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Evidential weights of multiple preferences for competitiveness

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ABSTRACT

The alternative selections or feasible sets in multi-attribute utility theory usually face problems of inaccuracy or inconsistency in weighting. Evidential weight and weight of evidence still have not resolved these problems in an efficient manner. This research proposes evidential weights of multiple preferences by using evidence and inference based on the rough set theory. An evidential probability, is constructed to resolve this weight. Technically, the evidential probability is required to satisfy the following conditions: uniqueness, independence and consistency, to identify various evidence and noise, and to provide quantities of certain evidence to resolve weights. Empirically, the resolved weights are fused into competitiveness utility for verification. A practical case successfully classifies dominating nations of World Competitiveness Yearbook. Another case analyzes the competitiveness trends of China during 1997 to 2012, predicting China will continue rising in near future.

1. Introduction

Multi-attribute utility theory (MAUT) aims to provide alternative selections or feasible sets [1–5]. However, its weighting has been facing inaccuracy, inconsistency, etc. problems for a long time [6–8]. From the view of decision making, these problems always challenge the fundamental evidence and inference. In 1921, the evidential inference, as proposed by Keynes, is based on the probability-relation to express the rational belief about the relevance between a primary proposition (premise) and a secondary proposition (conclusion) [9]; The evidential weight was an inferred outcome from relevance of evidence. The probability used to express the evidential relevance is called a priori probability. The priori is an argument before making an inference. As a rational relevance for weighting, he required that the evidential weight should increase with every accession of relevant evidence. But there are two barriers exist in expressing the relevance with the priori probability. First, the priori probability may technically either rise or fall with every accession of relevant evidence. Second, the priori probability in terms of Bayes sometimes cannot give a certain explanation. The subsequent studies experienced more impacts: (*i*) Epistemic relevance is short of reliability [10,11] (*ii*) Weighting usually does not have a clear priori [12] (*iii*) Incomplete or inaccurate priori often causes ambiguity aversion thus expanding uncertainty [13].

Utility aggregated from multiple preferences is often used for choice, ranking, sorting, and classification. It is the easiest and simplest indicator for a decision maker (DM). In the theoretical framework, there are three paradigms involved to solve the evidential weights for utility. One is proposed by Keynes [9] who introduces evidence to predict, probability to express relevance between evidence and conclusion, and two probability types for judgments, i.e. preference and irrelevance based

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on evidence. But these two probability types were not integrated to form a single priori for weighting. The second is weight of evidence (WoE) intending to express a weight (W) with a probability of hypothesis (H) provided with evidence (E) given assumed proposition (G), formulated as $W(H: E|G)$ [14–16]. However, WoE is criticized in the relevance assumptions built from Bayes' probability [17,18]. Up to now, WoE still faces challenges even it gets refinement in the fields such as human health [19], environment analysis [20], etc. The third is evidential weights based on conclusive preferences (EWP), developed from dominance-based rough set approach (DRSA) [21]. In practice, many cases have no such conclusive knowledge in the beginning. Therefore, evidential weights of multiple preferences (EWMP) is proposed by using evidence to infer a priori probability, named as evidential probability (EP) in this paper, to express the evidential properties like relevance and dominance between attributes.

Utility usually plays a checker for the resolved weights. In literatures, the above paradigms relate to two theoretical fields, i.e. MAUT centering on aggregating utility [6,22] and evidence theory (ET) focusing on combining evidence [10,23,24]. MAUT and ET are described next.

- MAUT, without conclusive knowledge, has been proceeding with conditional probabilities [6,25], independence [26], assessment of multiattribute preferences [2,27,28], and utility analysis [29,30]. But these studies focus on variable instead of evidence. The variable presents a scale about a measure. The evidence has characteristics or properties related to some subject of DM. Short of evidence imposes analytical difficulty on MAUT. According to our knowledge, this is the first time using evidence of relevance and dominance to resolve weights for competitiveness utility.
- ET aims to measure belief by evidence without conclusive knowledge initially. However, its belief function did not specify the evidential properties among evidences, thus, the belief combination encounters doubts in evidence dependence [31], side effect [32], and inconsistency [33]. Thereafter, ET separated into evidential reasoning and the rough set theories (RST). The former still does not cover the evidential properties [34,35], thus, it will not be discussed further here. Contrarily, the latter not only overlaps the evidence theory [36] but defines the approximation for relevance and dominance [37], presented as follows.

1.1. RST

RST provides non-determination or determination concepts with probabilistic approximations on uncertain (incomplete and imperfect) data. Its approximation can relate the premise of inference to conclusion thus having potential of explaining relevance or dominance of attributes. It is popularly applied in decision theory [36,38,39], multicriteria decision making (MCDM) [40–44], MAUT [45–47], etc. However, separated probabilities on accuracy, coverage, and certainty have not been converged into a unique probability to consistently explain the evidential relevance and dominance. As known, reality is unique. The probability expressing the evidential properties is better unique for reality. Further, many decision cases have no conclusive knowledge beforehand. The approximation of DRSA is not enough to satisfy such as deriving conclusion from evidence alone and converging the derived outcomes into a unique probability. Naturally, competitiveness weighting is complicate and tough. An adaptive DRSA for competitiveness is necessary. We are motivated to modify DRSA into an evidential model as Fig. 2 composed of approximations and induction rules, using evidence for inference, expressing an inference with a probability, and converging the probabilities of the evidential properties into a unique probability, i.e. EP. Systematically, an approach based on the evidential model is designed to aggregate evidence identified by EPs to resolve EWMP; then utilities of EWMP are fused for decision analysis and prediction. This approach is abbreviated as EPU meaning utility rooted in EP. Finally, EPU will verify her results with WCY for quality evaluation.

In short, this research aims to use evidence to infer EWMP for competitiveness analysis and prediction. Followings are description about the goal: the evidence playing an object for inference has rational characteristics demanded by DM, the inference will derive weighting support through induction, the multiple attributes declare the environment of derivation, and the ordinal preference gives an ordering scale such that combined preferences can be distinguished. The competitiveness is defined by WCY with more than 300 variables, 20 attributes, and 4 factors in a hierarchical structure. The novel idea and implementation of EPU is presented next.

1.2. The framework of EPU approach

Our methodology will fulfill the research motivation and implement empirically. We design a framework for EPU which includes an evidential model expressing induction and probabilities for the evidential properties, a mathematical model containing EPs for aggregating evidence and resolving EWMP, and utility fusion for prediction and analysis. EPU has three stages, as shown in Fig. 1, the evidential model in Stage 1, the mathematical model in Stage 2, and the fusion process in Stage 3.

Stage 1: Fig. 2 is an evidential model used to present how the evidence from an attribute's approximation supports a dominance set of another attribute. The objective of Stage 1 is to transform the evidential properties into the unique probability, EP.

Stage 2: A mathematical model is designed to contain all EPs to aggregate evidence. The objective of Stage 2 is to resolve EWMP in a normalized format. EWMP can quantitatively present a scale of an attribute's dominance supported by the others. The logical link between Stages 1 and 2 is explained in Section 2.3.2.