Expert Systems with Applications 38 (2011) 1509–1514

Contents lists available at ScienceDirect

Expert Systems with Applications

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

Constructing road safety performance indicators using Fuzzy Delphi Method and Grey Delphi Method

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A R T I C L E I N F O

Keywords:
Safety performance indicator
Fuzzy Delphi Method
Grey Delphi Method
Regional road safety
Urban road safety
Highway safety

A B S T R A C T

The main goal of this paper is to construct three sets of road safety performance indicators, which are regional road safety performance indicators, urban road safety performance indicators and highway safety performance indicators, respectively. Fuzzy Delphi Method and Grey Delphi Method are applied to quantify experts' attitudes to regional road safety, urban road safety and highway safety. Comparing the results of two methods, the different results of two methods are analyzed, and then the final safety performance indicators are obtained by taking the intersection of results of two methods. Finally, three sets of performance indicators are constructed, which can be described and evaluated the safety level of region, urban road and highway, respectively. The research findings show that the method used in this paper is feasible and practical and can be provided as a reference for the administrative authority of road safety.

1. Introduction

Road safety management is an important means for forecasting and preventing traffic accidents, and its core is the evaluation, forecast and decision-making technique of road safety. Especially, road safety evaluation is the foundation of safety management. In general, the process of evaluation is made up of evaluation object, evaluation indicator, weighting and evaluation model. In practice, the process of weighting and evaluation model is always paid much attention, but the selection of evaluation indicator is ignored. In fact, it is very important to choose scientific and rational evaluation indicators, which is the first step to conduct evaluation and the key problem concerning the success or failure of the whole process of evaluation. Therefore, how to establish a set of scientific and rational road safety performance indicators is the key problem for road safety management.

Many researchers have dedicated to the research of the macro road safety model over 50 years, and these research results were remarkable, such as Smeed's law (Smeed, 1949), Rumar descriptive model (Rumar, 1987), Koornstra's function (Koornstra, 1996), Navin Model (Navin, Bergan, & Zhang, 1996) and Trinca model (Trinca, 1988). These models were used to compare countries' road safety level by means of risk indicators, such as fatalities per vehicles, fatalities per population, fatalities per vehicle kilometers or the number of passenger miles. But some indirect influence factors, such as Socio-economic factor level and social medical condition, have not been considered.

Some researchers established a comprehensive performance indicators taking into account the impact of direct and indirect influence factors from the view of systems engineering. Al-haji (2003) proposed a road safety development index (RSDI) allowing comparison among nations and adopted a framework used to develop a human development index (HDI), which included nine basic dimensions with 14 indicators and averaged them to produce the RSDI. Fu and Fang (2006) proposed highway network safety performance indicators, which included five basic dimensions with 13 relative indicators. Wu, Liu, and Xiao (2006) proposed freeway safety performance indicators, which included three basic dimensions with 11 indicators. Ma, Sun, and Han (2008) proposed urban road safety performance indicators, which included three basic dimensions with 11 indicators. Above all, these safety performance indicators have overcome the deficiency of indicators which were considered from the aspect of accidents, and have made great progress. But the present researches do not specify the detailed process of constructing road performance indicators and why those indicators are selected.

Delphi Method was widely applied to select performance indicators in many fields, but it requires multiple investigations to achieve the consistency of expert opinions and experts are required and forced to modify their opinions so as to meet the mean value of all the expert opinions. However, Fuzzy Delphi

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doi:10.1016/j.eswa.2010.07.062

Method requires only a small number of samples and the derived results are objective and reasonable. Not only it saves time and cost required for collecting expert opinions but also experts' opinions will also be sufficiently expressed without being distorted (Hsu & Yang, 2000; Ishikawa et al., 1993; Kuo & Chen, 2008; Murry, Pipino, & Gigch, 1985). Furthermore, grey system theory also can deal with uncertain, hazy and incomplete data (Liu, Dang, & Fang, 2004). Grey whitening weight function can be described evaluation objects belonging to the degree of a certain grey class, and it has been widely used (Li, Wang, & An, 2008; Shao, Tang, & Bai, 2003; Xie & Pan, 2007). Therefore, two kinds of methods are used to filter road safety performance indicators, which are Fuzzy Delphi Method and Grey Delphi Method, respectively.

The main goal of this paper is to construct three sets of road safety performance indicators, which are regional road safety performance indicators, urban road safety performance indicators and highway safety performance indicators, respectively. Through Fuzzy Delphi Method and Grey Delphi Method, the importance of indicators can be derived. The comparative analysis on the results of two methods was carried out, and then three sets of road safety performance indicators could be constructed. The research results can be provided as a reference for the administrative authority of road safety.

2. Methodology

In order to simplify the process of survey, three primary road safety performance indicators from the region, the urban road and the highway were proposed with reference to the related literatures. They are summarized in Appendices A, B and C, respectively. Based on three primary road safety performance indicators, the questionnaire was designed. A panel of 15 members from universities and research institutions was formed. The importance of road safety performance indicators was divided into five grades, and five-point Likert scales, ranging from five, "very important" to one, "not very important" were used for scoring of each indicator. At last, a total of 15 questionnaires (one for each expert) were distributed, and 13 returned were valid. The valid response rate was 86.7%.

2.1. Fuzzy Delphi Method

The Delphi Method was first developed by Dalkey and Helmer (1963) in corporation and has been widely applied in many management areas, e.g. forecasting, public policy analysis and project planning. However, the traditional Delphi Method also has some disadvantages, such as low convergence expert opinions, high execution cost, the possibility of filtering out particular expert opinions, and so on. Therefore, Murry et al. (1985) proposed the concept of integrating the traditional Delphi Method and the fuzzy theory to improve the vagueness of the Delphi Method. Membership degree is used to establish the membership function of each participant. Ishikawa et al. (1993) further introduced the fuzzy theory into the Delphi Method and developed max–min and fuzzy integration algorithms to predict the prevalence of computers in the future. But the limitation of this method is only applicable to predict time series data. Hsu and Yang (2000) applied triangular fuzzy number to encompass expert opinions and establish the Fuzzy Delphi Method. The max and min value of expert opinions are taken as the two terminal points of triangular fuzzy numbers, and the geometric mean is taken as the membership degree of triangular fuzzy numbers to derive the statistical unbiased effect and avoid the impact of extreme values. The advantage of this method is simplicity that all the expert opinions can be encompassed in one investigation. As a result, this method may create a better effect of criteria selection. Kuo and Chen (2008) summarized advantages of the Fuzzy Delphi Method, and applied it to construct key performance appraisal indicators for mobility of the service industries.

In this paper, the Fuzzy Delphi Method proposed by Hsu and Yang (2000) was adopted in the process of the selection of road safety performance indicators. Geometric means are used to denote experts consensus in this paper, and the process is demonstrated as follows:

(1) Experts' opinions were collected from questionnaires, and questionnaires were dealt with. At the same time, the triangular fuzzy numbers $\widetilde{a}_i$ were created, which were shown as follows:

$$\widetilde{a}_i = (\alpha_i, \delta_i, \gamma_i),$$
$$\alpha_i = \min(B_{ij}),$$
$$\delta_i = \left(\prod_{k=1}^{n} B_{ij}\right)^{1/n},$$
$$\gamma_i = \max(B_{ij}),$$

where i is the number of indicators; j is the number of experts; α_i is the bottom of all the experts' evaluation value for indicator i; δ_i is the geometric mean of all the experts' evaluation value for indicator i; γ_i is the ceiling of all the experts' evaluation value for indicator i; B_{ij} is the evaluation value of the jth expert for indicator i.

(2) Selection of performance indicators.

In this paper, the geometric mean δ_i of each indicator's triangular fuzzy number was used to denote the consensus of the expert group on the indicator's evaluation value, so that the impact of extreme values could be avoided. The threshold value r was determined. If δ_i is no less than r, indicator i is accepted, and vice versa.

2.2. Grey Delphi Method

Grey Delphi Method is the integration of grey system theory and Delphi Method, which uses grey whitening weight function based on Delphi questionnaires to select evaluation indicators. The process of Grey Delphi Method was as follows.

Step 1. According to the evaluation requirement, s grey classes were developed and the selection range of value of indicator j $[a_j^1, b_j^s]$ was divided into k grey classes.
Step 2. For $k = 1$ and s, half trapezoidal whitening weight function was used. The formations were as follows.

$$f_j^1(x) = \begin{cases} 1, & x \leqslant a_j^1, \\ \frac{b_j^1 - x}{b_j^1 - a_j^1}, & a_j^1 < x \leqslant b_j^1, \\ & x > b_j^1, \end{cases} \tag{1}$$

$$f_j^s(x) = \begin{cases} 0, & x < a_j^s, \\ \frac{x - a_j^s}{b_j^s - a_j^s}, & a_j^s \leqslant x < b_j^s, \\ 1, & x \geqslant b_j^s. \end{cases} \tag{2}$$

For $k = m$ $(m = 2, 3, \ldots, s-1)$, triangular whitening weight function was used. The formation was as follows:

$$f_j^k(x) = \begin{cases} 0, & x \notin [a_j^k, b_j^k], \\ \frac{x - a_j^k}{\lambda_j^k - a_j^k}, & x \in [a_j^k, \lambda_j^k], \\ \frac{b_j^k - x}{b_j^k - \lambda_j^k}, & x \in [\lambda_j^k, b_j^k], \end{cases} \tag{3}$$