GOVERNANCE OF FUZZY SYSTEMS TO PREDICT DRIVER PERCEPTION OF SERVICE QUALITY OF VARIABLE MESSAGE SIGNS

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ABSTRACT

Advanced traveler information systems (ATIS) are an intelligent transportation sub area that has significant interactions between the systems and humans, whether they are vehicle operators, passengers, or pedestrians. Given this circumstance, consideration of how drivers perceive and evaluate the service quality provided by these systems is an important factor in evaluating the performance of these systems. An important element in the transmission of information to travelers, as part of an ATIS, is the variable message sign (VMS). In evaluating the service quality by VMS, there are two methods that have been generally used. One is to evaluate the service quality indirectly through the investigation of traffic operational effects. For example, how much does the installation of ATIS along the road increase average vehicle speed or reduce average delay? Investigating these effects is relatively easy, but it is difficult to truly evaluate how drivers perceive the service quality of these devices or how satisfied drivers are with the service they are receiving using these measures of effectiveness (MOEs).

1.0 INTRODUCTION

Another way to investigate driver satisfaction of service quality would be to use a survey. For instance, motorists could be asked about their satisfaction with the contents and accuracy of information provided by a VMS. By employing a survey, the service quality and reliability that drivers perceive can be evaluated; however, only basic results, such as a simple percentage or degree of satisfaction relative to each criterion could be provided. These types of results are limited and not really sufficient to represent drivers’ perception of service quality. They cannot represent appropriately the variability and complexity of human perception. Another problem with using a survey method is the difficulty of describing the survey results quantitatively and objectively because surveys primarily use linguistic terms,
not exact quantitative scales, to evaluate a subject’s response and those linguistic terms are determined by subjective human decision making processes. Thusly, there is a need to interpret quantitatively and objectively drivers’ perceptions as indicated in the results of the survey, to aggregate the drivers’ responses to various questions related to VMS service, and to evaluate the overall driver perception of the system. In the *ITS Evaluation Resource Guide*, user satisfaction is regarded as one of the measures of effectiveness of mobility. It is also indicated that user satisfaction measures characterize the difference between users’ expectations and experience in relation to a service or product. Relative to this guideline, several evaluations have been performed. Studies of ATIS in Arizona and Missouri (Orban et al. 2000) were conducted in which an analysis of user satisfaction was included. In these studies, simple percentages corresponding to each evaluation criterion were presented as the final results. However, this type of approach does not provide sufficient or meaningful detail relative to making design decisions when contrary findings are indicated. This was similar to the methodology and analysis of ATIS. The major drawback to all of these studies is that they were unable to investigate the individual differences in the participants’ subjective assessment of service quality. In this study, a method of evaluating VMS service quality based on fuzzy set theory is introduced. Fuzzy sets, where a more flexible sense of membership is possible, are classes with “un-sharp” and vague boundaries. Fuzzy sets theory is a branch of set theory that is useful for the representation of imprecise knowledge of the type that is prevalent in human concept formation and reasoning. Its usefulness lays in the concept that fuzzy theory can represent a type of uncertainty due to vagueness or fuzziness The membership function is the most important element of the fuzzy approach as it makes it possible for fuzzy set theory to be used to evaluate uncertain and ambiguous matters. One of the most important and difficult tasks for applying fuzzy technique is to correctly measure the membership function. In this research, the role of the membership function is to represent an individual and subjective human perception as a member of a fuzzy set. This membership function can represent the degree of the subjective notions of a vague class with an infinite set of values between 0 and 1. In the procedure describe herein, two membership functions for five linguistic scales and an evaluation of the relative importance of six service-related criteria were formulated using results from a survey conducted for this study. The second fuzzy membership function was determined applying which is commonly used in multiple decision making analysis. Individual perceptions of the service were evaluated using results from a previously conducted survey subjected to two fuzzy membership functions.

### 2.0 AGGREGATION OF THE INDIVIDUAL PERCEPTIONS

The 322 individual perceptions of VMS service evaluated above should be aggregated to represent the group’s overall opinion. For aggregating the fuzzy number of the perceptions, a “arithmetic mean” of the fuzzy numbers, which represent all individual perceptions, were calculated using a fuzzy average operation based on the “α-cut” concept of fuzzy sets and an interval analysis. The outputs from this step are still fuzzy numbers, and they should be transformed into crisp numbers to be more easily understood.
3.0 DEFUZZIFICATION

To transform the final fuzzy set that represents the group’s overall opinion into crisp numbers, a defuzzification procedure was conducted. Out of several defuzzification methods, the defuzzified method developed by Juang, et al. was used due to its simplicity and ease of computation. It is a mapping model for measuring fuzzy numbers using estimated utility

\[ u = \frac{(A_L - A_R + 1)}{2} \]

where
- \( u \) = the utility to measure or rank a fuzzy number,
- \( A_L \) = the area enclosed to the left of the characteristic function that characterizes the fuzzy number,
- \( A_R \) = the area enclosed to the right of the characteristic function that characterizes the fuzzy number,

The utility yields a value between 0 and 1, and the higher utility value indicates the higher service quality of VMS. Through these procedures, the survey results from the prior study, which consisted of simple percentages, were converted to an overall measure of service quality that takes into consideration the variance of human perception and the degree of importance of the six criteria. The final number represents the overall service quality perceived by all drivers.

4.0 CONSTRUCTION OF MEMBERSHIP FUNCTIONS

As mentioned previously, the types of fuzzy membership function were determined after a review of the data. To find the first membership functions for five scales of linguistic statements, the universe interval, from 0 to 1.0, was partitioned with unit length (0.05) intervals. Then normalized frequencies of each unit interval were calculated. The shapes of the histograms derived from these normalized frequencies indicated that a trapezoid membership function was the most appropriate type of membership function for representing five scales of linguistic statements indicated that a trapezoidal membership function is commonly used to represent a fuzzy interval estimate. The trapezoidal membership function is specified by four parameters \( \{a, b, c, d\} \) as following mentioned in Table 2-2. Finally, to determine the membership function, three rules for designing the membership function were considered:

- Rule 1: Each membership function overlaps only with the closest neighboring membership functions
- Rule 2: For any possible input data \((x)\), its membership values in all relevant fuzzy sets should sum to one or nearly so.
- Rule 3: The range of top of trapezoid should be approximately matched with the standard deviation of the input value, \( x \).

Procedures described above and their parameter values. The second set of membership functions, which represent the fuzzy weight of six criteria, was created by the 23 sets of weights evaluated. This procedure was repeated with all of the survey results, which created 23 PCMs and sets of weights. Review of the data indicated that triangular fuzzy membership functions were the most suitable type of membership function for representing the weights of
the six criteria. A triangular membership function is specified by three parameters \(\{a, b, c\}\), and the precise appearance of the function is determined by the choice of parameters.

![Fuzzy Membership Function of Five Scales Linguistic Statement](image)

**Figure 1. Fuzzy Membership Function of Five Scales Linguistic Statement.**

**Table 1. The PCM and Weight judged by an Individual Response (Participant \(i\))**

<table>
<thead>
<tr>
<th>Scale</th>
<th>(a)</th>
<th>(b)</th>
<th>(c)</th>
<th>(d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (Strongly Disagree)</td>
<td>-0.1</td>
<td>0</td>
<td>0.100</td>
<td>0.200</td>
</tr>
<tr>
<td>2 (Disagree)</td>
<td>0.100</td>
<td>0.200</td>
<td>0.325</td>
<td>0.475</td>
</tr>
<tr>
<td>3 (Neither agree nor disagree)</td>
<td>0.325</td>
<td>0.475</td>
<td>0.575</td>
<td>0.675</td>
</tr>
<tr>
<td>4 (Agree)</td>
<td>0.525</td>
<td>0.675</td>
<td>0.750</td>
<td>0.850</td>
</tr>
<tr>
<td>5 (Strongly agree)</td>
<td>0.750</td>
<td>0.850</td>
<td>1</td>
<td>-</td>
</tr>
</tbody>
</table>

These three parameters were finally determined using the min, modal, and max values. The second set of fuzzy membership functions. As can be seen in the figure, drivers regard comprehension, accuracy, and usefulness of VMS as being more important than visibility, legibility to read, and correspondence to their expectancy. This result is similar to an earlier study of criteria for traffic sign design and evaluation. In this study, Dewar conducted a survey that examined the relative importance of criteria used for traffic sign design and evaluation and indicated that the criteria related to the content of a traffic sign (e.g. understandability) were more important than the criteria related to visibility and identification (e.g. legibility or reaction time).
This scale, which represents each level of “agreement” with an integer, was transformed into a fuzzy number using the first fuzzy membership function. The individual perceptions transformed as fuzzy sets were aggregated by the fuzzy weighted average based on extended algebraic operations.

Table 2: The Individual Perception and the Arithmetic Mean Value

<table>
<thead>
<tr>
<th>Driver</th>
<th>$\eta_0$</th>
<th>$\eta_{0.5}$</th>
<th>$\eta_1$</th>
<th>$\eta_{0.5}$</th>
<th>$\eta_0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.015</td>
<td>0.051</td>
<td>0.095</td>
<td>0.172</td>
<td>0.337</td>
</tr>
<tr>
<td>2</td>
<td>0.038</td>
<td>0.098</td>
<td>0.171</td>
<td>0.244</td>
<td>0.464</td>
</tr>
<tr>
<td>3</td>
<td>0.013</td>
<td>0.036</td>
<td>0.067</td>
<td>0.142</td>
<td>0.308</td>
</tr>
<tr>
<td>4</td>
<td>0.018</td>
<td>0.053</td>
<td>0.103</td>
<td>0.182</td>
<td>0.385</td>
</tr>
<tr>
<td>5</td>
<td>0.095</td>
<td>0.225</td>
<td>0.385</td>
<td>0.453</td>
<td>0.845</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>150</td>
<td>0.140</td>
<td>0.340</td>
<td>0.586</td>
<td>0.837</td>
<td>1.000</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>322</td>
<td>0.180</td>
<td>0.451</td>
<td>0.779</td>
<td>0.820</td>
<td>1.000</td>
</tr>
<tr>
<td>Arithmetic Mean</td>
<td>0.120</td>
<td>0.300</td>
<td>0.523</td>
<td>0.580</td>
<td>0.959</td>
</tr>
</tbody>
</table>
5.0 CONCLUSION

In this paper, quality of VMS service was evaluated using the fuzzy approach. Generally, quality of service is a significant indicator in evaluating the performance of transportation facilities. However, it is difficult to measure because the quality of service that a human perceives is affected by various factors, and it is represented well in qualitative linguistic terms, but not quantitatively. Current approaches for evaluating the service quality of transportation facilities are limited because human thinking is subjective and complicated, and human perception cannot be represented by binary or numerical information. The proposed method makes numerical evaluation of service quality feasible. To apply this method, two fuzzy membership functions were determined through a survey. Many previous studies did not concentrate on the construction of the fuzzy. Membership functions, even though this is the most significant step for fuzzy applications. In this paper, the first membership function, which represents five scales of linguistic statements, was constructed using the interval estimation method. The second set of fuzzy membership functions, which represent the importance of the weight of six criteria for evaluating VMS service quality, were determined using eigenvector method. Quality of VMS service perceived by an individual driver was evaluated using the fuzzy weight average. A set of 322 quality measures were computed, and they were aggregated and transformed to one number using the arithmetic fuzzy mean. The defuzzified final value indicates the degree of satisfaction with VMS service that was perceived by the participating drivers. This value takes into consideration the variance of human perception and the degree of importance of the six criteria.

REFERENCES