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Soft risk maps of natural disasters and their applications to decision-making ☆

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Abstract

A soft risk map of natural disaster is aimed at the visualization of risk levels of natural disasters defined by the fuzzy probabilities. In this paper, we discuss three soft risk maps and show their applications. A soft risk map of flood is applied to help choose zones for investment in projects whose profits depend on water resources, cost and flood risk. A soft risk map of drought can help an investor to choose an appropriate city to invest in a flower shop whose profits depend on drought risk and the number of customers. With a soft risk map of earthquake, a licensee designing a nuclear power station can reasonably adjust the earthquake-resistant parameters to avoid underestimating earthquake.

Keywords: Natural disaster; Risk map; Fuzzy probability; Decision-making

1. Introduction

Natural disasters take away the lives of many thousands of people each year. A risk map of natural disaster is a regionalization map that identifies the places that might be adversely affected in the event of natural disasters. When we employ probabilities to represent risks [2], the map is called a probability-risk map. For generating this kind of map, it is necessary to estimate the probability distribution $p(x)$ about an index x measuring adverse event, such as earthquake and flood.

The system of any natural disaster is complex. Data available to estimate $p(x)$ are usually insufficient or impossible to support the development of a complete model. It is impossible to accurately estimate $p(x)$. Nobody can guarantee that an estimate $\hat{p}(x)$ is accurate within a specified error range.

In this case, fuzzy probabilities would be useful to represent fuzzy risks, giving rise to a new type of risk map. In the early studies of fuzzy research, the fuzzy probability is defined as the probability of a fuzzy event

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[16] where the basic probability distribution $p(x)$ is known. However, in many cases, the focus point is just to find $p(x)$. The fuzzy researchers generally consider the fuzzy probability as the imprecise probability rather than the probability of a fuzzy event. In 1998, Huang [5] suggested using the interior–outer-set model (IOSM) to calculate the imprecise probability based on a given sample. Huang and Shi [8] and Huang and Moraga [7] improved this model. In 2002, Huang [6] made a successful application of IOSM, where the result was concordant with the practical situation. Employing the model, in 2005, Zhang [17] worked out the first soft risk map with the earthquake records of $M \geqslant 5.0$ during 1900–2000 of Kunming, Chuxiong, Dali, and Lijiang in Yunnan Province, China.

Naturally, researchers interested in the development and use of risk maps of natural disasters would like to know whether the new kind of risk map becomes beneficial in decision-making. In Section 2, an outline is provided to help those readers who have not been exposed to the concept of soft risk maps and interior–outer-set models. The example in Section 3 shows the advantages of a soft risk map of flood, using which one can choose the most suitable zones to invest in projects being potentially affected by flood. In Section 4, we examine how a soft risk map of drought can help a businessman to choose an appropriate city for investing in a flower shop where profits depend not only on drought risk, but also on the number of customers. We show that if we have a soft risk map of earthquake, it is possible for a licensee in a nuclear power station to reasonably adjust parameters for earthquake-resistant design (Section 5). We then conclude the paper in Section 6.

2. Soft risk maps

2.1. Risk maps

A risk map of natural disasters is an atlas of a community or geographical zone that identifies the places and the buildings that might sustain heavy damages caused by natural disasters. The objective of a risk map is to identify the probability of the occurrence of a specific hazard, as well as its intensity and areas of impact, within a period of time. In many cases, the estimation of the probabilities is so inaccurate that it is practically useless if we even regard them as crisp values.

2.1.1. Fuzzy probability

There are other concepts and notions of theories and models addressing imprecision, uncertainty and partial knowledge with respect to probability concept, which are referred to as imprecise probabilities. In statistical applications, imprecise probabilities usually come from subjectively assessed prior probabilities. The fuzzy set theory is applicable to the modeling of imprecise subjective probabilities, suggested by many researchers (for example, Budescu and Karelitz [1], Nau [12], and Walley [15]).

To avoid any confusion, we focus on studying the fuzzy probability that can be represented by a possibility–probability distribution.

Definition 1 [7]. Let $(\Omega, A, \mathbf{P})$ be a probability space, and P be the universe of discourse of probability. Let the possibility that an event occurs with probability p be $\pi_x(p)$. Then,

$$\Pi_{\Omega,P} = \{\pi_x(p) | x \in \Omega, p \in P\}, \tag{1}$$

is called a *possibility–probability distribution* (PPD).

We note that, in Definition 1, $\mathbf{P}$ is employed to represent a probability measure defining a probability space, and P is the universe of discourse of probability. The PPD is a model of the second-order uncertainty [3] along with the first-order uncertainty that may form hierarchical models [4].

2.2. Interior–outer-set model

Traditionally, the major challenge in fuzzy probability is considered to find a suitable methodology for the determination of the membership function $\pi_x(p)$ through interviewing by experts. In practice, when engineers analyze physical systems they tend to rely on crisp formulations to evaluate those systems. In other words,