Forensic Science International 263 (2016) 27–38

Contents lists available at ScienceDirect

Forensic Science International

journal homepage: www.elsevier.com/locate/forsciint

Calculation reliability in vehicle accident reconstruction

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ARTICLE INFO

Article history:
Received 24 September 2015
Received in revised form 11 March 2016
Accepted 16 March 2016
Available online 26 March 2016

Keywords:
Reconstruction of vehicle accidents
Calculation reliability
Calculation uncertainty
Bayesian networks
Collision location
Daubert standard

ABSTRACT

The reconstruction of vehicle accidents is subject to assessment in terms of the reliability of a specific system of engineering and technical operations. In the article [26] a formalized concept of the reliability of vehicle accident reconstruction, defined using Bayesian networks, was proposed. The current article is focused on the calculation reliability since that is the most objective section of this model. It is shown that calculation reliability in accident reconstruction is not another form of calculation uncertainty. The calculation reliability is made dependent on modeling reliability, adequacy of the model and relative uncertainty of calculation. All the terms are defined. An example is presented concerning the analytical determination of the collision location of two vehicles on the road in the absence of evidential traces. It has been proved that the reliability of this kind of calculations generally does not exceed 0.65, despite the fact that the calculation uncertainty itself can reach only 0.05. In this example special attention is paid to the analysis of modeling reliability and calculation uncertainty using sensitivity coefficients and weighted relative uncertainty.

1. Introduction

The reconstruction of a road vehicle accident is a multi-faceted engineering task and can be understood as a reverse engineering operation, designed to reconstruct the cause of an event and its course. It requires not only a wide knowledge of various technical areas, but also the skills to analyze research results from other fields of natural sciences (toxicology, forensic genetics, medicine, etc.). Results of reconstruction are assessed in terms of the reliability of a particular system of engineering operations.

The process of accident reconstruction includes the following steps:

(a) analysis of the facts and creation of a data set $\mathbf{D} = \{\mathbf{D}_1, \ldots, \mathbf{D}_i, \ldots \mathbf{D}_n\}$, where $\mathbf{D}_i$ is any subset of all the physical evidence gathered at the scene of accident;
(b) analysis of testimony of witnesses;
(c) identification of subsystems (i.e. elementary tasks) $f_i = f_i(x_p, \ldots, x_q)$, $i = 1, \ldots, m$, where $x_p, \ldots, x_q$ are variables (attributes of a subsystem);
(d) reconstruction of subsystems $f_{i_0} = f_i(d_p, \ldots, d_q)$, $i = 1, \ldots, m$, that is the calculation of the value of function $f_i(x_p, \ldots, x_q)$ at point $\mathbf{D}_i = \{d_p, \ldots, d_q\}$;
(e) reconstruction of the whole system (accident), that is integration of partial information and the course of events during the accident, which allows the expert to take a deeper look into the cause-and-effect relationships;
(f) formulation of conclusions (and sometimes recommendations).

From the perspective of accident reconstruction as a technical process what is of particular importance is the uncertainty of calculation results, i.e. the band in which the result is expected. It reflects in a rich source of literature focused on such issues such as:

– general scheme of uncertainty analysis methods [1];
– uncertainty of measurements performed at the accident scene [2];
– perception of obstacles, time to collision and driver reaction time [3,4];
– application of the total differential in its various forms [5,6];
– parametric sensitivity to uncertainty [6–8];
– uncertainty of the critical speed formula [9,10];
– conditional probability and Bayesian uncertainty analysis [11–13];

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http://dx.doi.org/10.1016/j.forsciint.2016.03.038

– modeling uncertainty of the tire in programs for simulation of vehicle motion dynamics [14];
– Monte Carlo method [7,8,15,16];
– design of experiments [17,18];
– analysis of hypotheses using Bayesian networks [19] and likelihood ratio [20];
– verification of programs for simulation of vehicle dynamics including partial systems (e.g. steering, drivetrain, suspension, ABS, ESP) [21–23];
– modeling uncertainty of collision [24];
– uncertainty of transformation of data recorded by EDR (Event Data Recorder) [25];
– incidents/accidents analysis in terms of improving traffic safety and accident prevention [13].

The uncertainty of calculations results or analysis in other areas of natural sciences in the popular meaning is often considered to be synonymous with the accuracy of traffic accident reconstruction. However, it is only one of the important but not crucial components. That is why in [26], a formalized concept of the reliability of vehicle accident reconstruction, as a structure defined using Bayesian networks, was introduced.

The aim of the current article is to analyze the term of *calculation reliability* in the vehicle accident reconstruction. The scope of the article covers defining the *calculation reliability* and its components together with an example with discussion and conclusions. In order to better understand the broader context of this term, an expanded definition of reconstruction reliability is proposed in Appendix.

2. Bayesian networks

Since in what follows conditional probability and Bayesian networks (BN) will be used, it is necessary to give a short introduction. A comprehensive description of the BN theory is beyond the scope of this article, but can be found in many works, e.g. [27,28]. In brief:

Bayesian network (belief network) is a probabilistic directed acyclic graphical structure, whose nodes represent random variables X_q and edges represent the direct relationships between them. For each node X_q a conditional probability table (CPT) given immediate parents X_{pa_q} is defined. The values in CPT are assessed on the basis of relevant databases or experience of the person creating the network. In Fig. 1 a simple general network consisting of $n = 3$ nodes is presented, together with the basic terms, which allows calculation of the probability of good humor given the weather and promotion at work.

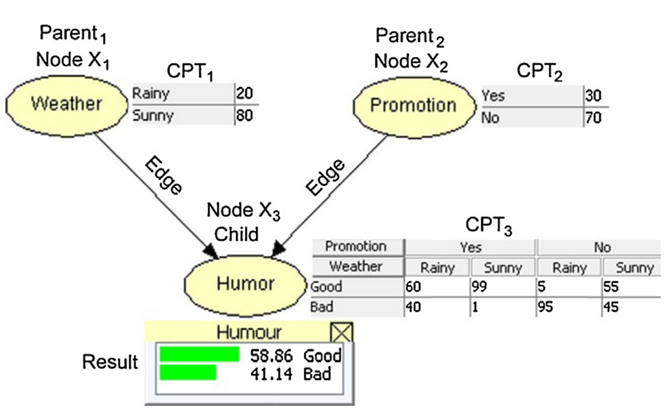

Fig. 1. Example of an elementary BN and basic terms.

Complex networks are built from elementary structures representing serial, converging or diverging direction of inference. A BN must meet the so-called Markov properties: there are no direct dependencies in the system modeled which are not already explicitly shown via arcs. The most general form of the joint distribution consistent with all properties of the graph is represented by the formula

$$P(X_1, \ldots, X_n) = \prod_{q=1}^{n} P(X_q | X_{pa_q}), \tag{1}$$

where $X_{pa_q} \subset \{X_1, \ldots, X_{q-1}\}$ – nodes (variables) which are direct parents of nodes X_q.

3. Calculation reliability

Definition 1. *Calculation reliability* $\rho_i^{(c)}$ is the probability that in a particular case the model (method) gives a true result given known modeling reliability $\rho_i^{(m)}$, adequacy of the model $\rho_i^{(a)}$ and relative uncertainty of the calculation u_i

$$\rho_i^{(c)} = P(X_4), \quad i = 1, \ldots, m \tag{2}$$

It is defined in Fig. 2 by means of a BN, where the events are referred to as:

X_1 model;
X_2 model applied to solve the particular problem at hand;
X_3 data;
X_4 calculation;and their probabilities are:
$\rho_i^{(m)} = P(X_1)$ which is modeling reliability;
$\rho_i^{(a)} = P(X_2)$ which is the adequacy of the model;
$u_i = P(X_3)$ which is the relative calculation uncertainty;
$\rho_i^{(c)} = P(X_4)$ which is the calculation reliability.

Definition 2. *Modeling (or method) reliability* of an *i*th subsystem is the conditional likelihood that the use of the model would give the result *E*, if the true value of the calculated (or measured) quantity was *H*

$$\rho_i^{(m)} = P(E|H, I), \quad i = 1, \ldots m, \tag{3}$$

where *I* denotes the surroundings (context) information. Note that in the process of validation the *H* value is regarded as the perfect value. *Modeling reliability* can be calculated using the formula

$$\rho_i^{(m)} = 1 - \Delta M_i, \quad i = 1, \ldots, m \tag{4}$$

where ΔM_i is the modeling uncertainty defined as follows:

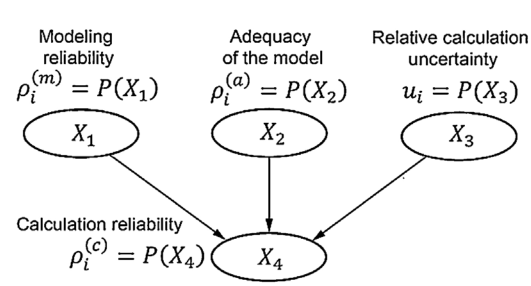

Fig. 2. Definition of the subsystem calculation reliability by means of BN.