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Prioritizing highway safety improvement projects: A multi-criteria model and case study with *SafetyAnalyst*

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ABSTRACT

This paper presents a multi-criteria model for prioritizing highway safety improvement projects, in which a set of criteria related to the project's technical, economic, and social impacts are properly weighted in consideration. The proposed model features an Analytical Hierarchy Process (AHP) framework to tackle the multi-criteria decision making problem. Different from the conventional AHP, this paper adds a fuzzy scale level between the criteria level and the alternative level, which offers the advantage of preventing the vagueness and uncertainty on judgments of the decision-maker(s). Such a unique modeling feature is further embedded with a non-linear optimization formulation to maximize the consistency in pair-wise comparison and weight estimation for each criterion. Case study results reveal that the proposed model is efficient not only for selecting the most suitable project for a specific site, but also for determining the priorities for implementing those suitable projects among multiple sites given the budget constraint. Comparative study between the proposed model and the existing ranking methods has also indicated its capability to capture the comprehensive impacts of all contributory factors which have been neglected by most existing single multi-criteria approaches during the safety project selection process. The clarity of model inputs, ease of synthesizing the final score of each candidate project, and the interpretation of results with respect to different selection criteria offer its best potential to be used as an effective tool for highway safety managers to assess and refine the safety improvement investments.

1. Introduction

Over the past several decades, highway safety has emerged as one of the most critical concerns faced by the responsible transportation/highway infrastructure management agencies. The Safe, Accountable, Flexible, and Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU), which was signed into law on August 10, 2005, established the Highway Safety Improvement Program (HSIP) as a core Federal-aid program (FHWA, 2008a). To ensure HSIP was implemented as intended, a number of research issues were proposed, including estimating accident frequency, identifying high accident locations, and prioritizing candidate improvement projects, etc. This study will present a new approach focused on prioritizing candidate safety improvement projects to assist responsible agencies in achieving the best possible safety improvement results with a limited budget.

Prioritizing safety improvement projects is a complicated and often tedious task. The large number of competing alternatives requires a credible methodology for prioritization, so to maximize the return from use of a limited budget (Melachrinoudis and Kozanidis, 2002). A review of the literature reveals that a commonly used approach for prioritizing highway safety improvement projects is to formulate an optimization problem that takes the ranking criteria as the objective and includes a budgetary constraint. Typical objectives that have been reported in the literature include reduction in accident frequencies (Melachrinoudis and Kozanidis, 2002; Banihashemi and Dimaiuta, 2005), weighted accident reduction based on the severity level (Kar and Datta, 2004), weighted reduction in accidents and gain in delay cost (Banihashemi, 2007), and the net benefits (Harwood et al., 2004).

Despite the significant contribution by those studies, optimization models with a single objective may not be able to capture various aspects of a candidate project comprehensively and effectively. To remedy this deficiency, multi-criteria analyses have been proposed to support decision-making that involves prioritizing and selecting safety improvement projects under conflicting objectives and constraints. Chowdhury et al. (2000) has formulated a multi-objective optimization model where the expected loss disutility is minimized subject to the constraint of limited funds. Lambert et al. (2003) has introduced a graphic-based method to trade off multiple criteria during the process of allocating transportation funds to guardrails. In their studies, only crash severities are taken

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into account, while other important factors (e.g., traffic exposure) are neglected. In addition, the combination of various countermeasures is simply obtained by optimizing each individual objective, which has ignored the fact that different objectives usually have different levels of importance during the process of project selection.

To contend with the above critical issues, this paper will introduce a new multi-criteria methodology for prioritizing highway safety improvement projects based on an extended analytical hierarchy process with fuzzy logic, in which a set of criteria related to the project's technical, economic, and social impacts are properly weighted in consideration. The proposed approach has the potential to capture all the contributory factors during the safety project selection process, and offers an effective tool in practice for highway infrastructure and safety managers to assess and refine the ranking results.

2. Selection of ranking criteria

Traditional ranking criteria for setting priorities of highway safety improvements mainly include the number of accidents reduced, the number of fatal and injury accidents reduced, the project cost, the expected project benefits, cost-effectiveness of the project, benefit-cost ratio of the project, and net project benefits (Hauer et al., 2002; FHWA, 2002; Banihashemi, 2007). The first three criteria aim solely at either maximizing the number of accidents reduced or minimizing project cost, while the latter four criteria, though taking into account more than one criterion, require converting each criterion into the same unit (usually in monetary values). Despite their simplicity and wide use in ranking safety improvement projects, those criteria may generate quite different or even contradictory ranking lists. Taking the dataset from *SafetyAnalyst* (A state-of-the-art software Federal Highway Administration developed to address site-specific safety improvements) as an example, the demonstrated example contains a series of sites (intersections) and one or more projects selected for possible implementation at each specific site. The ranking results (see Table 1) reveal significant discrepancies existing in the priority scores of different candidate projects with respect to different criteria, which may cause a dilemma in the decision-making process.

Hence, multiple criteria that are related to a broad range of concerns on the project's technical, economic, and social impacts need to be considered and properly weighted such that the most suitable decision can be made with reasonable assurance. In this paper, ranking criteria are selected mainly based on recommendations from the Federal Highway Administration (2008b) and on causes justifying the priorities of highway safety improvement projects from the standpoint of the government and highway authorities. Selected criteria will be related to the goal of prioritizing safety improvement projects with respect to the following concerns:

- Safety improvement concern: to ensure that the chosen projects are with the most safety improvements. This concern can be further subdivided into two indicators: total accidents reduced and total fatal and injury accidents reduced.
- Economic concern: to measure costs associated with the implementation of the proposed improvement projects. This concern breaks into two indicators: project construction cost and project service life. And
- Social importance concern: to indicate the importance of implementing recommended projects in social term. Two indicators, Annual Average Daily Traffic (AADT) of implementation year and AADT Growth factor, are employed to quantify the amount of traffic that can potentially benefit from the implementation of the chosen project within its service life.

Details of each criterion are listed in Table 2.

3. The proposed multi-criteria ranking model

3.1. The fuzzy-AHP structure

The Analytical Hierarchy Process (AHP) has been widely used for tackling multi-criteria decision-making problems since being developed by Saaty (1980). The use of AHP in transportation engineering fields has increased in recent years for prioritizing resources (Zhang et al., 2002; Larson and Forman, 2007; Filippo et al., 2007; Wei et al., 2007). However, its application in prioritizing highway safety improvement projects is very limited.

Typically, AHP allows decision makers to decompose a complex problem into three hierarchical levels: the goal, criteria, and alternatives. Different from the conventional AHP structure, this paper adds a fuzzy scale level between the criteria level and the alternative level to facilitate the normalization of different indicator scales. Fig. 1 presents the hierarchical structure of the proposed multi-criteria model used to obtain priority scores for selecting highway safety improvement projects, which includes four levels:

Table 1
An example of discrepancies in existing ranking methods.

Site ID	Candidate projects	# Total accidents reduced	# FI accidents reduced	Construction costs	Ranking results with existing methods							
					FI	TOT	CC	SB	CE	CE_EPDO	BC_ratio	NB
1	P 1	63.75	21.5	10,000	9	4	4	9	5	7	7	9
2	P 1	171.65	144.65	80,000	1	2	14	1	1	3	4	1
3	P 1	17.82	14.79	5000	13	14	1	13	6	4	3	13
	P 2	14.69	16.93	60,000	10	15	12	11	15	15	15	11
4	P 1	22.46	9.12	10,000	15	13	4	15	12	13	13	15
	P 2	32.62	12.18	30,000	14	10	8	14	13	14	14	14
5	P 1	50.64	47.96	5000	4	6	1	5	2	1	1	5
	P 2	25.32	35.97	30,000	6	12	8	4	14	9	10	4
6	P 1	33.94	15.09	20,000	12	9	7	12	9	12	12	12
	P 2	30.36	16.68	5000	11	11	1	10	7	10	9	10
7	P 1	199.7	102.75	80,000	3	1	14	2	4	8	8	2
	P 2	44.73	23.87	30,000	8	8	8	8	11	11	11	8
8	P 1	54.69	30.74	10,000	7	5	4	7	3	2	2	7
	P 2	48.61	44.71	30,000	5	7	8	6	10	6	6	6
	P 3	106.34	103.38	60,000	2	3	12	3	8	5	5	3

Note: P *i* = Project *i*; FI = Fatal and injury accidents reduced; TOT = Total accidents reduced; CC = Construction cost; SB = Safety benefit; CE = Cost effectiveness; CE_EPDO = Cost effectiveness equivalent-property-damage-only; BC_ratio = Benefit cost ratio; NB = Net benefit; AHP = The proposed fuzzy-AHP model.