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Decision-making for civil infrastructures incorporating the time-varying effect of risk preference

Chen Pan[a], Quanwang Li[a,*]

[a]*Department of Civil Engineering, Tsinghua University, Beijing 100084, China*

Abstract

Life cycle cost (LCC) analysis offered a useful framework to think about the efficiency of infrastructures investment. However, the widely accepted algorithm of the LCC doesn't account for the decision maker's attitude toward the risk of future consequences. The cumulative prospect theory (CPT) can be used to reveal the decision maker's preference under different risk and uncertainty conditions, and has been applied in literature to some design optimization issues. Nevertheless, previous research didn't consider the fact that people's risk preference may vary with time, i.e., there is a reasonable tendency that people will be more risk-averse to the near future losses than to the far future losses. Recognizing this, this paper adopts the CPT model in the minimum expected cost analysis, and moreover incorporates the time-varying weighting function included in the CPT model to reflect the possible changing of risk preference toward future events. A seismic retrofit optimization of a dam built in strong earthquake-prone area is used to demonstrate the application of the method, and it is found that considering the time-varying of risk preference leads to a low design level compared with that by the CPT model, but a high design level compared with the traditional LCC.

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Keywords: Decision model; Life cycle cost; Civil infrastructure; Risk preference; Cumulative prospect theory.

1. Introduction

The risk faced by structural design is reflected by the consequence and the corresponding likelihood. The traditional probability-based design method, which focuses on obtaining the failure probability of defined limited

* Corresponding author. Tel.:86-10-62797673; fax:86-10-62791891.
E-mail address: li_quanwang@mail.tsinghua.edu.cn

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state and excludes the catastrophic losses (consequences), may lead to an inadequate structural performance [1,2]. Thus, to achieve a reasonable performance goal accounting for both the failure probabilities and costs, life cycle cost (LCC) analysis is proposed and the minimum expected LCC is suggested to be the optimal choice of design variables. However, the minimum expected LCC criterion cannot reflect the importance of decision maker's attitude toward risk. In other word, it is assumed that decision maker is risk neutral in the algorithm of LCC. This assumption often violates the real condition in the decision-making process and leads to the real choice divergent from the choice derived from the minimum expected LCC [3]. To overcome this, several descriptive decision models have been applied such as the subjective expected utility theory (UT) and the cumulative prospect theory (CPT) [4,5]. CPT, which is developed by Kahneman and Tversky, is a viable approach to think about and deal with human behaviors under risk and uncertainty.

CPT has been applied in literature to some design optimization issues [6,7]. K.Goda, etc. utilized it in seismic design preference and discussed the results sensitivity to key parameters included in CPT [8]. Eun Jeong Cha, etc. acquired quantitative risk aversion parameters related to initial capital and maximum loss limit, and applied it to investigating civil infrastructure design optimization problems [9]. Nevertheless, previous researches transformed the losses brought by future catastrophic events into the present value, then used the CPT to make the judgement. An assumption is embedded in this method, namely, risk attitude toward the present events is the same as that toward future events, which is not always true in the real choice-making process. For example, there is a reasonable tendency that people will be more risk-averse to the near future losses than to the far future losses.

Recognizing this, this paper establishes a new infrastructure decision model based on cumulative prospect theory, which is capable of reflecting the time-dependent characteristics of people's risk preference. An example involving a seismic retrofit of a dam built in strong earthquake-prone areas is used to demonstrate the application of the method, and results are compared with those of traditional LCC method.

2. Review of life cycle cost and cumulative prospect theory

In general, the expected life-cycle cost of a structure has three essential components: initial cost (C_0), damage and repair cost (C_R), and operation cost (C_M). Over the design service life (T), it can be expressed as a function of T and engineering design parameter vector Z as follows:

$$E[\mathrm{LCC}(T,Z)] = C_0(Z) + E[C_R(T,Z)] + C_M(T,Z) \tag{1}$$

However, the expected LCC can't reflect people's subjective cognition of risk due to that the monetized consequences and objective probabilities may not equal to subjective evaluation of them. The phenomena of decision under risk such as framing effect, certainty effect, and reflection effect, were observed and paid high attention by psychologists and economists [10]. To explain these phenomena, they developed various modified or new models. A widely recognized one of them is cumulative prospect theory (CPT).

In CPT, the individual choice process under uncertainty can be regarded as a combination of two stages. First of them is editing. Suppose that n outcomes x_i with probability p_i ranked in an arising order, i.e., $x_1 \leqslant \ldots \leqslant x_i \leqslant 0 \leqslant x_{i+1} \leqslant \ldots \leqslant x_n$, in which the outcome x_i is edited with respect to a reference point (0), and the definition of gains or losses is corresponding to it. The reference point is affected by the current wealth level and the expectation of decision maker. Commonly, it is assumed to be the status quo. The second stage is evaluation. The expected LCC is replaced by the value V, which is expressed as,

$$V = V^- + V^+ = \sum_{i=1}^{k} v(x_i)\pi_i^- + \sum_{i=k+1}^{n} v(x_i)\pi_i^+ \tag{2}$$

where v is the value function which determines the subjective assessment of monetary gains and losses; π^+ and π^- are the decision weights separately for losses and gains. The parametric shapes of the value function is often written as a power function on account of its simplicity and match with data, as follows [11],