidly by adding the areas of the triangles in each case.

Third, it is assumed that the state of user equilibrium is also generated even if fuzziness of travel time exists. Different results for user equilibrium are observed for conditions of fuzzy information when compared with those obtained under conditions of prefect information. In other words, the link performance function is extended in view of the concept of fuzzy numbers. In particular, the extension principle of fuzzy numbers allows that the comparison methods mentioned above are also valid when fuzzy travel time is applied on the route. Therefore, the fuzzified user equilibrium assignment model can be proposed with these concepts. In this section, the Fuzzified Frank-Wolfe(FFW) algorithm is introduced to obtain a fuzzy optimal solution as the solution of a conventional problem. In changing the algorithm, the modification is only to replace the crisp value of the travel time function t(x) with the representative values of the fuzzy travel time function $t_F(x)$. The fuzzified algorithm, therefore, is easily derived from a simple extension of the conventional algorithm. The results of a numerical example are presented to consider the stability of the algorithm. Different results of user equilibrium are observed when compared with those obtained under conditions of information. The relation between the width of the fuzzy travel time distribution and traffic flow is estimated on each link. It is observed that the user equilibrium flows shift according to the fuzzified link performance function. It is also mentioned that the idea can be applied to produce Fuzzy Incremental Assignment (FIA).

Fourth, the application of the proposed method to a realistic problem is discussed. The information given to the drivers seems to change their perception of link travel time. In particular, this fact is usually observed when the change of the perceived width of fuzzy numbers according to the travel time information in TFN has an impact on the traffic flow on networks. Because the different definition of left and right spreads of travel time represents the change in human perception under different conditions of information, the impact can be evaluated as a change in traffic volume on the network.

In conclusion, the relationship between information and traffic flow can be described by the proposed method. It becomes obvious that the traffic equilibrium flow changes according to traffic information which is available to the drivers. The results of traffic flow analysis under fuzzy information, therefore, become useful for the discussion of a future traffic information system.

1. Introduction

The traffic assignment technique is most popular in traffic flow analysis based on OD traffic demand. The User equilibrium (UE) state is produced as a result of the independent route choice of motorists with prefect information. It is reasonable to assume that a motorist will try to minimize his or her own travel time when travelling. A stable condition is reached only when no traveller can improve his travel time by unilaterally changing routes. This user equilibrum definition is based on the so-called Wardrops'principle.

To realize a state of ideal UE, some assumptions, such as that all motorists have full information and always choose the minimum route with respect to their travel time, are needed. However, it seems still to be defficult to observe this condition in the real world even when information devices on motorway and streets are rapidly developing[1,2].

Many kinds of modification have been proposed to approach realistic application. The most simple solution is to use the results of a survey. Several investigations into the actual conditions, and questionnaire surveys of motorists' behaviour on the road, have been carried out, but they still remain small in size and not enough to justify an advanced assumption of route choice behaviour.

From a theoretical point of view, stochastic assignment techniques are well known and seem to be a generalization of user equilibrium assiignment[3,4]. The perceived travel time can be leeked upon as a random variable distributed across the population of drivers. Route choice behaviour should be therefore considered in terms of stochastic theory.

In this study, the perceived travel time itself is reconsidered in the view of human perception. Traffic information systems have been able to display much information to motorists, but it is still doubtful that every motorist understands the concept of travel time without fuzziness even though an accurate measured time is displayed.

The following approach is based on fuzzy theory. It might be thought that an interpretation of link performance which is different from the stochastic approach is proposed. The approach is not against the stochastic approach at all. Furthermore, both approaches look like vertical and horizontal axes and they will be able to combine to establish the advanced model. The following approach, therefore should be regarded as another extended direction of conventional UE assignment technique.

2. Description of Fuzzy Travel Time

As fuzzy theory has been applied to many transport problems, the detailed content of the theory will not be described here.

A fuzzy number can be useful to describe the perceived travel time. A fuzzy number is a sort of fuzzy set defined in real numbers. It corresponds to linguistic expressions such as "about 30 minutes" or "approximately 3 o'clock"[5,6]. In other words, the actual travel time can be described as a number with some estimated range. The membership function, therefore, might be a possibility distribution of perceived link travel time. In the real world, it can be considered that the driver defines unconsciously his possibility distribution of travel time and makes decisions, even though information making use of crisp words appears on the information equipment.

The fuzzy description is therefore an acceptable way to demonstrate human perception of travel time.

To obtain an estimate of travel time perception, a questionnaire survey was carried out of motorists on the Hanshin Expressway, which is one of the largest city motorways in Japan. The experimental survey was made of 58 presons registered as monitors to the Hanshin Expressway. Assuming that the informed travel time on motorways and streets is defined by 15 minute intervals from 15 to 60 minutes, respondents were reguested to describe each response as a number with a width of perception.

Four average fuzzy numbers for each road type are displayed in Figure

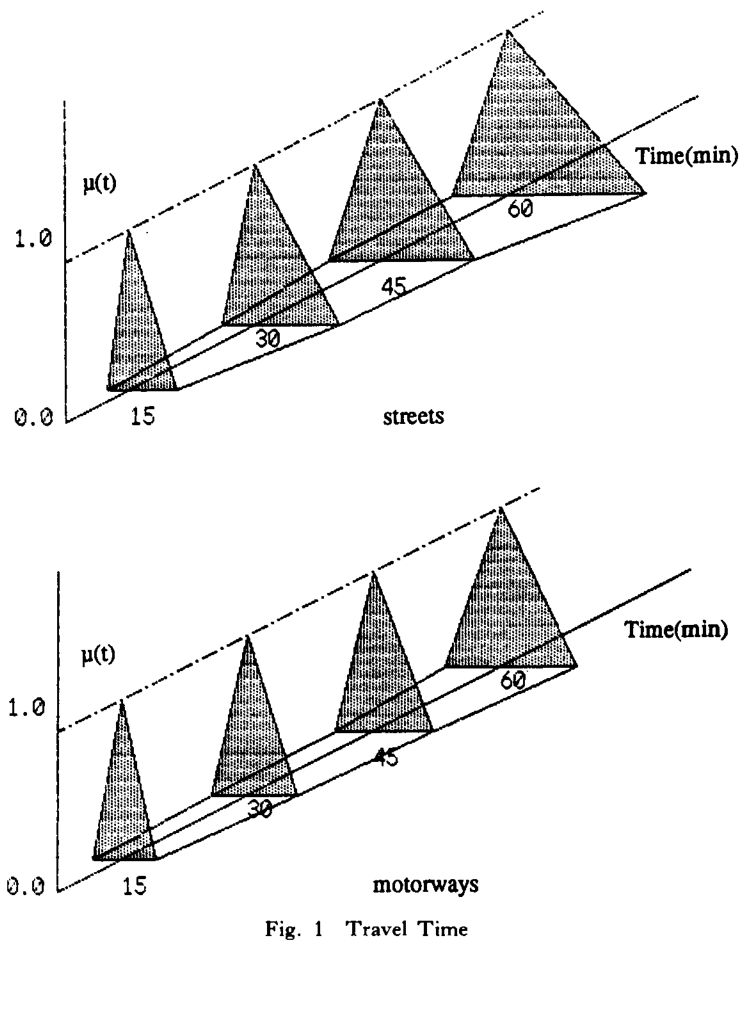

Fig. 1 Travel Time

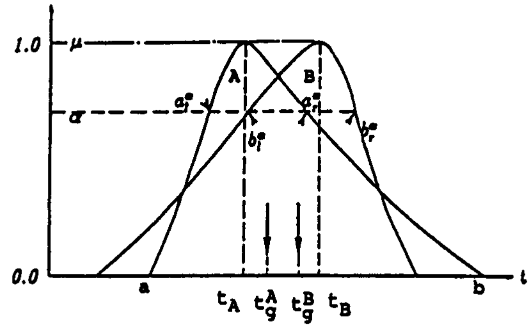

Fig. 2 Expression of Fuzzy Travel Time

1. Comparing the two Figures, the width of the triangle increases in proportion to the informed crisp travel time in both cases. The absolute width of the triangle of streets is always larger then that of motorways. Also, the street triangles have a right wing longer than their left one.

It is known that motorists feel traffic informaiton on motorways is more reliable than that on streets.

Another question is how humans distinguish between fuzzy numbers by comparison with one another. The corresponds to decision modelling with fuzzy information. In the study, a defuzzification method is used for transforming fuzzy numbers into representative crisp values. The centre of gravity method is most popular in defuzzification[7].

This method is very simple but useful because the centre of gravity point of the distribution is easily found with the following equation. (see Figure 2)

$$t_g = \int_a^b t \cdot \mu(t)\, dt \Big/ \int_a^b \mu(t)\, dt \tag{1}$$

On the other hand, the measure of compatibility is introduced to define the difference between fuzzy numbers[8-10]. The compatibility index is a sort of extension of the distance of real numbers. All fuzzy numbers are described as a combination of α-level sets as shown in eq. (2) and eq. (3).

It should be mentioned that the α-level set, A_α, is a non-fuzzy set. Therefore, the concept of resolution identity is applied to the relationship between a fuzzy number and a non-fuzzy number.

$$A_\alpha = \{x \mid \mu_A(x) \geq \alpha\}, \qquad \forall\alpha\in[0,1] \tag{2}$$

$$A = \bigcup_\alpha \alpha \cdot A_\alpha,\ B = \bigcup_\alpha \alpha \cdot B_\alpha,\ \forall\alpha\in[0,1] \tag{3}$$

This foumulation is known as the decomposition theorem. From the above formulas, a fuzzy set can be decomposed to a group of α-level sets and vice versa. Assuming fuzzy number sets A and B are normally distributed, the distance between fuzzy numbers A and B is defined as follows:

$$\Delta(A,B) = \{\Delta_l(A,B) + \Delta_r(A,B)\}/2 \tag{4}$$

In this formula, the terms, Δ_l(A,B) denote the difference in the left spreads of fuzzy numbers; similarly the term Δ_r(A,B) corresponds to the difference in right spreads. When the level of α is defined, the numerical difference δ on each level α simply comes from maximum and minimum values of the intreval, which is represented as an α-level set.

$$\delta(A_\alpha, B_\alpha) = \{\Delta_l(A_\alpha, B_\alpha) + \Delta_r(A_\alpha, B_\alpha)\}/2 \tag{5}$$

The difference between fuzzy numbers A and B is, therefore, obtained through the definite integral over α.

$$\Delta(A,B) = \int_0^1 \delta(A_\alpha, B_\alpha)d\alpha = 1/2\int_0^1 \{(a_l^\alpha - b_l^\alpha) + (a_r^\alpha - b_r^\alpha)\}d\alpha \tag{6}$$

This defference, (ΔA, B) means the sum of the time difference on every α-level when the travel time was observed as a fuzzy number. This concept is indicated by shading in Figure 3. It corresponds to the total area bounded by the wing lines of fuzzy numbers.

3. User Equilibrium With Fuzzy Information

The formulation and an algorithm for user equilibrium under fuzzy information are introduced. In particular, a formulation with triangular fuzzy numbers (TFN) is proposed in this section.

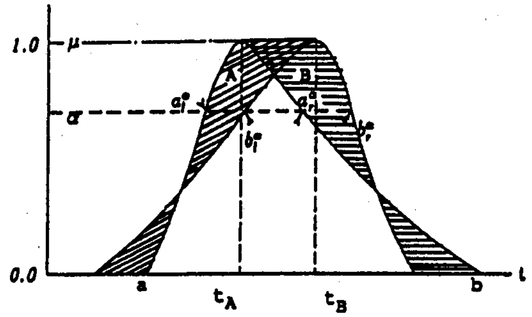

Fig. 3 Compatibility of Fuzzy Travel Times

3.1 Triangular Fuzzy Number

To define a fuzzy number which describes travel time perception, a membership function should be given. A triangular fuzzy number is one of the typical fuzzy sets which appear in many practical engineering applications. The membership function of a TFN is formulated as a pair of linear functions[8, 9, 11].

$$\mu(t)=\begin{cases} 0, & t\leq t_{al} \\ (t-t_{al})/(t_a-t_{al}), & t_{al}\leq t\leq t_a \\ (t_{ar}-t)/(t_{ar}-t_a), & t_a\leq t\leq t_{ar} \\ 0, & t_{ar}\leq t \end{cases} \tag{7}$$

Two triangular fuzzy numbers of travel time appear in Figure 4. The travel time t_a when μ(t) is equal to one corresponds to the value at which the preception of the driver is expressed by a crisp number or a verbal descriptor. Furthermore, the values t_{al} and t_{ar} correspond to the width of preceived travel time. Those values

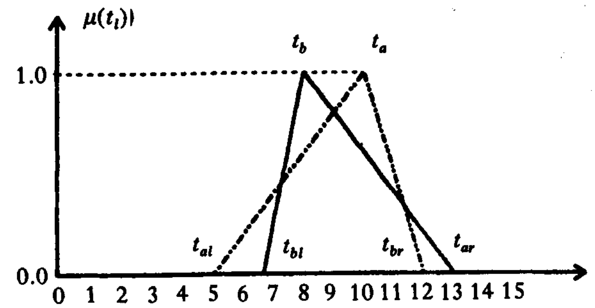

Fig. 4 Triangular Fuzzy Travel Time

t_{al}, t_a and t_{ar} are named left spread, mean and right spread respectively. In this case, the mean spread corresponds to the location when the value of the membership function is one. The following formulas show one of the relationships between spread and mean.

The parameters, γ_a and β_a are given to define the slope of membership function. A link is denoted as belonging to L, a group of links included in a particular route. The shape of the triangle can be changed according to the values of the values of the parameters. The widths of triangles are determined in proportion of the magnitude of perceived travel time t_a. This relationship is easily observed from the survey result. When both γ_a and β_a are equal to zero, the travel time is recognized to be nonfuzzy (i. e. t_a).

$$t_{al}=(1-\gamma_a)\cdot t_a, \quad 0\leq\gamma_a\leq 1.0, \quad \forall a\in L \tag{8}$$

$$t_{ar}=(1+\beta_a)\cdot t_a, \quad \beta_a\geq 0, \quad \forall a\in L \tag{9}$$

When γ_a is equal to zero and β_a is not zero, there will be a right-angle triangle whose base lies on the part of $t\geq t_a$. This shows the situation in which motorists feel they need at least as much time to travel as the informed travel time. This definition also suggests that traffic on these links is in an unstable condition because traffic congestion or traffic obstacles occur very often.

On the contrary, fuzzy travel time is described with an upper limit when $\gamma_a \neq 0$ and $\beta_a = 0$. In this case, motorists feel that traffic conditions in their experience are even better than the physical information displayed on the road.

Two ways of description were mentioned: one corresponds to heavy traffic conditions and the other to smooth traffic conditions.

3.2 Representative Values[8-10]

The comparison between fuzzy travel times is easily performed with TFN representation. In the centre of gravity method, a combination of eq. (1) and eq. (7) leads to the following equation.

$$t_g(x_a)=t_a\cdot(3-\gamma_a+\beta_a)/3 \tag{10}$$

The unique point which represents the distribution of TFN is derived. In a similar way, the difference of fuzzy travel times is obtained. If t_a and t_b denote means of fuzzy travel time respectively, the difference is derived from eq. (6) and eq. (7):

$$\Delta(t_a, t_b) = \{t_a \cdot (4 - \gamma_a + \beta_a) - t_b \cdot (4 - \gamma_b + \beta_b)\}/4 \tag{11}$$

where, $t_i^* = t_i \cdot (4 - \gamma_i + \beta_i)/4$, then, $\Delta(t_a, t_b) = t_a^* - t_b^*$

This fact shows that the comparison can be carried out with the representative value t^*. It is useful to embody the basic idea of that triangular fuzzy number in an example.

Consider the simple example depicted in Figure 4, where there are two fuzzy travel times, A ($t_a = 10$, $\gamma_a = 0.5$, $\beta_a = 0.2$) and B ($t_b = 8$, $\gamma_b = 0.2$, $\beta_b = 0.6$). The difference is calculated as $\Delta t = -0.04$ in the gravity method and $\Delta t = 0.$ 5 in the compatibility menthod. The result of the route choice coomes out or the reverse reversed according to the definition of t. The difference between eq.(10) and eq.(11) sometimes gives a different result.

In addition, the following advantage is obtained from using a TFN. A triangular fuzzy number is generally denoted as N (p, r, q), where p, r and q are left spread, mean and right spread respectively. The extension principle is applicable to calculations among these fuzzy numbers. In particular, the sum of two fuzzy numbers is given from the following equation.

$$N(p, r, q) + N(u, t, v) = N(p+u, r+t, q+v) \tag{12}$$

The result of the summation is also defined as a TFN whose parameters are linearly combined. Therefore, the discussion of link travel time is easily extended to the perceived travel time on the particular route. This fact confirms easily that the proposed theory may be easily extended to a realistic size of transport network.

3.3 Formulation

The optimizing problem with fuzzy travel time can be formulated only when the crisp performance function is replaced by a representative value function[12-14]. In general:

$$\min \quad Z = \sum_{a \in L} \int_0^{x_a} t_F(x) dx \tag{13}$$

s.t.

$$\sum_{k\in K_{ij}} x_{ijk} = T_{ij}, \quad \forall i\in I, j\in J \tag{14}$$

$$\sum_{i\in I} \sum_{j\in J} \sum_{k\in K_{ij}} x_{ijk} \cdot d_{aijk} = x_a, \forall a\in L \tag{15}$$

$$x_{ijk}0, \forall i\in I, i\in J, k\in K_{ij} \tag{16}$$

where,

Z : objective function
$t_F(x_a)$: representative value of fuzzy travel time according to traffic flow x_a
T_{ij} : traffic demands from origin i to destination j
x_{ijk} : traffic flow on route k between origin i and destination j
$d_{aijk} = \begin{cases} 1 & a\in k \\ 0 & a\notin k \end{cases}$

This problem is no more defficult to solve then the usual UE problem. Throughout this process, the modified part of the formula is quite small because the function of the representative values from a TFN are not fuzzy but unique. It should be recognized that an interruption of fuzzy travel time gives rise to a shift of the performance function. It should be immediately understood that the same equilibrium as obtained by a conventional approach happens only when all fuzzy travel times are defined as $\gamma_a + \beta_a = 0.0$ (all isosceles triangles).

3. The Algorithm

The concept of the conventional UE algorithm is applicable to solve the fuzzified problem. The modification of the algorithm is very simple as follows:

step 1. Initialization. Perform an all-or-nothing assignment based on $t_a^{(0)} = t_a(0)$. Obtain feasible solutions of link flow $\{x_a^{(1)}\}$.

step 2. Crisp travel time. Obtain crisp link travel time $t_a^{(n)}$ based on B.P.R. performance function.

step 3. Fuzzified travel time. Obtain the representative values of path travel time which are used by oll OD traffic volumes T_{ij}.

step 4. Shortest path searching. Search for a shortest path based on the representative values of travel time.

step 5. Direction finding. Use all-or-nothing assignment to obtain the descent direction $d^{(n)} = y^{(n)} - x^{(n)}$.

step 6. Optimal step size. Solve the following linear problem to obtain step size α^*.

$$\min \quad Z(x^{(n)} + \alpha \cdot d^{(n)})$$

$$\text{s.t.} \ 0 \leq \alpha \leq 1$$

step 7. Updating. Obtain the new feasible solution by

$$x^{(n+1)} = x^{(n)} + \alpha^* \cdot d^{(n)}$$

step 8. Convergence test. If the following equation was satisfied, then stop. Otherwise, set n=n+1 and go to step 2.e

$$|Z(x) \cdot d^{(n)}| \leq \varepsilon$$

where, ε is a convergence criterion.

In step 3, fuzzy travel time on each path is calculated from the link travel times. As mentioned previously, the path travel time is still described as a TFN by the extension principle. The final representative values of fuzzy travel time are obtained according to the defuzzification method:

Centre of gravity:

$$t_{ijk}^{(n)} = \sum_{a \in L} d_{aijk} \cdot t_a^{(n)} (3 - \gamma_a + \beta_a)/3$$

Compatibility:

$$t_{ijk}^{(n)} = \sum_{a \in L} d_{aijk} \cdot t_a^{(n)} (4 - \gamma_a + \beta_a)/4$$

These differences come from the definition of the fuzzified route choice mechanism mentioned in the previous section. All of the algorithms are very similar to each other. These procedures will be called FFW (Fuzzified

Frank-Wolfe) Method.

4. Numerical Example

To consider the practical use of the fuzzified user equilibrium, a search for the relationship between traffic information and human perception should be undertaken.

4.1 Basic Example

Consider the urban transportation network consisting of streets and motorways as showm in Figure 5, information equipment has been settled on motorways. This network has a motorway, link 6 (link 20 for the opposite direction). The matrix of origin-destination and parameters of link conditions appear in Table 1 and Table 2 respectively. The crisp travel time which corresponds to the mean of the TFN yields to the modified B. P. R. function. The fuzzified travel time is produced from this value with spread parameters γ and β.

A uniform fare system has been aboped on the urban expressways of Japan. To define the motorway link, the balanced time which comes from the flat toll fare for the motorway (450 yen/veh) and the average value of time (50 yen/veh min) is added to the physical travel time of link 6.

According to the values of the parameters, links can be classified into four groups.

a. A link which has non fuzzy travel time with perfect information obtained from the information equipment.

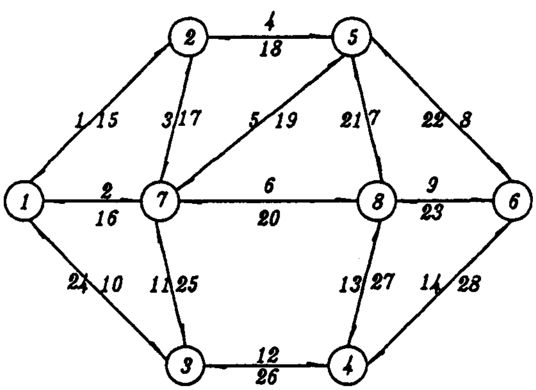

Fig. 5 Network

Table 1 OD Traffic Table

O/D	1							
1	0	2						
2	500	0	3					
3	500	1000	0	4				
4	1000	1000	500	0	5			
5	1000	1000	1000	1000	0	6		
6	2000	1000	2000	500	500	0	7	
7	500	500	500	1000	500	1000	0	8
8	500	1000	1000	500	500	500	500	0

b. A link which has fuzzy travel time with imperfect information even in standard traffic.
c. A link which has fuzzy travel time which tends to be longer than the standard in worse traffic conditions.
d. A link which has fuzzy travel time which tends to be shorter than the standard in better traffic conditions.

The links in type a only agree with a perfect information assumption. The classification among b, c and d, depends on the shape of the TFN. For example, link 1, which has the parameters, $\gamma=0.4$, $\beta=0.2$, belongs to type d because the parmeter γ is greater than β. They may be called (a) crisp link, (b) type S, (c) type R and (d) type L.

4.2 The Result of Calculation

Link flows are obtained as a result of traffic assignment. The differences between the methods are also discussed. Both results of standard UE and fuzzified UE are shown in Table 3.

The percentage in the Table represents the difference between fuzzified and standard user equilibrium link flows. Some observations from the results are summarized:

(a) Crisp Link (Type C)

Table 2 Initial Conditions of Link

No. of Link	Crisp		Fuzzy	
	t^0(min)	C(Veh)	γ	β
1	15	4000	0.4	0.2
2	10	4000	0.1	0.5
3	10	4000	0.2	0.2
4	15	4000	0.4	0.2
5	10	4000	0.2	0.2
6	8	6000	0.0	0.0
7	10	4000	0.2	0.2
8	15	4000	0.4	0.2
9	10	4000	0.1	0.5
10	15	4000	0.2	0.4
11	10	4000	0.2	0.2
12	15	4000	0.2	0.4
13	10	4000	0.2	0.2
14	15	4000	0.2	0.4

[Notes] t^0 : Initial travel time of link, C : Link capacity.
Only one way parameters of each link are shown, because a symmetric network is used.

Considering the traffic flow on link 6, there is a small difference on the crisp link. This link represents a motorway route which has a toll system. Since traffic flows generally relate to the magnitude of resistance to the entrance fee, this link is not strongly influenced by flow changes on other routes.

(b) Symmetric Links(Type S)

No difference from the crisp result should be observed if both travel times are described as symmetric fuzzy numbers. These links are, therefore, affected more strongly by the neighbouring links than by the width of their own

Table 3 Link Flow and Its Changes

No. of Link	Condition of Link	UE	Fuzzified UE & Change Rates	
			Gravity	Compatibility
1	L	1678	1934 +256(+15%)	1880 +202(+12%)
2	R	3014	2844 −170(−6%)	2884 −130(−4%)
3	S	2545	2648 +103(+4%)	2629 +84(+3%)
4	L	3525	3632 +107(+3%)	3608 +80(+2%)
5	S	3131	3123 −17(−0%)	3131 0(0%)
6	C	5702	5674 −28(−0%)	5676 −26(−0%)
7	S	2206	2076 −130(−6%)	2113 −93(−4%)
8	L	2964	3179 +215(+7%)	3129 +165(+6%)
9	R	1923	1781 −142(−7%)	1819 −104(−5%)
10	R	1939	1896 −43(−2%)	1907 −22(−1%)
11	S	3214	3200 −14(−0%)	3202 −12(−0%)
12	R	3643	3571 −72(−2%)	3585 −58(−2%)
13	S	3487	3495 +8(+0%)	3495 +8(+0%)
14	R	2623	2551 −72(−3%)	2564 −59(−2%)

[Notes] $\varepsilon=0.005$, L : Left spread is larger than right spread on TFN travel time,
C : Crisp link, R:Right spread is larger than left spead on TFN travel time,
S : Symmetric TFN travel time.

spread. The traffic decreases on link 7 (−6% by the centre of gravity method) and increases on link 3 (3 to 4% in both cases). The change of traffic on these links seems to have a strong relationship with the change of perception on neighbouring links. In particular, flows on links 8 and link 9 influenced traffic on link 7. Similarly, flows on link 1 and link 2 influenced the traffic on link 3.

(c) Links with a larger right spread(Type R)

Traffic flows on this type of link have reasonably reduced number of vehicles in comparison with the standard UE result. The largest change is observed on link 9 for which the degree of rigth spread is largest. This shows that flow change depends directly on the initial definition of TFN.

(d) Links with a larger left spread (Type L)

An increase of traffic volume is observed on these links. This is a reasonable result because the travel time has the possibility of being shorter than the standard. Though the difference from the mean travel time is smaller than that of right handed links, the traffic flow changes more.

In particular, even though the absolute volume of traffic is small on link 1, the largest change of flow is observed (12 to 15% in both methods).

The change of traffic on the whole network is depicted in Figure 6. The thickness of lines corresponds to the rate of change. The distribution of impacts on the whole network is observed in the figure. Larger changes in traffic are mainly observed on the upper area of the network (i. e. link 1 to link 9). The absolute traffic volume on the crisp link (link 6) changes greatly and affects the surrounding links.

In addition, the characteristics of the two proposed methods can be recognized

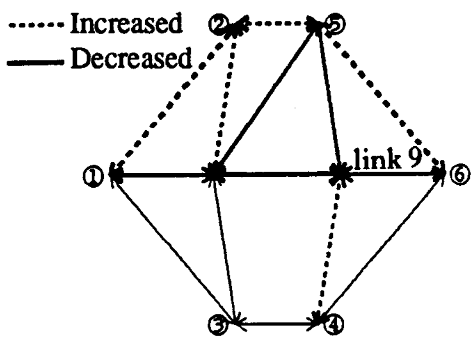

Fig. 6 Change of Link Traffic Flow

from the comparison of the results of assignment. There is only a small difference between the link flow patterms. This fact shows that the state of user equilibrium itself has not changed drastically.

On the contrary, only a small difference in variation of link flows is obtained with both methods. The result of assignment in the centre of gravity approach is more different from the standard assignment result than from the compatibility approach. Comparing eq. (10) with eq. (11), it can be seen that the representative value becomes quite different from the value of the mean when a normal and convex function like a TFN is used for the description of fuzzy travel time.

4.3 Application to Information Service Problems

Travel time information is in service on urban expressways and some streets in Japan. Some other2 examples might be found in other countries. If the driver receives the travel time for the route from origin to destination in advance, he or she can choose the shortest path without any fuzziness. This advantage would be given by complete information service facilities.

It is still difficult, however, to provide the travel time information for every OD pair. Furthemore, even given the amount of equipment to be constructed in the near future, it should be considered what will occur when the detectors are out of order or when heavy congestion happens on the motorway.

Some drivers give up their trips, but most of the still continue to drive under fuzzier circumstances. Consider a typical and simple example. In the previous example in section 4.2, it was assumesd that drivers know travel time only on the motorway (link 6). Accurate crisp information does not exist on the motorway any more, because of some trouble with the information equipment.

In the numerical example in Figure 6, travel time for link 6 has no left spread (i.e. $\gamma = 0.0$) and the right spread is varied from zero to twice the mean (i.e. the parameter β, changes from zero to 1.0). The other parameters are fixed.

The result of the calculation ($\gamma=0.0$, $\beta=1.0$) is shown in Table 4. When the width of the right spread is twice as much as the mean, the rate of change of link flow is at most 8 precent. The impact of perception change in one particular link on other links seems to be small.

In a realistic sense, quality of information just on the particular link (the motorway) does not seriously influence other streets. The reason for this is that many fuzzy links still exist when only a small part of the network is covered by an information system.

To consider the impact on traffic flows, the largest changes of traffic flow are observed on the links connected to the motorway link. The increase in traffic

Table 4 Link Flow And Its Change

No. of Link	Basic Case			Fuzzified Case		
	Conditions	Gravity	Compatibility	Conditions	Gravity	Compatibility
1	L	1934	1880	L	1895 −9(−2%)	1847 33(−2%)
2	R	2844	2884	R	2814 −30(−1%)	2866 −18(−0%)
3	S	2684	262	S	2554 −94(−4%)	2559 −42(−2%)
4	L	3632	3608	L	3712 +80(+2%)	3666 +58(+2%)
5	S	3123	3131)	S	5273 +114(+4%)	3215 +84(+3%)
6	C	5674	5676	R	5396 −278(−5%)	5467 −209(−4%)
7	S	2076	2113	S	2241 +165(+8%)	2225 +112(+5%)
8	L	3179	3129	L	3208 +29(+0%)	3155 +26(+0%)
9	R	1781	1819	R	1704 −59(−3%)	1753 −66(−4%)
10	R	1896	1907	R	1963 +67(+4%)	1949 +40(+2%)
11	S	3200	3202	S	3240 −40(−1%)	3235 −53(−2%)
12	R	3571	3585	R	3655 +84(+2%)	3652 +67(+2%)
13	S	3495	3495	S	3486 −9(−0%)	3477 −17(−0%)
14	R	2551	2564	R	2611 +60(+2%)	2608 +44(+2%)

[Notes] L: The left spread is larger than the right spread on TFN travel time, C : Crisp link, R: The right spread is larger than the left spread on TFN travel time,S : Symmetric TFN travel time.

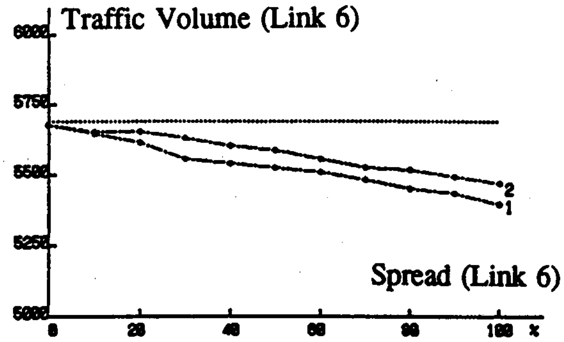

Fig. 7 Tendencies/Trends of Traffic Flow on Motorway (Link 6)

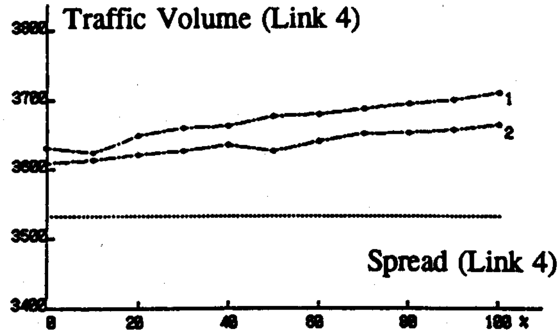

Fig. 8 Tendencies/Trends of Traffic Flow on Street (Link 4)

is 3 to 4 percent on link 5, and 5 to 8 percent on link 7, with either method.

The relationship between the motorway and its alternative streets also can be seen. Trends of traffic flows on link 6 and link 4 are shown in Figure 7 and Figure 8 respectively according to the width of the rigth spread. The following conclusions may be drawn from this observation:

(1) The traffic on the motorway decreases stepwise as fuzziness of travel time grows. In particular, the maximum change form the standard UE is observed as about 6% when β equals 1.0.

(2) The traffic on an alternative street increases according to the degree of fuzziness. The increase in traffic seems mainly to be a diversion from the motorway. The final state is about 5% apart from the standard condition.

(3) The traffic volume does not always change at the same rate. A different user equilibrium can be observed for each degree of fuzziness.

In this example,both approaches (centre of gravity and compatibility) obtained almost the same results. It becomes obvious that the application of the UE concept with fuzziness to traffic information problems gives us useful results in evaluating the present conditions for information about whiich method will be utilized.

Additionally, it must be mentioned that the proposed approach may also be used to modify Incremental Assignment which is regraded as one of the most practical solutions of the UE problems.
It hsa been reported that Fuzzified Incremental Assignment (FIA) could be produced in the same manner[12,16].

5. Concluding Remarks

This paper proposes to describe human perception of transport networks, fuzzified link description and UE assignment with fuzziness. In particular, the gravity and compatibility of TFN are shown as defuzzification approaches. The result of fuzzified UE traffic assignment also well indicates the influence of fuzziness on travel time to link flows. The main findings are summarized as follows:

(1) The width of link travel time can be described by fuzzy numbers. This was confirmed by the survey results from motorway users. In addition, a model of human pereption will be easily established by using fuzzy theory.

(2) If a triangular function is used as a membership function for fuzzy numbers, the shape of the function is easily changed with parameters β and γ. In this sense, TFN gives a flexibility to link representation according to actual information services.

(3) Flow pattems of fuzzified user equilibrium are influenced by the shape of the membership function for travel time. The advantage of this for the method is that the result includes the standard equilibrium state. The state. The result, therefore, should be considered an extension of the standard UE state.

(4) A similar traffic flow was produced with both the centre of grabity approach and the compatibility approach. Each has its own advantage in both a theoretical and a practical sense. Therefore, the choice of method depends on the purpose of the modelling.

(5) The proposed nethod can be applied to evaluate the impact of transport information devices. It is obvious that same approach will be usable for the evaluation of other kinds of transport measures.

Research based on the relationship between traffic information and transport behaiour will become more important in the near future. This study can be regarded as a first step to describe motorists' perceptions with the concept of fuzzy travel time. To provide sutitable information with which to manage the traffic on the roads correctly, modification of the opresent models ndeeds to correspond to more complicated situations.

Empirical surverys of fuman perception of travel time, description of route choice behaviour with uncertainty, and the practical application of fuzzified assignment to realistic networks have all been carried out independently. For future study, it is concluded that the combination of knowledge obtained from each result shown gives a strong solution to the problem.

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