ROUTE GUIDANCE SYSTEM USING FUZZY INFORMATION

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INTRODUCTION

The recent developents in telecommunication and information processing technologies have brought about the possibilities of using the existing transportation facilities more efficiently. The Intelligent Vehicle-Highway Systems (IVHS) is a co-ordinated effort to enhance the utilization of transportation facilities by integrating the functions of vehicles and highways through information. An important element of the IVHS development is a driver-aid system which interprets the information on traffic conditions and advises the driver as to the selection of the path and udpdating the travel status (or his travel schedule compliance).

In this paper, we propose two models which are applicable when the travel time estimates are perceived as fuzzy quantity by the driver. The first model determines the shortest path among alternative paths. This model accounts for driver's path preference (or bias) among alternative paths. The second model computes the required departure time when the desired arrival time as well as the estimated travel time is given as fuzzy quantities. This model can be used to assess the on-time or delay status of the vehicle enroute. The mathematical bases of the models proposed in this paper are arithmetic operations of fuzzy numbers for the computation of estimated travel time, and the possibility and necessity measures for the comparison of fuzzy numbers.

Many researchers have studied the nature of the information, decision pattern and compliance of the driver-aid system. It has been pointed out by Chen and Ervin[1] that the compliance to the route guidance information is more likely if the advice is aimed at individual optimum rather than the global optimum. Bonsall and Parry[2] have studied the driver acceptance of route guidance informations. They conclude that the acceptance is determined by various characteristics like the quality of the information, and characteristics of individual drivers. Hammerslag and Van Berkum[3] and Oda[4] state that the choices of the route and destination are dependent on the perceived travel time, rather than the objective travel time. The travel time information provided by the system is perceived in different ways by different drivers. Polak and Jones[5] show that passengers are more interested in the pre-trip information, and prefer to choose a route or mode prior to starting the trip and stick to it. Kitamura and Jovanis[6] show that the drivers tend to adjust the departure time on a selected route, rather than switching to alternative routes along the trip.

1. THE DESCRIPTION OF THE SYSTEM

A route guidance system which consists of a central information processor, on-board guidance and the driver is assumed. The central processor monitors the traffic conditions on the network and estimates travel time on each link. On the vehicle, the driver registers his trip origin and destination and alternative trip paths with his preference on the on-board guidance system. The on-board guidance system then obtains the network travel time information from the central processor and compares the travel time on the alternative paths, and determines the shortest time path for the driver. In this process, the travel time estimates obtained from the central processor is treated as fuzzy numbers instead of crisp numbers. Further, the on-board guidance system constantly monitors the progress of the vehicle along the route, and advises the driver if he is able to arrive at the destination on time. Since the available travel time information is fuzzy, the advice will not be precise but rather fuzzy, such as "more or less on-time" or "very late".

The proposed guidance system can deal with the following characteristics of information in the IVHS guidance system: one, approximate nature of the estimated travel time information and the driver's perception of it; two, the driver's bias towards particular path in evaluating the alternative paths; and three, the fuzzy notion of the desired arrival time on the part of the driver.

The flow of information in the system is shown in Figure 1. The three elements of the system are the vehicle, the driver, and the central processor. These elements are shown by boxes and the information transmitted from one to the other are shown by arrows.

2. THE MODELS

The proposed models of the guidance system are divided into the following functional elements:

1. Estimation of the travel time on the links by the central processor
2. Computation of the travel times on alternative paths
3. Selection of the best path
4. Evaluation of the trip status.

2.1. Modelling of the estimation of travel time

The travel time on a link is estimated from the information on the speed of the vehicle. The speed sensors measure the speeds of individual vehicles and estimate average travel speeds on the links. The speed is treated as a fuzzy number in this model. If the speed measurements on a link lie within the range $[s_1, s_2]$, the fuzzy number of the speed can be represented by a possibility distribution π_s. It has the modal value $s_m = \frac{1}{2}(s_1 + s_2)$ and it is symmetrical on either side, represented by

$$\pi_s = (s_m, k) \tag{1}$$

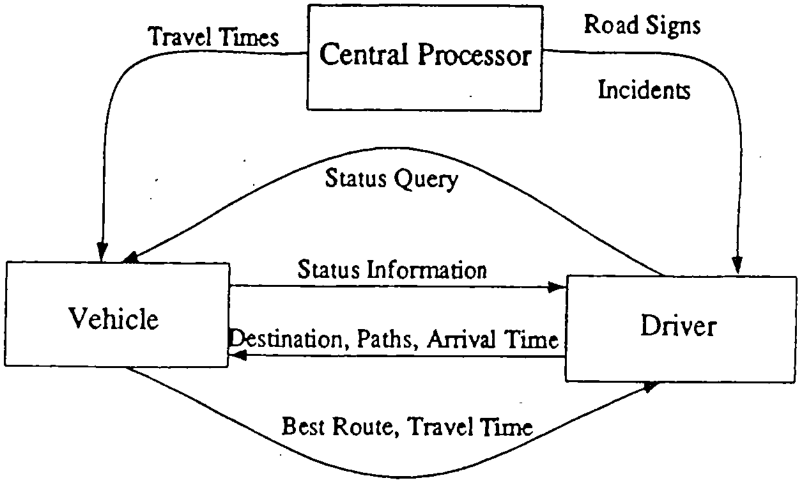

Figure 1. Flow of Information in the Assumed Route Guidance System

where, k is the spread about the modal value, $k = s_m - s_1 = s_2 - s_m$.

The reliability of the estimate can be adjusted by the specificity factor r in π_s as follows:

$$\pi_s = \begin{cases} 0 & \text{for } s \leq s_1 \\ (\frac{s-s_1}{k})^r & \text{for } s_1 \leq s < s_m \\ (\frac{s_2-s}{k})^r & \text{for } s_m \leq s < s_2 \\ 0 & \text{for } s \geq s_2 \end{cases} \tag{2}$$

The value of r controls the shape of the possibility distribution. When the value of r is 1, the distribution is a TFN (triangular fuzzy number). When $r = \infty$, the fuzzy number becomes a single number. As $r \to 0$, the distribution becomes an interval.

If the speed is given by this possibility distribution,π_s and the length of the link is L, then the possibility distribution for the travel time on the link, π_t is given by

$$\pi_t = \frac{L}{\pi_s} \tag{3}$$

The division operation in equation (3) is done using the extension principle of fuzzy numbers.

2.2. Computation of the travel time for the trip

The travel time between nodes in a network is expressed as a fuzzy number. Given a driver specified path, the vehicle retrieves the information on the travel times along the driver specified path. If the path P_1 consists of a set of sequential nodes $I = \{p_1, p_2, ..., p_n\}$, then the travel time on the path P_1 is given by

$$\tilde{T}(P_1) = \tilde{t}(p_1, p_2) + \tilde{t}(p_2, p_3) + ... + \tilde{t}(p_{n-1}, p_n) \tag{4}$$

where $\tilde{T}(P_1)$ represents the fuzzy travel time on the path P_1, and $\tilde{t}(p_i, p_{i+1})$ represents the fuzzy travel time on the link connecting the nodes p_i and p_{i+1}.

2.3. Modelling of the selection of the best path

The travel times on the selected set of paths are compared and the shortest path is chosen. The methodology proposed for the selection of the shortest path uses the possibility and necessity measures and the concept of truth value.

Let us consider the problem of comparing two fuzzy numbers, M and N, as shown in Figure 2, the following fuzzy measures can be computed using the method proposed by Dubois and Prade[7].

1. Possibility that M is the smaller of the two, $\Pi(M)$
2. Necessity that M is the smaller of the two, $N(M)$.

From the basic properties of fuzzy measures, the following conditions hold

1. $N(M) \leq \Pi(M)$
2. $N(M) > 0 \Longrightarrow \Pi(M) = 1$

Following the reasoning proposed by Dubois et al[8], the statement that 'M is the smaller of the two' is completely *true* if $\Pi(M) = 1$ and $N(M) = 1$. The statement is completely *false* if $\Pi(M) = 0$ and $N(M) = 0$. For the values in between these two extremes, partial truth values are assigned. In this paper, we propose the concept of *perceived level of truth* that takes into account the bias the decision maker has.

The perceived level of truth τ is expressed as a function of the possibility measure, the necessity measure, and a parameter that represents the bias. The percieved level of truth of the statement 'M is smaller of the two', $\tau(M)$, is given by

$$\tau(M) = \begin{cases} \frac{\Pi(M)+N(M)}{2-\beta} & \text{if } \Pi(M) + N(M) \leq 2 - \beta \\ 1 & \text{otherwise} \end{cases} \tag{5}$$

where the value of β varies between 0 and 1. $\beta = 1$ represents complete bias and in this case, the perceived truth value is 1 at $\Pi(M) = 1$ and $N(M) = 0$. $\beta = 0$ represents no bias, or, the decision maker has no information or preference. In this case

$$\tau(M) = \frac{\Pi(M) + N(M)}{2} \tag{6}$$

When $\beta = 0$, $\tau(M) = 1$ only if $\Pi(M) = 1$ and $N(M) = 1$. This means that if the decision maker has no bias, then complete truth is percieved only if it is *necessarily* true. This is equivalent to the truth functional proposed by Gaines[8]. A plot of the value of perceived truth value against possibility and necessity measures is shown in Figure 3.

We now compare different paths and find the shortest one when the travel time on each is known as fuzzy. Given paths $P_1, P_2, ..., P_n$, the possibility that P_1 is the best route is given by

$$\Pi(P_1) = \Pi(\tilde{T}(P_1) < \tilde{T}(P_2)) \wedge \Pi(\tilde{T}(P_1) < \tilde{T}(P_3)) \wedge ..... \wedge \Pi(\tilde{T}(P_1) < \tilde{T}(P_n)) \quad (7)$$

and the necessity that P_1 is the best route is given by

$$N(P_1) = N(\tilde{T}(P_1) < \tilde{T}(P_2)) \wedge N(\tilde{T}(P_1) < \tilde{T}(P_3)) \wedge ..... \wedge N(\tilde{T}(P_1) < \tilde{T}(P_n)) \quad (8)$$

Assuming there is no bias, the percieved truth of the statement that 'P_1 is the best route' is

$$\tau(P_1) = \frac{\Pi(P_1) + N(P_1)}{2} \quad (9)$$

This truth value is computed for each of the paths as $\tau(P_1), \tau(P_2)....., \tau(P_n)$. The path with the highest perceived truth value is chosen as the best route.

2.4. Modelling of trip status information

The driver's desired arrival time at the destination is registered with the vehicle. The desired arrival time is considered to be a fuzzy quantity. From the desired arrival time and the estimated travel time, the required departure time can be estimated through the principle of deconvolution of fuzzy addition.

If the required departure time is 'before the current time', then the driver is running late. If the required departure time is 'after the current time', then the driver is on time. The memberships of the required departure time in the sets 'before the current time' and 'after the current time' can be expressed in terms of possibility measures and necessity measures. As explained above, the truth value of the statement that the driver is running late can be obtained from the fuzzy measures.

$$\tau(L) = \frac{\Pi(L) + N(L)}{2} \quad (10)$$

where L is the statement 'vehicle is running late',
$\tau(L)$ represents the truth value of the statement 'vehicle is running late',
$\Pi(L)$ is the possibility that 'vehicle is running late', and
$N(L)$ is the necessity that the 'vehicle is running late'.

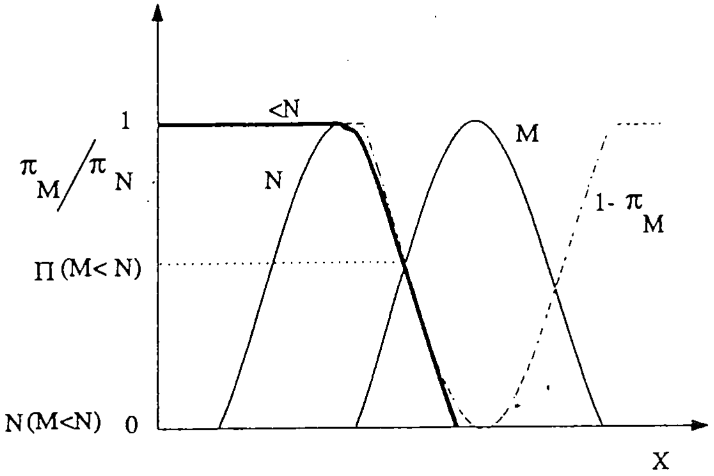

Figure 2. Comparison of Fuzzy Numbers

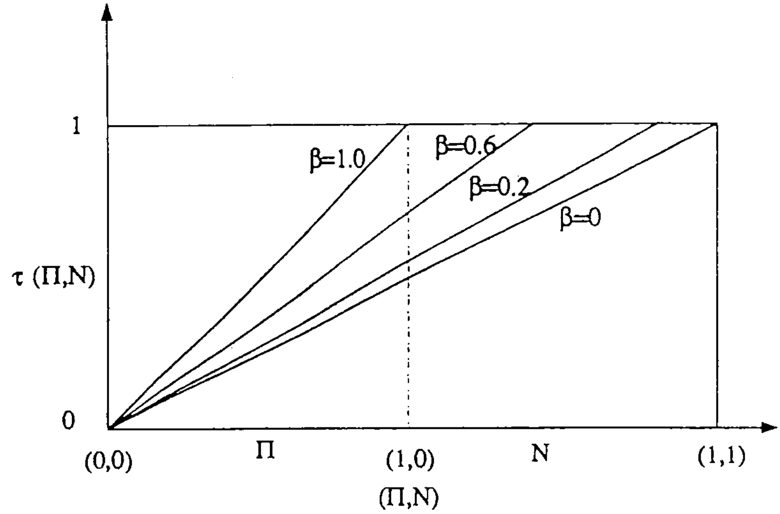

Figure 3. Perceived Truth Value as a Function of β, Π, and N

Similarly, the truth value of the statement, 'vehicle is on time', $\tau(O)$ is given by

$$\tau(O) = \frac{\Pi(O) + N(O)}{2} \tag{11}$$

where O is the statement 'vehicle is on time',
$\tau(O)$ is the truth value of the statement 'vehicle is on time',
$\Pi(O)$ is the possibility that the 'vehicle is on time', and
$N(O)$ is the necessity that the 'vehicle is on time'.

The degree of truth value can be interpreted linguistically. For example, $\tau(L) = 1$ may be interpreted as "running very late", and $\tau(L) = 0.6$ may be interpreted as "running somewhat late". Similarly, $\tau(O) = 1$ may be regarded as "very much on time", and $\tau(O) = 0.6$ as "somewhat on time". This information on the trip status can be determined from the knowledge of the approximate travel times on the links, and the desired time of arrival at the destination. The information on the status of travel would reduce the driver's anxiety about on-time arrival.

3. EXAMPLES

Assume an urban road network as shown in Figure 4. The estimated travel time on each of the links is indicated as a triangular fuzzy number. The fuzzy travel times (in minutes) are represented as two-tuples with mid-values and spreads. For example, (10,2) represents a triangular fuzzy number with a mid-value of 10 and a spread of 2 on either side. Thus the lower value is 8 and the upper value is 12.

Let the origin node of a trip be node 2. The driver wishes to arrive at node 7 in about 25 minutes with (25,7). Three alternative paths indicated by the driver are indicated as P_1, P_2, P_3 in Figure 4. In this example, the driver is assumed to determine the shortest route based on unbiased decision ($\beta = 0$).

Travel times on each path

Travel time on path P_1, $\tilde{T}(P_1)$ = (5,1)+(10,3)+(25,8) = (40,12)
Travel time on path P_2, $\tilde{T}(P_2)$ = (15,5)+(10,3)+(5,1) = (30,9)
Travel time on path P_3, $\tilde{T}(P_3)$ = (2,1)+(5,2)+(10,3)+(2,1)+(5,1) = (24,8)
$\tilde{T}(P_1)$, $\tilde{T}(P_2)$, and $\tilde{T}(P_3)$ are shown in Figure 5.

Derivation of perceived truth value

$\Pi(\tilde{T}(P_1) < \tilde{T}(P_2)) = 0.6$; $\Pi(\tilde{T}(P_1) < \tilde{T}(P_3)) = 0.2$; $\Pi(P_1) = 0.6 \wedge 0.2 = 0.2$
$\Pi(\tilde{T}(P_2) < \tilde{T}(P_1)) = 1.0$; $\Pi(\tilde{T}(P_2) < \tilde{T}(P_3)) = 0.65$; $\Pi(P_2) = 1.0 \wedge 0.65 = 0.65$
$\Pi(\tilde{T}(P_3) < \tilde{T}(P_1)) = 1.0$; $\Pi(\tilde{T}(P_3) < \tilde{T}(P_2)) = 1.0$; $\Pi(P_1) = 1.0 \wedge 1.0 = 1.0$
$N(\tilde{T}(P_1) < \tilde{T}(P_2)) = 0.0$; $N(\tilde{T}(P_1) < \tilde{T}(P_3)) = 0.0$; $N(P_1) = 0.0 \wedge 0.0 = 0.0$
$N(\tilde{T}(P_2) < \tilde{T}(P_1)) = 1.0$; $N(\tilde{T}(P_2) < \tilde{T}(P_3)) = 0.0$; $N(P_1) = 1.0 \wedge 0.0 = 0.0$
$N(\tilde{T}(P_3) < \tilde{T}(P_1)) = 1.0$; $N(\tilde{T}(P_3) < \tilde{T}(P_2)) = 0.8$; $N(P_1) = 1.0 \wedge 0.8 = 0.8$

The perceived truth value for each path is computed according to equation (9): $\tau(P_1) = 0.1$, $\tau(P_2) = 0.325$, $\tau(P_3) = 0.9$.
Thus, path P_3 is chosen as the best route.

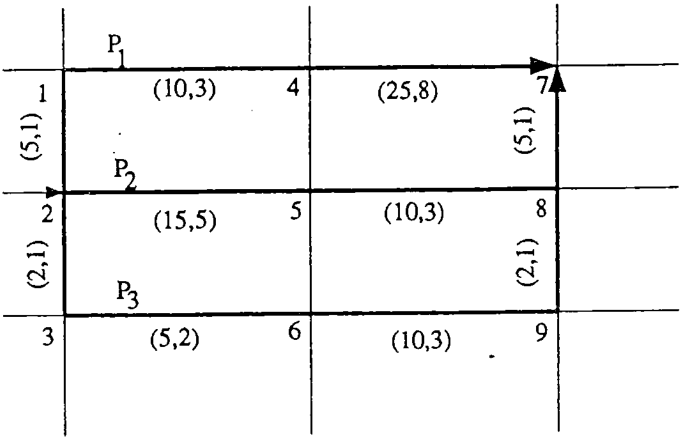

Figure 4. Example Network.

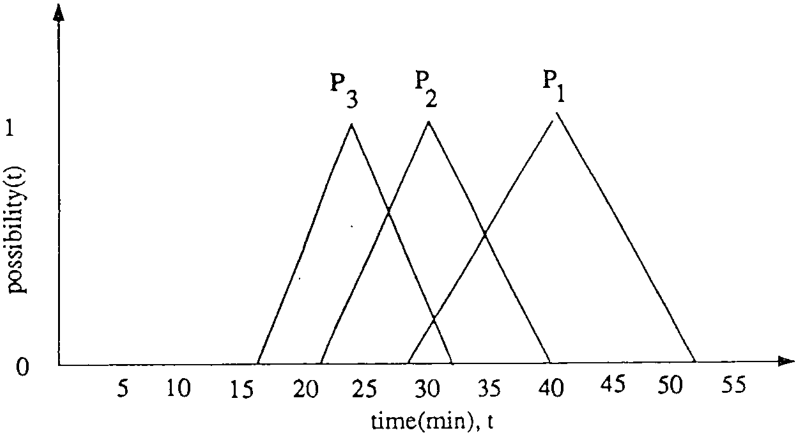

Figure 5. Path Travel Times in Fuzzy Numbers

Travel status (on-time or delay status)

Assume that the driver takes path P_3 and 7 minutes into his travel he has reached node 6. At this point, he wants to know the delay status.
The estimated travel time on the remaining path (nodes 6-9-8-7) = (10,3)+(2,1)+(5,1) = (17,5). The desired arrival time at node 7 = (25,7)
Let the required departure time at node 6 be $\tilde{D}$. Then

$$\tilde{D}+(17,5) = (25,7)$$

$\tilde{D}$ is solved by deconvolution. Using the procedure suggested by Kaufmann and Gupta[9], $\tilde{D}$ can be estimated as

$$\tilde{D} = (25\text{-}17,7\text{-}5) = (8,2)$$

Because the curent time =7, "Before the current time", B is given by

$$\mu_B(x) = \begin{cases} 1 & \text{if } x < 7 \\ 0 & \text{if } x \geq 7 \end{cases} \tag{12}$$

and "After the current time", A is given by

$$\mu_A(x) = \begin{cases} 1 & \text{if } x \geq 7 \\ 0 & \text{if } x < 7 \end{cases} \tag{13}$$

The possibility that "$\tilde{D}$ is B" is equivalent to the possibility that the vehicle is "running late", $\Pi(L)$, and is given by $\Pi(L) = \vee(\pi_{\tilde{D}}(x) \wedge \mu_B(x)) = 0.5$.
The necessity the "$\tilde{D}$ is B", equivalent to the necessity that the vehicle is "running late", $N(L)$, is given by $N(L) = \wedge(1 - \pi_{\tilde{D}}(x) \vee \mu_B(x)) = 0$.
Therefore, $\tau(L) = \frac{.5+0}{2} = 0.25$
Similarly, $\Pi(O) = 1$, $N(O) = 0.5$, and $\tau(O) = 0.75$
Thus, the conclusion is that the driver is "on time" to a degree 0.75 or "more or less on time". The driver may receive this message from the on-board guidance system.
Now let us suppose that the driver stopped on the link between the nodes 6 and 9 and he reaches node 9 at 22 minutes after the start, after taking 15 minutes from node 6 to node 9.
The time for the remaining trip(nodes 9-8-7)= (5,1)+(2,1) = (7,2)
The required departure time = (25-7,7-2) = (18,5) by decovolution. Thus the on-time status is:
$\Pi(L) = 1, N(L) = 0.8, \tau(L) = 0.9$
$\Pi(O) = 0.2, N(O) = 0, \tau(O) = 0.1$
The conclusion is that the driver is "running late" to a degree 0.9 and "on time" to a degree 0.1. This indicates that the driver is "running quite late".

4. CONCLUSION

A set of models for a route guidance system is proposed. The models treat the driver perceived travel time estimate as a fuzzy number. The best path is determined by comparing the fuzzy travel times on alternative paths. In this process, the driver's bias can be incorporated. The bias may be considered as the driver's propensity towards risk taking or risk averting (attitude towards decision making). Thus, it can be adapted to individual driver's personality if installed on-board a vehicle.

The proposed model also has the ability to provide information on the delay status of the trip to the driver on a real time basis. This information helps to reduce the anxiety in the driver's mind about whether he will reach his destination in time. An example that illustrates the process of route choice decisions and the process of evaluating the trip status has been provided. This example shows that the model yields decisions and informations which are reasonable. However, a validation of the model requires the development of a simulation model and a comparison of the global performance with other route choice and route guidance models.

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