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On the use of fuzzy inference techniques in assessment models: part II: industrial applications

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Abstract In this paper, we study the applicability of the monotone output property and the output resolution property in fuzzy assessment models to two industrial Failure Mode and Effect Analysis (FMEA) problems. First, the effectiveness of the monotone output property in a single-input fuzzy assessment model is demonstrated with a proposed fuzzy occurrence model. Then, the usefulness of the two properties to a multi-input fuzzy assessment model, i.e., the Bowles fuzzy Risk Priority Number (RPN) model, is assessed. The experimental results indicate that both the fuzzy occurrence model and Bowles fuzzy RPN model are able to fulfill the monotone output property, with the derived conditions (in Part I) satisfied. In addition, the proposed rule refinement technique is able to improve the output resolution property of the Bowles fuzzy RPN model.

Keywords Assessment models · Monotone output property · Output resolution property · Failure mode and effect analysis · Risk priority number

1 Introduction

An assessment model is a mathematical model, which quantifies a situation/object and produces a measuring index, either in a numerical score of a continuous scale or a category to a situation/object, taking into consideration its attribute(s) (Dubois and Prade 1997; Cunningham 1986; Chatterji 2003). The estimated score or category

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represents the level of criticality or wellness, which will result in certain actions or decisions to be taken. From the literature review, fuzzy set methods have been widely used in assessment models (Dubois and Prade 1997; Figueira et al. 2005; Triantaphyllao 2000; Kaliszewski 2006). In Part I of this work, definitions of two common theoretical properties of assessment models, i.e., the monotone output property and the output resolution property, and the conditions how a Fuzzy Inference System (FIS)-based assessment models to fulfill the properties are presented. In this sequel paper, we focus on the fuzzy inference system (FIS)-based assessment models, with application to Failure Mode and Effect Analysis (FMEA) methodology (Ireson et al. 1995; Chrysler Corporation et al. 1995). Specifically, we examine the applicability of the two properties and the derived conditions to a proposed fuzzy occurrence model (a single-input fuzzy assessment model) and the Bowles fuzzy Risk Priority Number (RPN) model (Bowles and Peláez 1995) (a multi-input fuzzy assessment model). Both models are constructed with real information collected from a semiconductor manufacturing plant for Flip Chip Ball Grid Array (FCBGA) (Tummala 2000) products.

With regard to FMEA, a number of soft computing techniques have been researched to enhance its methodology. For example, in Lee (2001), a Bayesian belief network for FMEA modeling and analysis was examined. Application of expert systems to FMEA was suggested in Russomanno et al. (1992). In Bell et al. (1992), use of causal reasoning for automating FMEA was presented, while in Peláez and Bowles (1996), application of the fuzzy Cognitive Map to FMEA was explored. In this paper, we first examine the findings as presented in Part I with a proposed FIS-based occurrence model (a single-input fuzzy assessment model). The fuzzy occurrence model is proposed to automate the conventional occurrence score rating procedure. It produces a fuzzy occurrence score as a measure of occurrence of failures.

To further ascertain the effectiveness of the proposed monotone output and output resolution properties, an enhanced Bowles fuzzy RPN model is applied to FMEA problems. The Bowles fuzzy RPN model is a popular method, and has been successfully applied to a number of FMEA problems. For example, it was applied to FMEA of an auxiliary feed water system and a chemical volume control system in a nuclear power plant (Guimarães and Lapa 2004a,b). It was also used in FMEA of an engine system (Xu et al. 2002), a semiconductor manufacturing line (Tay and Lim 2006), and a fishing vessel (Pillay and Wang 2003). Over the years, several enhancements have also been proposed to the Bowles fuzzy RPN model. Development of a Bowles fuzzy RPN model using the grey relation theory is presented in Pillay and Wang (2003). In Xu et al. (2002), a Bowles fuzzy RPN model which allows interdependencies among all failures to be considered is proposed. In Tay and Lim (2006), a method to reduce the number of fuzzy rules in the Bowles fuzzy RPN model is reported. However, to the best of our knowledge, little attention is paid on the validity and the efficiency of the estimated numerical scores, as available in the literature. Therefore, in this paper, we investigate the efficiency of the estimated numerical scores, for both fuzzy occurrence model and Bowles fuzzy RPN model, in order to allow valid and meaningful comparisons among different failure modes in FMEA to be made.

This paper is organized as follows. Section 2 presents a review of FMEA methodology. In Sect. 3, the fuzzy occurrence model is presented. Besides, the applicability of the proposed property and derived conditions are examined. In Sect. 4, the Bowles