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Assessing uncertainty in extreme events: Applications to risk-based decision making in interdependent infrastructure sectors

Kash Barker [a,*], Yacov Y. Haimes [b,1]

[a] School of Industrial Engineering, University of Oklahoma, 202 West Boyd Street, Room 124, Norman, OK 73019, USA
[b] Center for Risk Management of Engineering Systems, University of Virginia, 112 Olsson Hall, Charlottesville, VA 22903, USA

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ABSTRACT

Risk-based decision making often relies upon expert probability assessments, particularly in the consequences of disruptive events and when such events are extreme or catastrophic in nature. Naturally, such expert-elicited probability distributions can be fraught with errors, as they describe events which occur very infrequently and for which only sparse data exist. This paper presents a quantitative framework, the extreme event uncertainty sensitivity impact method (EE-USIM), for measuring the sensitivity of extreme event consequences to uncertainties in the parameters of the underlying probability distribution. The EE-USIM is demonstrated with the Inoperability input–output model (IIM), a model with which to evaluate the propagation of inoperability throughout an interdependent set of economic and infrastructure sectors. The EE-USIM also makes use of a two-sided power distribution function generated by expert elicitation of extreme event consequences.

1. Introduction

Recent natural disasters and malevolent man-made events have increased the interest in understanding extreme events and planning for their occurrence. Recent focus (e.g., by the US Department of Homeland Security (DHS)), has been given to preparedness activities that improve response to and recovery from such extreme events. Indeed, the utility of risk-based decision making is not necessarily to articulate the “best” policy option, but rather to avoid the extreme, the worst, and the most disastrous options. To do so, a decision maker must be able to measure the outcomes of such extreme events and measure how risk management can control them.

Asbeck and Haimes [1] and Haimes [2] introduce the partitioned multiobjective risk method (PMRM) and discuss the fallacy behind using the expected value of adverse outcomes when analyzing and managing risks as the sole measure for risk, because such a measure does not accurately capture outcomes that are due to catastrophic, not-unlikely events. Frowhein et al. [3] provide a number of measures to quantifying extreme event consequences, including the PMRM. However, Taleb [4] warns that parametric uncertainties and estimation errors in probability distributions can result in adverse effects in the understanding of extreme events.

Data describing extreme events, due to their low probability of occurrence, are understandably sparse. The assessment of likelihood can suffer from the subjectivity of the data source, particularly due to the sparseness of data, as expert-elicited likelihoods are frequently used. Probability distributions derived from expert elicitation can suffer from a number of errors [5–8]. Oberkampf et al. [9] highlight the difficulties that arise in interpreting model outputs when uncertainties exist in model parameters. Further discussions of the propagation of uncertainties as applied to risk assessments include Refs. [10–13].

Expected and conditional expected values of consequences due to disruptive events can vary widely depending on the choice of parameters of the underlying probability distribution from which these risk measures are calculated. This paper provides a framework, referred to here as the extreme event uncertainty sensitivity index method (EE-USIM) [14], for calculating and analyzing the sensitivity of extreme event consequences with respect to uncertainty in the parameters of underlying probability distributions of disruption consequences.

The EE-USIM, graphically in Fig. 1, is derived from three main methodological components: sensitivity analysis of probability distribution parameter uncertainties using the uncertainty sensitivity index method (USIM) [2,15,16], extreme event analysis using the partitioned multiobjective risk method (PMRM) [1,2], and the comparison of risk management strategies via the tradeoffs among multiple, noncommensurate, and competing objectives.

* Corresponding author. Tel.: +1 405 325 3721; fax: +1 405 325 7555.
E-mail addresses: kashbarker@ou.edu (K. Barker), haimes@virginia.edu (Y.Y. Haimes).
[1] Tel.: +1 434 924 0960; fax: +1 434 924 0865.

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