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Methods for describing different results obtained from different methods in accident reconstruction

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ABSTRACT

There is always more than one method can be employed to reconstruct a traffic accident and then more than one result can be obtained. How to describe these different results becomes an issue. Two solutions were given, the first is to fuse different results to one result, while the other is to rank different results according to their credibility. Methods based on the Ordered Weighted Averaging (OWA) operator and Uncertain Ordered Weighted Averaging (UOWA) operator were proposed to fuse different certain results and different interval results to one result, respectively. And methods based on the Combination Weight Arithmetic Average (CWAA) and OWA operators were proposed to rank different certain or interval results. Finally, a true vehicle-motorcycle accident was given to demonstrate these proposed methods, results showed that all methods work well in practice. If the calculation uncertainty was not considered, the fused result 64.56 km/h and a ranked vector can be obtained; if the calculation uncertainty was considered, the fused result [62.13, 68.13]km/h and a ranked interval number set can be obtained. Because that all final results were obtained by employing widely used mature operators, they deserve to be trusted. The research provides more reliable choices to describe different results obtained from different methods in accident reconstruction.

1. Introduction

The basic ideal of accident reconstruction is to deduce the whole process of a traffic accident based on traces left at the accident scene [1]. Results obtained from accident reconstruction not only can be applied in the field of forensic science [2–4], but also can be applied in the field of traffic safety [5–8]. This leads to a large number of scholars dedicated themselves to the field of accident reconstruction.

Scholars had proposed at least five kinds of methodology to describe the relationship between the reconstructed result and traces left at the accident scene. The first one includes methods based on theory and/or empirical formulas. Common methods include models based on the braking distance [1,9], the throw distance of the pedestrian [9–11], the deformation of the involved vehicle [12,13] and the injury of the human body [14–16]. The second one includes methods based on simulation software, such as the Pc-Crash [17,18] or other kinds of software [19]. The third includes methods based on true vehicle tests. In some cases, in order to know more information about the accident, true vehicle tests will be conducted according to information obtained from the accident scene. The fourth includes methods based on information obtained from video or images [20,21] and the fifth includes methods based on information obtained from car recording tools, such as Event Data Recorder (EDR), Black Box, GPS and Residual Speedometer [22–25].

Obviously, such many methods do help users to obtain a more credible reconstructed result, because that more suitable methods can be selected when they reconstruct an accident. But no one in the field dare to say that the result obtained by one method is the absolutely right one. The only thing users can do is to conclude which result is the best one according to their experience.

Under such condition, in order to enhance their confidence, users usually like to reconstruct an accident by employing more than one method. Such as Ref. [26], 4 methods were employed and 5 results, which are 28.63 m/s, 16.83 m/s, 24.78 m/s, 24.44 m/s and 23.33 m/s, were obtained. Another typical case is a report in China [27] (the conclusion of the report and the corresponding translation can be found in Appendix A), 3 methods were

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employed to reconstruct an accident and finally a result "about 106 km/h" was obtained. The question is how was the result "about 106 km/h" obtained? This means that if users employed more than one method to reconstruct an accident and then how to describe those obtained results becomes a practical problem.

Critics may say that how to describe different results obtained from different methods is not a problem because that if there are enough traces and then users can employ cross-validation methods [28] to delete those wrong results. After that, it is easy to obtain a final result, such as the average of all obtained results. The problem is that the cross-validation method will work if there are some wrong traces/results in a case, but it may not work if there are only some uncertain traces/results. The case in Ref. [26] can be taken as an example, considering that the absolutely right situation of the accident is not know, experts may conclude which one is the best one and/or which one is the worst one, but it is a little hard for they to conclude which one is the wrong one. To say the least, even if some wrong results were deleted, the left two results, 24.44 m/s and 23.33 m/s which are the closest to the truth [26] and were obtained from the EDR Data and Speedometer respectively, are different. This means that how to describe different results is still a problem.

Obviously, it is not hard to describe different results obtained from different methods. The case in Ref. [26] can be selected as an example again. If only one final result is needed, and then the average 23.89 m/s or the interval [23.33, 24.44]km/h or "about 23.89m/s" or another arbitrary result "about 23.45 m/s" can be given. Considering that plenty of work had done to obtain these different results, reliable methods for describing different results deserves to be studied and the study will be meaningful.

2. Problem description

No matter how complicated an accident reconstruction model is, its expression can be given as

$$Y = f(X) \tag{1}$$

where Y is the accident reconstruction result, often refers to the reconstructed velocity and/or the impact position. X is traces involved in the accident, such as braking distance of the vehicle. f is a selected accident reconstruction model.

Because that there are a large number of methods can be employed, in order to enhance their confidence or other reasons, users always like to reconstruct an accident with more than one method. Supposing that s methods are employed to reconstruct a traffic accident,

$$Y_i = f_i(X), \text{ where } i = 1, \ldots, s \tag{2}$$

And then s reconstructed results Y_i will be obtained. How to describe Y_i becomes a practical and valuable problem.

Significantly, it is inconvenient to give out the final result as "the reconstructed result of the accident is Y_i according to the ith method". Two solutions will be given here.

The first solution is to fuse different results to one final result G.

$$G = g(Y_i),\ i = 1, \ldots, s \tag{3}$$

The second solution is to rank different results according to their credibility. The result can be given as an H

$$H = \{Y_j\} \quad \text{where } P(Y_{j+1}) > P(Y_j),\ 1 \le j \le s-1 \tag{4}$$

Where $P(Y_{j+1}) > P(Y_j)$ means the Y_{j+1} is more credible than Y_j. Here, the credibility is only a number describe the degree that how users/experts trust the result.

3. A method based on the OWA operator for fusing different certain results

If all reconstructed results are certain, and then a method based on the Ordered Weighted Average (OWA) operator can be proposed. The OWA operator was first introduced by Yager [29,30] as a tool to deal with the problem of aggregating multi-criteria to form an overall decision function. And then the OWA had received great attention and had been successfully applied in many domains, such as decision making, data mining and fuzzy system [31–34]. Obviously, the introduce of such a widely employed operator will make the proposed method reliable.

3.1. A brief introduction of the OWA

Suppose that OWA $:R^n \to R$, if

$$\text{OWA}_w(\alpha_1, \ldots, \alpha_n) = \sum_{j=1}^{n} w_j b_j \tag{5}$$

where $w = (w_1, \ldots, w_n)$ is weighting vectors related to OWA, $w_j \in [0, 1]$, $j \in N, \sum_{j=1}^{n} w_j = 1$; b_j is the jth elements of $(\alpha_1, \ldots, \alpha_n)$ in order from big to small; R is the set of all real numbers. And then the function OWA_w is named as the OWA operator.

3.2. Steps of the method

Step 1. To evaluate by experts. As for n results $(u_1, \ldots, u_n)$ obtained from n methods, m experts are invited to evaluate these results and give a mark. It should be noted that the expert only needs to give out a mark but do not need to rank these obtained results. All experts are recorded as D_k, where $k = 1, \ldots, m$. According to experts' marks, an evaluation matrix R can be given as Table 1.

Step 2. To confirm the w in Eq. (5). The method [35] based on combination number will be introduced here to confirm the w. Steps of the method are: firstly, the data $(\alpha_1, \ldots, \alpha_n)$ were ranked as a descending order to obtain the b_j, where $j = 0, \ldots, n-1$ and $b_0 > b_1 > \ldots > b_{n-1}$; and then the weight w_{j+1} of b_j can be calculated by Eq. (6).

$$\begin{aligned} w_{j+1} &= C_{n-1}^{j} / 2^{n-1}, j = 0, 1, \ldots, n-1 \\ C_{n-1}^{j} &= (n-1)!/j!(n-1-j)!, j = 0, 1, \ldots, n-1 \end{aligned} \tag{6}$$

Step 3. To calculate the integrated attribute value of each reconstructed result. After Steps 1 and 2, the integrated attribute value of an arbitrary result can be calculated by Eq. (7).

$$\begin{aligned} c_1 &= \text{OWA}_w(\alpha_{11}, \ldots, \alpha_{m1}) = \textstyle\sum_{j=1}^{n} w_j b_{j1} \\ &\ldots \\ c_n &= \text{OWA}_w(\alpha_{1n}, \ldots, \alpha_{mn}) = \textstyle\sum_{j=1}^{n} w_j b_{jn} \end{aligned} \tag{7}$$

And then the aggregation matrix R_j can be given as Table 2.

Step 4. To normalize the aggregation matrix. The integrated attribute value can be normalized by Eq. (8).

$$g_i = c_i / \sum_{i=1}^{n} c_i, (i = 1, \ldots, n) \tag{8}$$

And then a normalization matrix R_r can be given as Table 3.

Table 1
Evaluation matrix R.

	u_1	...	u_n
D_1	α_{11}	...	α_{1n}
...	...	...	...
D_m	α_{m1}	...	α_{mn}