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Implications of estimating confidence intervals on group fuzzy decision making scores

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ABSTRACT

Group multi-criteria decision making methodologies are widely used tools in a democratic environment. Previous research work in this field has been done by aggregating results of Analytical Hierarchical Process (AHP) and Analytical Network Process (ANP). Further, elaboration of the group methodology has been done to include the fuzziness in the decision making environment in the AHP and ANP analysis. The current aggregation methods in group fuzzy AHP and group fuzzy ANP yield a certain rank-based best option among the available alternatives and criteria according to aggregated mean score method. This research introduces the concept of calculating standard deviation and 95% confidence interval on the aggregated mean score of group fuzzy AHP (GFAHP) and group fuzzy ANP (GFANP). The standard deviation suggests the deviance in the group decision making from the mean scores of the group, and the 95% confidence interval (CI) gives upper and lower CI of the mean score, thus providing the decision makers an interval where the ranks obtained may be valid instead of a single absolute rank. Tukey's HSD tests were done to show if the mean score of the alternatives were statistically significantly different from each other. The study uses Arrow's theorem as a guiding principle which helps in understanding and making decisions in a group fuzzy environment with multiple alternatives where ranking and choosing the alternatives may not always yield a single best choice of alternative. The concept of confidence interval on the group fuzzy decision making scores has been presented by comparing its implication on GFAHP and GFANP using a case study example of online purchase of cookware, perfume and a watches through shopping platforms, Amazon, Walmart and Macy's with male and female participants. An important implication of the study is presented by the results which show that in many instances the ranks of the alternatives are not statistically different from each other. This study acts as a foundation for future research where the methodology used can be combined with Delphi or other complex group argumentation methods to gain more meaningful outcomes in ranking alternatives.

1. Introduction

Group decision making is a complex process requiring the need of multiple criteria decision making (MCDM) methods. MCDM deals with the problem of selecting the best option among the available alternatives which has the highest degree of satisfaction for all the relevant criteria or goals (Javanbarg, Scawthorn, Kiyono, & Shahbodaghkhan, 2012). In order to obtain the best classification among a set of alternatives, a ranking process is required (Javanbarg et al., 2012). Among the many available methods in MCDM, the Analytical Hierarchical Process (AHP) and Analytical Network Process are two typically used methods (Chai, Liu, & Ngai, 2013).

AHP was developed by Saaty with the aim of helping solve complex decision problems by breaking the problem into a multi-level hierarchical structure of objectives, criteria, sub-criteria and alternatives (Saaty, 1980; Saaty, 1982). However, the traditional AHP method suffers from a major weakness; it does not account for uncertainties in decision making. This gave rise to Fuzzy AHP (FAHP). FAHP is an extension of classical AHP, which takes into account the uncertainty of the process in making the decision and elaborates the standard AHP method into the fuzzy domain by using fuzzy numbers for calculations instead of the real numbers (Ayhan, 2013). In FAHP, the pairwise comparisons of both criteria and the alternatives are performed through the linguistic variables, which are typically represented by triangular numbers (Kilincci & Onal, 2011).

The Analytical Network Process (ANP) is an advanced generalization of AHP, which considers the dependence between the elements of the hierarchy. In other words, ANP allows for complex

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interrelationships among the decision levels and attributes and replaces hierarchies with networks in which the relationships between levels are not easily represented by higher, lower, dominant, subordinate, direct or indirect (Rouyendegh, & Serpil, 2010). The inability of the ANP like AHP to deal with the subjectiveness in the pairwise comparison process has been accommodated in the fuzzy ANP (FANP) method which explicitly models the uncertainty in terms of imprecision and vagueness present in the judgement process (Rouyendegh, & Serpil, 2010; Saaty, 1999).

Businesses group modelling or collaborative modelling involve a number of stakeholders (users, domain experts, system analysts etc.) with different skills, expertise and knowledge. These experts are brought together in a problem solving modelling activity. For this reason, research on group decision making in fuzzy environments is vital. In such conditions fuzzy AHP and fuzzy ANP methods have been found to be useful in solving problems in the hierarchical and networked problem domain. In this direction Ayhan (2013) and Zandi and Tavana (2011) have investigated the role of the group fuzzy AHP (GFAHP) and group fuzzy ANP (GFANP). GFAHP and GFANP are multi-criteria decision making methods where two or more stakeholders are part of the decision making process.

In a typical group decision making process using GFAHP and GFANP, the decision makers come out with independent preferences for the same set of questions. To arrive at a final score to rank the available alternatives aggregation of the individual scores of these decision makers is performed. This aggregated score is used to rank the available alternatives with the highest score alternative being ranked first and the lowest score alternative ranked last. This method looks straightforward, but may not represent the group's rank order output accurately in line with Arrow's Theorem (Arrow, 1950). Under this condition, consideration of confidence intervals on the mean score of the group is necessary to obtain the ranking structure. The confidence interval of a score gives the range in which the ranking of the alternative is valid. A statistical significance difference test is also done to verify if the mean scores are significantly different from each other. If the difference between the mean scores of the different alternatives are not significantly different then the ranking of the alternatives overlap. The overlap suggest that the mean scores of the two alternatives are not statistically different and thus, both criteria need to be investigated to arrive at an accurate ranking. If the group mean score of the alternatives are significantly different then they are ranked as per the value of the mean scores.

In this research, we examine the group decision making process in a fuzzy environment using a case study of online purchase of cookware, perfume and watches from the e-commerce websites, Amazon, Walmart and Macy's have been considered. These websites were termed here as the alternatives. To conduct the study, a total number of 20 sample participants (decision makers) with equal number of genders in the age group of 18–35 years were selected to participate in the study. All the participants had previous experience with online shopping at Amazon, Walmart and Macy's and their decision making was independent from one another. Three main criteria were chosen for the study; customer service, cost of the service and delivery of the product. The delivery criteria was further divided in the two sub-criteria: air delivery and ground delivery. In this paper, a triangular fuzzy scale was used for the fuzzy prioritization approach (Mikhailov, 2003) and individual fuzzy AHP and fuzzy ANP scores were calculated using the fuzzy decision matrices (Buckley, 1985). The individual scores of the male and the female participants for GFAHP and GFANP were aggregated using the arithmetic mean, which was then used for calculating the arithmetic standard deviation of the group. The mean value and the standard deviation was eventually used to calculate the 95% confidence intervals which gave the range in which the score ranks were valid. To verify the statistical significance between the mean scores of the alternatives Tukey's statistical HSD test was performed. The study used arithmetic aggregating method using the finding from Ramanathan and Ganesh (1994) who suggested that when the data is collected individually from the user and then aggregated to find the Aggregated Individual Preference (AIP), then arithmetic aggregation method is the most suitable method.

This research contrasts with previous work done in the field of MCDM in that it studied the implication of confidence interval on the GFAHP and GFANP scores and its effect on the ranking of the alternatives. This study shows there were instances where alternatives were not statistically different and hence ranking process could not be effectively applied. This promotes the use of more in-depth analysis to make better decisions.

2. Literature review

The Analytical Hierarchy Process (AHP) was proposed by (Saaty, 1980) to aid the decision making process. It is a multi-criteria decision making tool that uses the Eigen value approach to the pairwise comparison. AHP arranges factors important in the decision in a hierarchical chart and performs pairwise comparisons at each level of the chart. The chart is arranged by overall goal at the top, followed by criteria, sub-criteria, and alternatives for each. In AHP, the decision maker determines the strength of the preference and then calculation is done to find the maximum Eigen value, consistency index (CI), consistency ratio (CR) and normalized values of each criteria or alternatives so as to find an accurate score for the alternatives. In case the maximum Eigen value, CI and CR are satisfactory then the decision is taken based on the normalized value, otherwise the whole procedure is repeated until these values lie in a desired range (Vaidya & Kumar, 2006). AHP has been applied to many different types of decisions making environments (Saaty, 1982) such as social, manufacturing, political, engineering, education, industry and government among many others (Vaidya & Kumar, 2006). Vaidya and Kumar (2006) presented an article that sites 150 application papers of AHP and analyzes 27 of them critically.

Although AHP has been widely used, Dyer (1990) criticized the AHP methodology suggesting it to be flawed as it produces ranks which are arbitrary and not consistent with the actual preferences of the decision maker. This claim was countered by Harker and Vargas (1990) who suggested the argument by Dyer (1990) was risen due to lack of understanding of the underlying theory behind AHP.

Saaty and Vargas (2006), proposed the Analytic Network Process (ANP) as an improvement to AHP (Saaty & Vargas, 2006). While AHP represents a framework with a uni-directional hierarchical AHP relationship (Ding, 2010), the ANP feedback approach replaces hierarchies with networks in which the relationship between levels are not easily represented as higher or lower, dominator or subordinate, direct or indirect (Meade & Sarkis, 1999). In other words, ANP deals with the decision making process without making assumptions about the independence of higher level elements from lower level elements and about the independence of the elements within a level. ANP is an important tool for prediction and for representing a variety of competitors with their surmised interactions and their relative strengths to show its strength in making a decision. To date, a lot of research has been done to demonstrate the application of ANP in the field of strategic policy planning (Ulutas, 2005), market and logistics (Agarwal, Shankar, & Tiwari, 2006), economics and finance (Niemura & Saaty, 2004), civil engineering (Neaupane & Piantanakulchai, 2006) and many others (Ayag & Ozdemir, 2009; Carlucci & Schiuma, 2009; Görener, 2012; Lee & Kim, 2000; Saaty & Vargas, 2006).