

Measurement of dangerous traffic conditions through driving dependability analysis

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This paper presents a concept of driving dependability analysis based on driver specific error-inducing behaviors in various information processing stages, using database of bus drivers to measure dangerous traffic conditions. Formalized expert judgment method based on fuzzy sets was applied to determine variability of driving behaviour under traffic accident conditions. Based on case study conducted, it effectively predicted effect of driving errors on road traffic safety in quantitative and qualitative terms.

Keywords: Bus drivers, Driving dependability, Driving errors, Traffic accidents

Introduction

Majority (90-95%) of traffic accidents involves some driver-related factors¹⁻⁵. Much difficulty in properly modeling traffic accidents involves defining driving errors^{6,7}. Many traffic accident studies and databases offer only fuzzy descriptions of driving errors, but a proper delineation of possible driving errors requires a thoroughly theoretical understanding of driver information process and its limits in traffic system. As bus company in all cities is strictly managed and control by road and traffic regulating authorities, there is enough data of accidents records and reports for a better analysis of human factors contributing to traffic accidents⁸⁻¹⁰.

This study analyses driving error database of a bus company to quantitatively relate between traffic accidents rate and driving errors using formalized expert judgment method based on fuzzy sets.

Experimental

Driving Dependability Analysis Method (DDAM)

In traffic operation, driving involves a sequential process of perceiving and responding to traffic situation,

based on driver's knowledge and goals. For example, a steering input or brake application results dynamic changes in traffic situation (Fig. 1). Driving error refers to deviation between driving task required to be carried out at a given moment and dynamic response of driver during specified driving period in driver-vehicle-road environment system. Deviation may result in consequences of varying severity, ranging from essential harm to catastrophic accidents. Mathematically, driving error can be quantified by relative frequency of incorrectly accomplished driving tasks.

According to causation classification of driver error-inducing behaviors, driving errors can be categorized in three specific types [perception error (PE), decision making error (DE), and execution error (EE)]. PE is inappropriate traffic information acquisition and mistakes in evaluating a traffic situation. DE represents outcome of a number of problems including application of an inappropriate rule, lack of appropriate knowledge. EE involves inability to achieve a planned response for controlling or operating vehicle. Driving dependability is probability of performing a certain driving requirement at a specified period of time under a given set of traffic conditions.

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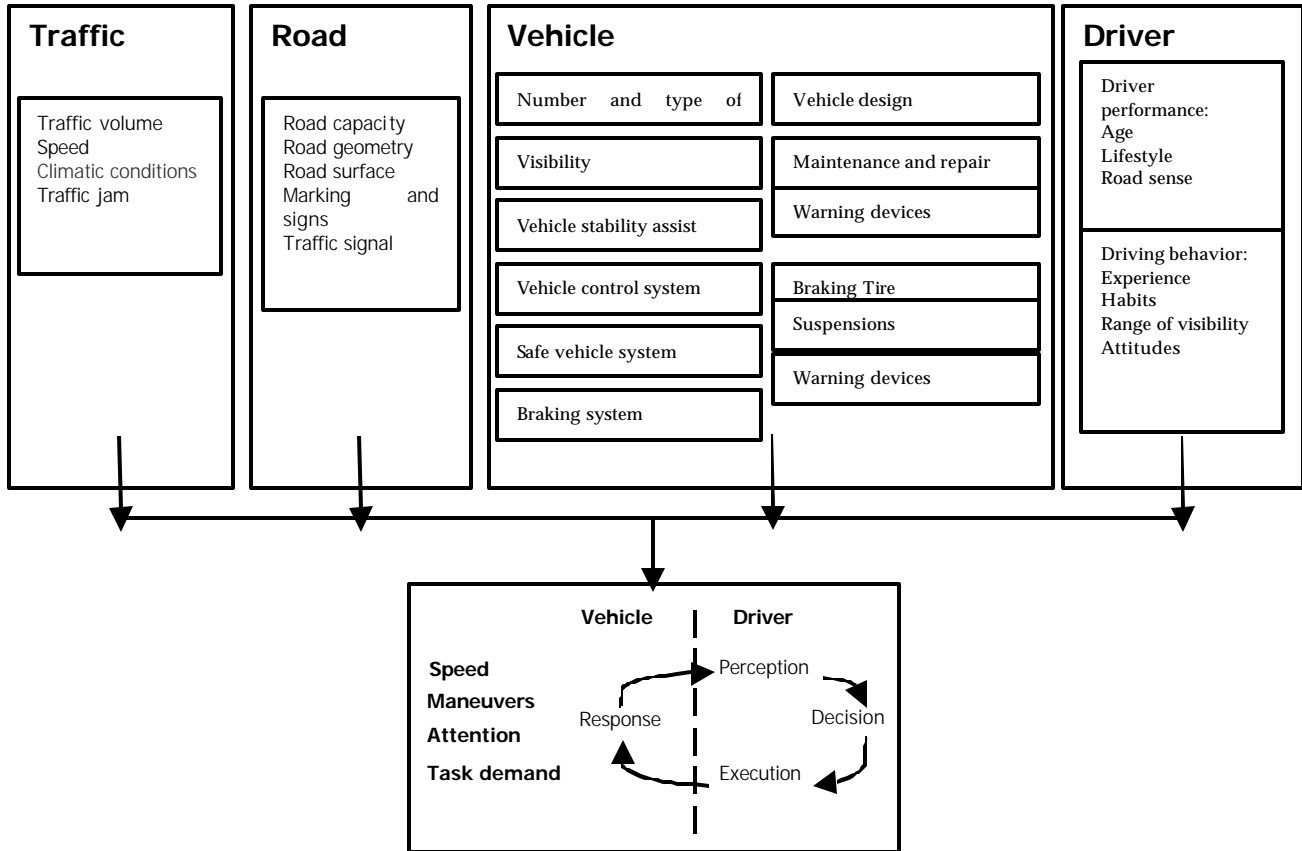


Fig. 1— Vehicle, road, driver and traffic conditions as contributing factors for shaping driving behaviour

Error-based Driving Dependability Model

Since driving errors by expert assessment are defined as theoretic driving errors in present study, quantitative analysis of driving errors in real world driver-vehicle-roadway environmental system would relate to key driving behaviour shaping factors (DBSFs). Consequently, identification of driving error mechanisms will help to understand driving internal behavioural process and to analyze notable impact of key DBSFs upon likelihood of driving errors in a specified driving task. From fundamentals of driving dependability analysis, probability of errors during perception stage (F_s), decision-making stage (F_o) and execution stage (F_R) can be calculated through multiplying theoretic probability of driving errors by measured values of DBSFs during F_s , F_o and F_R stages, respectively, as

$$\begin{aligned}
 F_s &= F'_s \times k_s \\
 F_o &= F'_o \times k_o \\
 F_R &= F'_R \times k_R
 \end{aligned}
 \dots(1)$$

where k_s , k_o and k_R are driving behaviour shaping factors scale of perception, decision-making and execution stage, respectively⁹.

Reliability of perception (R_s), decision-making (R_o) and execution stage (R_R) are complement of probability of driving errors in interrelated stages, as

$$\begin{aligned}
 R_s &= 1 - F'_s \times k_s \\
 R_o &= 1 - F'_o \times k_o \\
 R_R &= 1 - F'_R \times k_R
 \end{aligned}
 \dots(2)$$

Driving behaviour is a series system consisting of three stages from the view on reliability engineering. These stages are statistically independent to each other. Driving dependability (D) can be calculated as

$$\begin{aligned}
 D &= R_s \cdot R_o \cdot R_R = (1 - F'_s \times k_s) (1 - F'_o \times k_o) \\
 &(1 - F'_R \times k_R)
 \end{aligned}
 \dots(3)$$

Application of Driving Dependability Analysis Method (DDAM)

Error-based driving dependability model can be run on a sample dataset of bus driving errors in a bus company. Because of current limitations on availability of very specific data of traffic accidents, several simplifying steps were taken within application of DDAM. First simplification was that driving behaviour shaping factors are measured with respect to a single driver in a single vehicle under traffic accidents condition. Other vehicles and pedestrians are considered elements of roadway environment. Second simplification was truncation of all subsidiary driver actions due to lack of enough information. Third simplification was use of factors analysis rather than individual design-based statistics for quantification of basic errors probabilities, because availability of information focusing on driver behavior and fault causations for specific bus operation is very limited.

Accident Data Normalization

Sample accident dataset contained 4216 accident records randomly selected for 1982-1990 from traffic accident databases files including self-reported accidents by bus drivers. Data revealed that 3562 accidents correspond to these parameters out of 4216 accidents. Although this does not represent a significant proportion of accidents reported in this database, it is sufficient to provide a sample decomposition of how various factors contribute to occurrence of these traffic accident types. In present study, traffic accidents records having missing variables were excluded. Thus, total 30 variables were available in each accident record. Data was normalized as

$$V_{ij} = \frac{x_{ij} - y_{\min j}}{y_{\max j} - y_{\min j}} \dots(4)$$

where, $y_{\max j}$ and $y_{\min j}$ are maximum and minimum of jth variable in all observations, respectively.

Factors Analysis

In order to identify key DBSFs, a sufficiently large sample of driver group would be required. In present study, a driving shaping behaviour questionnaire was designed with comprehensive pool of 32 variables, which were derived from careful study of bus company documentation of safety rules and procedures, analysis of internal accidents reports in depth, extensive

discussions with company staffs, and individual driver interviews. All data about driving errors under traffic accidents conditions were collected from one bus company employing 5000-6600 drivers. Total 1660 driving shaping behaviour questionnaires were distributed to respondents included 1440 bus drivers(86.7%), 50 managerial staffs with past driving experiences (3%), 150 studied drivers in a driver training school (9%) and 20 truck drivers (1.2%). Respondents were asked to express their agreement with each of 32 items with concise explains in terms of 10-point scale from one (most agree) to ten (most disagree). Seven drivers involved in traffic accidents didn't return their questionnaires due to injuries.

Data was analyzed to determine meaningful factors emerging from each of headings. Analysis resulted in a reduction from original 32 variables to 19 variables based on principle of removing variables, which accounting for low factor loading (<0.55). Analysis of 19 variables produced 5 factors, consisting items and percentage of total variance, respectively, as follows: Factor 1, 6, 24.54%; Factor 2, 5, 21.03%; Factor 3, 3, 20%; Factor 4, 3, 16.75%; and Factor 5, 2, 12.97%. Factors could be represented by independent sets of key DBSFs by considering 96.45% of explained variance. It showed that different key DBSFs have various degrees of effect upon driving behaviour. Traffic and human factors in expert's assessment, resulted in final analysis, were psycho-physiological states of driver, dangerous consequences of driving erroneous actions, technical situations relating to interactions of driver and vehicle, time available to perform driving tasks, and road environmental conditions affecting driving behaviour.

Formalized Expert Judgment based on Fuzzy Sets

For special traffic operations, where accidental scenarios existed, experiences of experts were considered to establish probability figures. Thus formalized expert judgment based on fuzzy sets determined variability of driving behaviour under traffic accident conditions. Let X be a classical set, which generates a space, and its elements marked as x. Membership of set K, which is subset of space X, can be described by membership function μ_K , as

$$\mu_K = \begin{cases} 1, & \text{if and only if } x \in K \\ 0, & \text{otherwise} \end{cases} \dots(5)$$

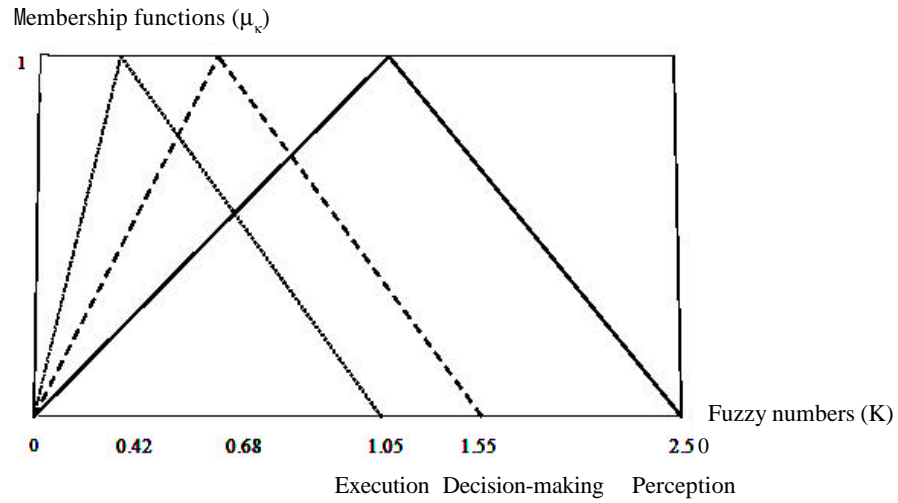


Fig. 2— Membership functions of DBSFs in each stage

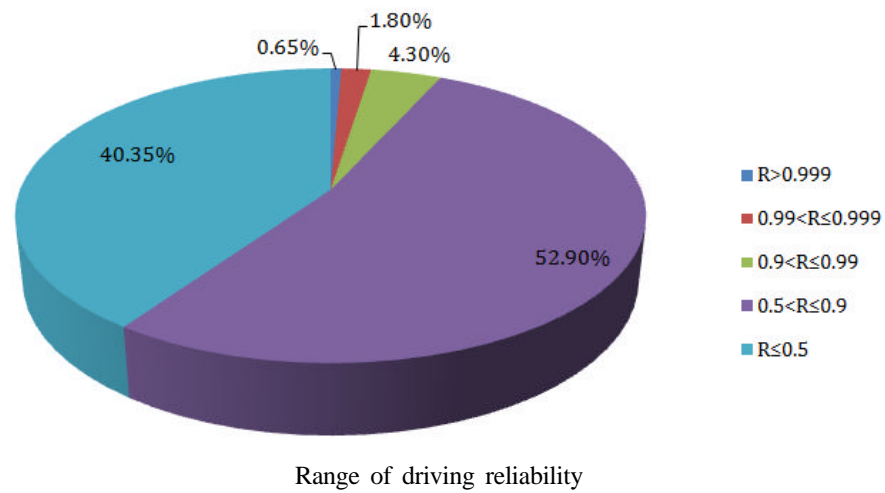
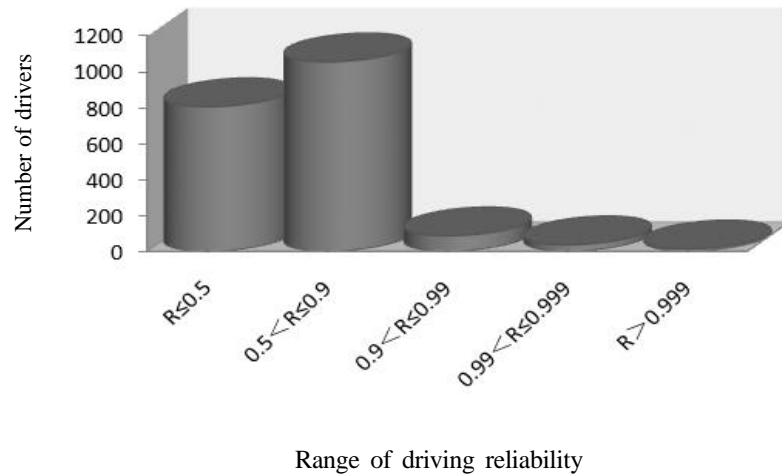


Fig. 3—Results of driving dependability analysis of 2000 drivers under traffic accident conditions

If membership function can get real values within interval $\{0,1\}$, set K is called fuzzy set, which expresses grade of membership of x to set K . More the value approximates to value 1, more so x belongs to set K . Since triangular distribution was used in a distribution of DBSFs with a low likely, likely and high likely probability, all membership functions of DBSFs within three stages were represented in terms of distributions (Fig. 2). These functions were used to classify driving errors into a finite set of categories for identifying and measuring dangerous traffic conditions.

Results and Discussion

Driving dependability analysis of 2000 bus drivers under traffic accident condition was calculated (Fig. 3) using combination of error-based driving dependability model with formalized expert judgment method based on fuzzy sets. Driving reliability (93.25%) of drivers under traffic accident condition was found lower to 0.9. Lower driving reliability in operation of traffic system has resulted in a traffic accident. As for normal daily driving, one of the most typical characteristics of driver behaviour is inherent variability. For example, driver may seriously underestimate speed of an oncoming car and decide to overtake it. Or driver may fail to carry out an action as planned for controlling vehicle. It is therefore difficult to separate driving errors from normal variation and define characteristics for a good or error-free driver. As a result, model-based methodology for driving dependability analysis will be able to pave way for future evaluating driving procedures and for its practical applications to a variety of traffic problems (driving errors prevention, driving skill train, driver safety education).

Conclusions

Model-based driving dependability analysis is an effective framework for describing traffic accident causation in both quantitative and qualitative terms. This

paper illustrates generally the use of formalized expert judgment based on fuzzy sets and driving dependability analysis for identifying, measuring, assessing dangerous traffic conditions. It is anticipated that model-based driving dependability analysis method will facilitate developing appropriate countermeasures to control traffic accidents.

Acknowledgments

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