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Research Article

Comprehensive Evaluation of Driver's Propensity Based on Evidence Theory

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Traffic safety is related closely with driver's physiological and psychological characteristics. And the influence on traffic safety is represented as driver's propensity. Evidence theory is introduced to the evaluation system of driver's propensity in this paper, and it is utilized to combine the expert opinions, which can eliminate unavoidable uncertain elements in the traditional appraisal methods. The appraisal problems of subjective index can also be resolved by this method in the appraisal system. Results show that the method is objective and reasonable, and driver's propensity can be evaluated effectively.

1. Introduction

Transportation is the fundamental industry, which plays an important role in the development of the national economy. However, with the progress of urbanization and the popularity of vehicle, the transportation problem is seriously increasing; road traffic accidents have decreased in China in recent years, but the trend of traffic environment deterioration has not been resolved fundamentally. The internal factor of the driver himself is one of the main factors causing traffic accidents [1–5]. According to the research of international and China domestic scholars, driver's physiological-psychological characteristics are related closely with traffic safety, and the influence of psychological characteristics on driver's behavior is more important than the physiological characteristics [6–10]. The differences of driving behaviors are caused by differences of driver's gender, age, driving age, driving experience, and personality. All the differences can be summarized as driver's propensity difference.

Therefore, the impact of driver's physiological-psychological characteristics on traffic safety performs primarily as driver's propensity [11].

Driver's propensity is driver's attitude towards the objective reality traffic situations under the influence of various factors. It shows the psychological characteristics of the corresponding decision-making tendencies and reflects driver's psychological emotional state in the process of vehicle operation and movement. At present, China domestic and international experts focus on driver's physical and mental comprehensive evaluation [12]. A variety of evaluation methods are put forward, such as multiple regression, discriminant function, and neural network evaluation system. Wang and Zhang [13–16] had researched preliminarily driver's tendency on special traffic scenes, such as free flow and car following; Feng and Fang had researched cluster analysis of drivers characteristics evaluation [10]; Chen et al. had researched subjective judgment of driving tenseness and control of vehicle motion [11]; Wang et al. had researched reliability and safety analysis methodology for identification of drivers' erroneous actions [12]; Cai and Lin had researched modeling of operators' emotion and task performance in a virtual driving environment [17]. However, it is very difficult to evaluate driver's propensity because of driver's psychological changes and individual differences. Therefore, the research difficulty is to find a more reasonable method of driver's propensity evaluation.

Evidence theory is proposed firstly by Dempster in 1967 and is further developed by Shafer in 1976 [18]. It is also known as the Dempster/Shafer evidence theory (D-S evidence theory), which belongs to artificial intelligence areas. Evidence theory is used in expert systems in early days and can deal with uncertain information. In evidence theory, the evidence is not the actual evidence, but is part of the person's experience and knowledge and the results of people's observation and research. It not only emphasizes the objectivity of the evidence, but also emphasizes the subjectivity of the evidence [19]. The core of DS evidence theory is evidence combination rules. It can deal with the synthesis problem of vague and uncertain evidence. The theory can be applied to multiple attribute group decision-making evaluation method with "evidence information." The driver's propensity with a comprehensive evaluation of various test indexes can be evaluated and the accuracy of driver's propensity diagnosis can be improved through evidence theory.

2. Evidence Theory

Evidence theory is based on the merger of the evidence and the update of belief function. Its uncertainty is described by the identify framework, basic probability assignment function, trust function, the likelihood function, correlation, and so forth.

2.1. Identify Framework and Basic Trust Distribution Function

Based on the probability, the event in probability theory is extended to proposition, the event sets are extended to the proposition sets, and then the corresponding relationship between the proposition and sets is established by the evidence theory. The uncertainty problem of the proposition is transformed into the uncertainty problem of the set by introducing the trust function. Assume that there is a problem that needs to be judgmed, the complete set of all possible answers to this problem is expressed by Θ. So, any concerned proposition corresponds to a subset of the Θ, Θ is the identify framework, and the selection of Θ depends on the level of knowledge and understanding.

Definition 2.1. Make Θ as a recognition framework, the basic trust distribution function m is a collection from subset 2^{Θ} to $[0,1]$, and A represents any subset of recognition framework Θ, $A \subseteq \Theta$, that meets

$$m(\emptyset) = 0,$$
$$\sum_{A \subseteq \Theta} m(A) = 1, \tag{2.1}$$

where $m(A)$ is called basic trust distribution function of event A, and it means that the trust level is the evidence for the A.

2.2. Combination Rule of Evidence

D-S combination rule responses to evidence combined effects, which combines the independent evidence information from different sources to produce more reliable evidence information. Assuming that E_1 and E_2 are two pieces of evidence at the identify framework, the corresponding basic trust distribution functions are m_1 and m_2, and focal element are $A_1, \ldots, A_k$ and $B_1, \ldots, B_l$, respectively, if

$$K = \sum_{A_i \cap B_j = \emptyset} m_1(A_i) m_2(B_j) < 1. \tag{2.2}$$

Then, these two groups of evidence can be combined and the combined basic probability assignment function m: $2^{\Theta} \rightarrow [0,1]$ meets

$$m(A) = \begin{cases} (1-K)^{-1} \sum_{A_i \cap B_j = A} m_1(A_i) m_2(B_j) & A \neq \emptyset, \\ 0 & A = \emptyset. \end{cases} \tag{2.3}$$

This is the famous D-S combination formula, where

$$K = \sum_{A_i \cap B_j = \emptyset} m_1(A_i) m_2(B_j). \tag{2.4}$$

It reflects the conflict coefficient among various evidences. The trust function given by m is called the orthogonal summation of m_1 and m_2, denoted by $m_1 \oplus m_2$.

3. Model Establishment

3.1. Multi-Index Evaluation Hierarchy Model

In order to improve the scientific nature of evaluation, the abstract goals are separated specifically into multilayered subobjectives. These sub objectives can be collectively referred to as indexes. Therefore, the object's evaluation can form a multilevel hierarchical structure of multi-index evaluation, the various evaluation indexes are synthesized from bottom to top, and the value of the evaluation objects is judged. Finally, the final evaluation results can be gotten. In the evaluation process, the corresponding weight needs to be established for each index, and the weight can be determined by expert judgment, which reflects the quantitative distribution of the relative importance of each index. Make relative weights of E_i as w_i $(i = 1, \ldots, r)$ and meet

$$\sum_{i=1}^{r} w_i = 1 \quad (w_1, \ldots, w_r \geq 0). \tag{3.1}$$

3.2. Discount Rate and Support Functions

The evidence theory usually uses the assumption of the identify framework Θ to undertake the uncertainty and also uses the support function to illustrate the uncertainty. But support functions may not reflect some special uncertainty of whole evidence, the uncertainty is α $(0 \leq \alpha \leq 1)$ for whole evidence, and the parameter α reflects the discount rate given by the decision makers for the indexes evaluation results, so the evaluation results are not fully convinced. Therefore, the evaluation results of key index can be made as a benchmark, if $w_k = \max\{w_1, \ldots, w_r\}$, then it is known as the key index.

Make $\beta_{kj}(1, \ldots, n)$ as the probability of the key index E_k at state Θ_j decision makers determined the extent to believe that the state Θ_j will occur under this value β_{kj}. Given the corresponding discount rate, that is, $m_{kj} = \alpha\beta_{kj}$ $(j = 1, \ldots, n)$, m_{kj}, is used to express the support degree or the trust degree produced by the key indexes of decision makers. For un-key indexes E_i, the probability is β_{ij} at the state Θ_j. Analogously, the support degree can be produced by the discount of β_{ij}. Owing to the importance degree of the relative key index, E_k relative to E_i is w_i/w_k, so the $(w_i/w_k)\alpha$ is regarded as discount rate, and the $m_{ij} = (w_i/w_k)\alpha\beta_{ij}$ $(j = 1, \ldots, n)$ is used to express the thesis support degree of the unkey index. Aimed at the multi-index comprehensive evaluation in the model of level results, a corresponding evidential reasoning model can be established, and the corresponding evidence synthesis method can get the comprehensive basic probability function.

3.3. Driver's Propensity Evaluation System

Combining the driver physiological-psychological indexes in the literature [19] and the relevant indicators of driver's propensity psychological questionnaire in the literature [20], driver's propensity evaluation system can be constructed (e.g., Table 1) and driver's propensity can be measured. The first layer is the target layer, the second layer is the property secondary index, and the third layer is the factor layer index.

3.4. D-S Evidence Reasoning Model and Solving Method

First, set evaluation level of each factor level index as extraversion propensity, intermediacy propensity, and introversion propensity. Then, establish the identify framework according to the evidence; experts of related areas give the uncertainty subjective judgment of the identify elements. Based on different experiences and observations, different experts get different evidences necessarily in the identify framework Θ and obtain the basic probability assignment function. Each basic probability assignment function is synthesized

Table 1: Measurement index and precision.

Goals	Properties	Factors
Driving propensity	Reaction judgment indexes	Reaction time Speed estimated Complex reaction judgment
	Driving control indexes	Accelerator pedal intensity Brake pedal braking force Steering wheel grip force
	Driving record indexes	Refueling frequency Lane change frequency Braking frequency

by the combination rule of evidence to the compound, and the results given are an evaluation state of driver's propensity.

4. Instance Analysis

According to the driver's propensity index evaluation system mentioned, make $E = \{E_1, E_2, E_3\}$ express attribute level, $E_1 = \{e_{11}, e_{12}, e_{13}\}$, $E_2 = \{e_{21}, e_{22}, e_{23}\}$, $E_3 = \{e_{31}, e_{32}, e_{33}\}$, $E_1 \sim E_3$ express factor collection, $\Theta = \{\theta_1, \theta_2, \theta_3\}$ express comment collection of extraversion propensity, intermediacy propensity, and introversion propensity. Using expert judgment method to establish the relative weight of the layers of indexes, property layer weight is a collection $W = (w_1, w_2, w_3) = (0.3, 0.3, 0.4)$, weight vector of factors collection E_1, E_2, E_3 is $V_1 = (v_{11}, v_{12}, v_{13}) = (0.34, 0.33, 0.33)$, $V_2 = (v_{21}, v_{22}, v_{23}) = (0.35, 0.40, 0.25)$, $V_3 = (v_{31}, v_{32}, v_{33}) = (0.42, 0.36, 0.22)$.

10 experts use the extraversion propensity, intermediacy propensity, and introversion propensity to evaluate the indexes, and the evaluation results are shown as follows:

$$R_1 = \begin{bmatrix} 0.2 & 0.8 & 0 \\ 0.1 & 0.8 & 0.1 \\ 0.1 & 0.9 & 0 \end{bmatrix}, \qquad R_2 = \begin{bmatrix} 0.1 & 0.8 & 0.1 \\ 0.2 & 0.8 & 0 \\ 0.3 & 0.7 & 0 \end{bmatrix}, \qquad R_3 = \begin{bmatrix} 0.2 & 0.7 & 0.1 \\ 0.1 & 0.8 & 0.1 \\ 0 & 0.8 & 0.2 \end{bmatrix}. \tag{4.1}$$

Among them, the matrix R_1 expresses that in the three factors of the property, "reaction judgment indexes," through the evaluation of "reaction time," the driver belongs to "extraversion propensity" by two experts, "intermediacy propensity" by eight experts, and "introversion propensity" by zero experts; through the evaluation of "speed estimate," the driver belongs to "extraversion propensity" by one expert, "intermediacy propensity" by eight experts, and "introversion propensity" by one expert; through the evaluation of "complex reaction judgment," the driver belongs to "extraversion propensity" by one expert, "intermediacy propensity" by nine experts, and "introversion propensity" by zero experts. The remaining two matrices have the same meaning. Now, take "reaction judgment indexes," for example, the evaluation of its driver's propensity is given in the calculation steps of evidential reasoning model. The evaluation information is shown in Table 2.

Transform the evaluation information of e_{11}, e_{12}, e_{13} into the basic probability assignment on the Θ. According to the relative weights between the factors, take $\alpha_1 = 0.8$ as

Table 2: Evaluation information of "reaction judgment indexes."

Factor	Weights	Extraversion propensity	Intermediacy propensity	Introversion propensity
e_{11}	0.34	0.2	0.8	0
e_{12}	0.33	0.1	0.8	0.1
e_{13}	0.33	0.1	0.9	0

the discount rate of the key factor e_{11}, the discount rate of the nonkey factor is $(e_{12}/e_{11})\alpha_1 = 0.776$, and the discount rate of e_{13} is $(e_{13}/e_{11})\alpha_1 = 0.776$, then 3 basic probability assignments can be gotten. The synthetic results are shown in Table 3.

The synthesis results of E_2 and E_3 (the discount rate of the key factor was 0.8 and 0.9) are shown in Table 4.

Table 4 can be seen as an expert evaluation information matrix of the attribute set $E = \{E_1, E_2, E_3\}$, then transform it to basic probability assignment in the Θ and synthesize (the discount rate of the key factor is 1). The synthesis results are shown in Table 5.

The synthesis results show that, the support degree of extraversion propensity evidence is about 0.7% through evaluating object, intermediacy propensity is about 98.8%, and introversion propensity is about 0.4%. If the uncertainty is eliminated, driver's propensity can be identified as intermediacy in theory.

5. Comparison of Evidence Synthesis Rules and Fuzzy Evaluation Method

For $E_1 = \{e_{11}, e_{12}, e_{13}\}$, its weight vector is $V_1 = (v_{11}, v_{12}, v_{13}) = (0.34, 0.33, 0.33)$, the comprehensive evaluation result of E_1 is $B_1 = V_1 R_1 = (0.134, 0.833, 0.033)$, and with the same reason, the comprehensive evaluation results of E_2 and E_3 are B_2 and B_3, denoted as

$$R = \begin{bmatrix} B_1 \\ B_2 \\ B_3 \end{bmatrix} = \begin{bmatrix} 0.134 & 0.833 & 0.033 \\ 0.19 & 0.775 & 0.035 \\ 0.12 & 0.758 & 0.122 \end{bmatrix}, \tag{5.1}$$

then $B = WR = (0.1452, 0.7856, 0.0692)$, B is the comprehensive evaluation result. The driver's propensity type is intermediacy according to the principle of maximum membership. It is the same as the result gotten by evidence theory reasoning mode. Because the fuzzy comprehensive evaluation is considered widely to be intuitive and reasonable, evidence theory reasoning model is verified to some extent.

6. Conclusion

Relationship between subgoals and overall goals is an inclusion relationship in fuzzy model, but in the evidence theory it is a "support" relationship, and subgoals are the support evidence. Obviously, evidence theory has a wider application range and more flexible application. In particular, the advantages of evidence theory can be better reflected when the individual property state is uncertain or unknown. In addition to the complete conflict, expert opinions cannot be synthesized by D-S theory, and other things can get better results.

Table 3: Synthesis conditions of "reaction judgment indexes" mass function.

Information source	Mass function	θ_1	θ_2	θ_3	Θ
e_{11}	m_{11}	0.16	0.64	0	0.2
e_{12}	m_{12}	0.0776	0.6208	0.0776	0.224
e_{13}	m_{13}	0.0776	0.6984	0	0.224
Synthesis	M_1	0.0333	0.9468	0.0051	0.0148

Table 4: Properties mass function.

Factors	Weights	Extraversion propensity	Intermediacy propensity	Introversion propensity	Θ
E_1	0.3	0.0333	0.9468	0.0051	0.0148
E_2	0.3	0.0835	0.8619	0.0103	0.0443
E_3	0.4	0.0539	0.8873	0.0392	0.0196

Table 5: Properties mass function synthesis situation.

Information source	Mass function	θ_1	θ_2	θ_3	Θ
E_1	M_1	0.025	0.7101	0.0038	0.2611
E_2	M_2	0.0626	0.6464	0.0077	0.2833
E_3	M_3	0.0539	0.8873	0.0392	0.0196
Synthesis		0.007	0.9875	0.0037	0.0018

Through establishing the identify framework, evidence theory is used to determine the basic probability assignment function; the qualitative "reaction judgment indexes, driving control indexes, and driving record indexes" are transformed into quantitative state. According to the different weights, the state of each index as well as the evaluation results of the experts is synthesized with combination rules, then the driver's propensity by the synthesis function *mass* is determined. Aimed at the limitations of the experts, the evidence theory is used to study the uncertainty problem in this paper. The results show that the trust function constructed in this paper expresses uncertainty and obtains more accurate, reliable, and objective evaluation results.

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