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Structural reliability of road accidents reconstruction

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ABSTRACT

Reconstruction of road accidents combines objective and subjective action. The former concerns science, the latter assessment of human behavior in the context of objective findings. It is not uncommon for experts equipped with an arsenal of tools to obtain similar results of calculations, but to present radically different conclusions about the cause of the accident. The use of sophisticated methods of uncertainty analysis does not guarantee improvement in quality of reconstruction, because, increasingly, the most serious source of reduced reliability of reconstruction is problems in logical inference. In the article the structure of uncertainty and reliability of accident reconstruction was described. A definition of reliability of road accident reconstruction based on the theory of conditional probability and Bayesian network, as a function of modeling, data and expert reliability (defined in the text) was proposed. The uncertainty of reconstruction was made dependent only on the uncertainty of the data. This separation makes it possible to conduct a qualitative and quantitative analysis of reconstruction reliability and to analyze its sensitivity to component parameters, independently of the uncertainty analysis. An example of calculation was presented. The proposed formalism constitutes a tool helpful to explain, among other things, the paradox of reliable reconstruction despite its uncertain results or unreliable reconstruction despite high precision of results. This approach is of great importance in the reconstruction of road accidents, which goes far beyond the analysis of a single, homogeneous subsystem.

1. Introduction

Reconstruction of a road accident is a number of activities designed to discover the scenario of the accident. A written report containing the description of the accident reconstruction, sometimes expanded to include additional analysis (e.g. recommendations) will be referred to as an "expert opinion" ("opinion" for short). It can be commissioned by various institutions, for example a court of justice, a government agency for transportation safety, a commission examining the cause of a catastrophe, an insurance company, etc.

In common opinion, the accuracy of calculations is a synonym of reconstruction correctness, which, as a rule, is big simplification. Undoubtedly, the accuracy of calculations has a profound impact on the correctness of reconstruction, but also the calculations themselves can be relatively easily verified. It can be noted that the use of increasingly sophisticated methods of error analysis does not guarantee improvement in quality of reconstruction, because what is a more and more important source of degradation in reconstruction/opinion reliability is problems of logical nature. The authority ordering the opinion often faces completely different difficulties. Having a few reports on the same case, but with completely divergent conclusions, it must assess which of them is more credible, if e.g.

– they differ in calculation uncertainty level (is the opinion in which only a single "exact" result of calculation was presented a "better" one, or one which takes into account the uncertainty?),
– or the results of objective analyses (i.e. concerning the natural sciences, including calculations with tolerance bands) are similar,
– or different methodology (e.g. mathematical models, simulation programs) was used etc.

It turns out that the calculation uncertainty itself is not sufficient to make the right choice and it is necessary to assess the reliability of the reconstruction/opinion.

Because reliability is the fundamental feature of the reconstruction/opinion from the standpoint of the court or another orderer, it seems advantageous to create a structural model of reliability of road accident reconstruction, which would allow both its formal description and quantitative analysis.

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Notation

F	set of subsystems
D	set of data–all evidences collected at the accident scene
$\mathbf{D}_i$	subset of data concerning *i*th subsystem
W	set of versions and/or hypotheses
f_i	function representing the *i*th subsystem
f_{i_0}	reconstruction of the *i*th subsystem (e.g. result of calculation)
F_0	reconstruction of the entire system (i.e. an accident)
$x_p,\ldots,x_q$	variables specific to the *i*th subsystem
τ_i	actual state
Δf_{i_0}	uncertainty of the *i*th subsystem
$\Delta f_{i_0}^{(rel)}$	relative uncertainty of the *i*th subsystem
ΔF_0	uncertainty of reconstruction of the entire system (i.e. an accident)
$\Delta\mathbf{D}$	set of data uncertainty containing all evidences
$\Delta\mathbf{D}_i$	subset of data uncertainty concerning *i*th subsystem
$\Delta\mathbf{M}$	set of modeling uncertainty
ρ_i	reliability of the *i*th subsystem reconstruction
$\rho_i^{(m)}$	modeling reliability of the *i*th subsystem
$\rho_i^{(d)}$	data reliability of the *i*th subsystem
$\rho_i^{(e)}$	expert reliability
ρ	reliability of the entire system reconstruction (i.e. an accident)
$P(A\vert B)$	conditional probability of event *A* given event *B*

2. Aim and scope of the article

The aim of the study is to define the reliability of accident reconstruction in formal terms and construction of its structural model.

The scope covers:

- description of the structure of accident reconstruction,
- description of the structure of uncertainty and reliability of accident reconstruction,
- definition of reliability of accident reconstruction,
- example.

3. Structure of road accident reconstruction

The process of creating an expert opinion includes the following stages:

(a) analysis of data (i.e. traces and other objective evidence),
(b) analysis of evidence,
(c) formulation of hypotheses or identifying various optional versions,
(d) reconstruction of the accident,
(e) linking partial information,
(f) verification of hypotheses/versions,
(g) analysis of possibilities of accident avoidance,
(h) formulation of conclusions.

The structure of accident reconstruction, including the description of sources of uncertainty in each stage, has been characterized in [1]. In short,

Analysis of data refers to objective evidence and to creation of a set of data

$$\mathbf{D} = \{\mathbf{D}_1, \ldots, \underbrace{\mathbf{D}_i}_{\substack{\{d_p,\ldots,d_q\} \\ \text{any subset}}}, \ldots, \mathbf{D}_s\}, \tag{1}$$

where e.g.: $\mathbf{D}_1$: photographic documentation of the accident scene, $\mathbf{D}_2$: inventory of all traces (measurements), $\mathbf{D}_3$: documentation of vehicles damage, $\mathbf{D}_4$: biological traces, $\mathbf{D}_5$: documentation of injuries, $\mathbf{D}_6$: throw distance of the pedestrian. As can be seen, $\mathbf{D}_i$ can correspond to both a set of data unique to *i*th subsystem (for example $\mathbf{D}_2 = \{d_k,\ldots,d_l\}$) and an exact value (for example $\mathbf{D}_6 = d_6$).

The next step is separating of subsystems $f_1,\ldots,f_m$, i.e. elementary tasks to be performed, and creation a set out of these

$$\mathbf{F} = \{f_1, \ldots, f_m\}, \tag{2}$$

where e.g.: f_1: photogrammetric transformation of snapshots, f_2: analysis of the mechanism of tire damage, f_3: analysis of the mechanism of collision, f_4: analysis of vehicle dynamics, f_5: analysis of DNA.

Analysis of testimony allows extraction of versions given by witnesses or formulation of a set of hypotheses about the course of events.

$$\mathrm{W} = \{w_1, \ldots, w_h, \ldots, w_s\}. \tag{3}$$

where $w_1,\ldots,w_h$: hypotheses; $w_{h+1},\ldots,w_s$: versions.

Reconstruction of a road accident is its recreation and describing its scenario, which consist of:

- reconstruction of subsystems,
- analysis of uncertainty,
- linking of information and formulation of conclusions for the entire system (the course and causes of the accident).

3.1. Reconstruction of subsystems

Reconstruction of a single subsystem f_i, $i = 1,\ldots,m$ can be compared to a laboratory examination which separated from the overall context does not have a complete picture of the events.

Let the function $f_i : \mathbb{A}_i \supset D \rightarrow \mathbb{B}_i$, $i = 1, \ldots, m$ denoting the *i*th subsystem be given by the formula

$$f_i = f_i(x_p, \ldots, x_q), \tag{4}$$

where **D**: domain; $\mathbb{A}_i$: domain of variables of the *i*th subsystem, generally covering different areas of knowledge; $\mathbb{B}_i$: domain of response of the *i*th subsystem; $x_p,\ldots,x_q$: variables specific to the *i*th subsystem (attributes of subsystem f_i).

The term *function* used has a wide range of meanings, it may be a simple formula, a complex numerical model, the analysis of a biological process, a logical structure etc.

Reconstruction of the ith subsystem is the value of function $f_i(x_p,\ldots,x_q)$ for the subset of data $\mathbf{D}_i = \{d_p, \ldots, d_q\}$

$$f_{i_0} = f_i(d_p, \ldots, d_q), \quad i = 1, \ldots, m, \tag{5}$$

i.e. result of calculation, orthophotomap, result of laboratory analysis etc. The attribute of f_{i_0} is uncertainty Δf_{i_0}, $i = 1,\ldots,m$.

3.2. Linking partial information

Only after obtaining $f_{i_0}, i = 1, \ldots, m$ it is possible to take a comprehensive look at the cause of the accident and formulation of conclusions by integration of information, verification of versions/hypotheses and analysis of possibilities of accident avoidance. It allows going deeper into the cause-and-effect relationships.