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Applying Fuzzy Based Multi-Criteria Decision-Making Method for Identification and Analysis of Stakeholders of an Information System: A Case Study

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ABSTRACT

Stakeholders are the key sources of the requirements of software. For the development of a useful software product, it is indispensable to identify and analyze the stakeholders of software. Various methods have been developed for identifying and analyzing the stakeholders of software. Based on our review, we found that little attention is given for the analysis of stakeholders using cognitive psychology model, which is concerned with how stakeholders think, learn, solve problems, and make decisions based on the need of the software projects. To address this issue, a method has been developed using "Technique for Order of Preference by Similarity to Ideal Solution" (TOPSIS), fuzzy logic, and verbal protocol technique. The usefulness of the proposed method is discussed by considering the stakeholders and requirements of Institute Examination System (IES) and Library Information System (LIS). In the case study, the verbal technique has been employed for the collection of data by the subjects who analyzed both IES and LIS based on their understanding. The results of the proposed method are compared with the following methodologies, i.e., StakePage, StakeRare and StakeSoNet, based on ACT-R model.

Keywords: Information System, StakePage, StakeRare, StakeSoNet, Stakeholders, and Fuzzy Logic.

INTRODUCTION

Stakeholders are the main sources for the requirements of software which must be identified and classified in the early phase of software development process. One of the key activities of software development process is the identification and analysis of stakeholders who will work on software project in an Information Technology (IT) company [1]. Stakeholders are the group of people or individual who can affect the business of a company. Various types of stakeholders are involved in an IT company like developers, testers, project managers, requirements analyst, consultants, etc. Stakeholders are broadly divided into two parts, i.e., (a) internal stakeholders and (b) stakeholder stakeholders. Internal stakeholders have direct relationship with the IT company like investors, project managers, developers, etc. External stakeholders are directly connected with an IT company and have direct impact on the outcome. The external stakeholders include the following: end-users, software product suppliers, etc. A systematic identification and analysis of stakeholders can lead to elicitation of complete set of FRs and NFRs, which may lead to the development of successful software in different sectors like institute sector, school sector, banking sector, etc. [2].

The purpose of an information system is to perform various operations in an organization so that daily need of end-users can be satisfied. The operation includes the following, i.e., capturing the information, storing the data, and handle it as per the requirements of clients. Such kind of operation plays an important in manging the daily activities of an organization; and it can be developed only if the participating stakeholders have been properly identified and analysed according to the need of the project [3]. Different methods, i.e., StakeRare [4], StakeSoNet [5], StakePage [6], etc., have been proposed by the researchers for identifying and

analysing the stakeholders so that the need of an IT company can be fulfilled. Few researchers have also focused on the detection of discordances among the stakeholders prior to the starting of the software requirements elicitation process. For example, Akram et al. [7] developed a method for the detection of discordances among the stakeholders using fuzzy logic. In another study, Akram et al. [8] classified the stakeholders of library information system using fuzzy adjusted cosine similarity measure.

Based on the review of various studies on requirements engineering, it is found that little attention is given to the identification and analysis of stakeholder's using cognitive psychology model. Most of the focus is on the elicitation of various types of requirements, i.e., functional requirements (FRs), non-functional requirements (NFRs), testing requirements of software [9], modeling of FRs and NFRs using use-case diagrams [10]. Arif et al. [9] elicited the FRs and NFRs using UML and goal-oriented method with focus of NFR-framework. In their work, the authors have modelled FRs using various unified modeling language (UML), i.e., use-case diagrams, class diagrams, and activity diagrams. The NFR-framework was employed for representing the NFRs of the system. Different types of NFR propagation rules were introduced by considering the requirements of library information system (LIS). The relationship between different types of UML diagrams were investigates by Siau and Lee [10] in which use-case diagrams and class diagrams were analysed by using the concepts of cognitive psychology. In a recent study, Saxena et al. [11] developed a method using fuzzy TOPSIS for the identification and analysis of the stakeholders. In their work, the stakeholders have been analysed and compared with the following methods, i.e., StakeRare and StakeSoNet methods. In this paper, we have extended our work [11] and analysed the stakeholders using the proposed method as well as the other state-of-the art methods, i.e., StakePage, StakeRare and StakeSoNet methods. The contributions of our work are as follows:

1. An integrated method has been developed by using the fuzzy logic, TOPSIS and cognitive psychology
2. The stakeholders of the IES and LIS have been analysed by using the proposed method
3. The results of the proposed method have been compared with StakePage, StakeRare, and StakeSoNet methodologies using ACT-R model, which is a cognitive psychology-oriented model.

There are six sections in this paper. Section 2 provide the background on stakeholder identification methods and ACT-R model. Section 3 presents the proposed method for analyzing the stakeholders. The experimental work is carried out in Section 4. The results are explained in Section 5. Finally, the Section 6 presents the conclusion.

LITERATURE REVIEW

The objectives of this section are to examine the mathematical basis of the ACT-R model and assess the literature on stakeholder recognition and evaluation techniques. In Section 2.1, we presented the literature survey for three stakeholder identification and analysis methods selected in this study, i.e., StakePage, StakeRare and StakeSoNet, which have been employed in the experimental work. The theoretical underpinnings and research hypotheses are explained in Section 2.2.

Methods for Stakeholders Identification Techniques

Requirements elicitation is a key sub-process of software development in which stakeholders and their needs are elicited with a group of elicitation techniques [12]. This task involves identifying and prioritizing software requirements. Lim and Finkelstein [4] introduced the StakeRare technique, which employs social networking and collaborative filtering to identify and prioritize the requirements of extensive projects. This approach defines the participants, and then leaves it to them suggesting all the stakeholder to recommend other stakeholders based on their role. The social network of the stakeholders is constructed where a stakeholder becomes single node and its recommendations become links. The social network measures are used to rank the stockholders based on their work effect. The StakeRare approach was evaluated by considering the 25,000 client systems. This information was gathered after having surveyed 87 stakeholders. The experimental results show that StakeRare predicts stakeholders effectively. Inspired by [4], Hassan et al. [5] introduced the StakeSoNet methodology in 2021 to help stakeholders understand the social network they built where nodes are the representation of stakeholder and arcs are the recommendations between the stakeholders. In this method, fuzzy logic was employed for dealing with uncertainty. This method comprises the following phases: (a) Get a starting list of stakeholders; (b) identify the role of each participant in the social platform. (c) create a social graph (d) rank stakeholders based on their centrality measures after formulating relationships between elected and remaining stakeholders. In addition to this, Hassan et al. [6] developed a StakePage method for analyzing the stakeholders based on the page ranking algorithm.

ACT-R Model

The notion of schemas and scripts, used to represent different informative systems, is the basis of the ACT-R model. The dichotomy of propositional-based theories includes the theory of schemata and scripts. By using an operation set, the ACT model can replicate the functionality of any framework. Siau [13] introduced a reference framework for systems analysis and design research, based on cognitive psychology. We use the model of human information processing, which incorporates the notion of schemata and scripts, often known as ACT-R or the revised ACT model. It is one of the main models in cognitive psychology [14]. The notion of the nature of human knowledge and how it is

arranged and applied is contained in the ACT-R model [10]. This paradigm has a goal stack and both declarative and procedural long-term memory. The ACT-R model has also been employed for analyzing the stakeholders of an information system in [11]. Figure 1 exhibits the ACT-R model. This study has formulated the following hypotheses (H):

- H1: The completeness of analysing the proposed method, StakePage, StakeRare, and StakeSoNet methodologies is different.
- H2: The sequence combination of the methods, i.e., the proposed method, StakePage, StakeRare, and StakeSoNet affects the completeness of the stakeholders.
- H3: Perceived usefulness is dissimilar among the following methods, i.e., proposed method, StakePage, StakeRare, and StakeSoNet methodologies.
- H4: Perceived ease of use is dissimilar among the proposed method, StakePage, StakeRare, and StakeSoNet methodologies.

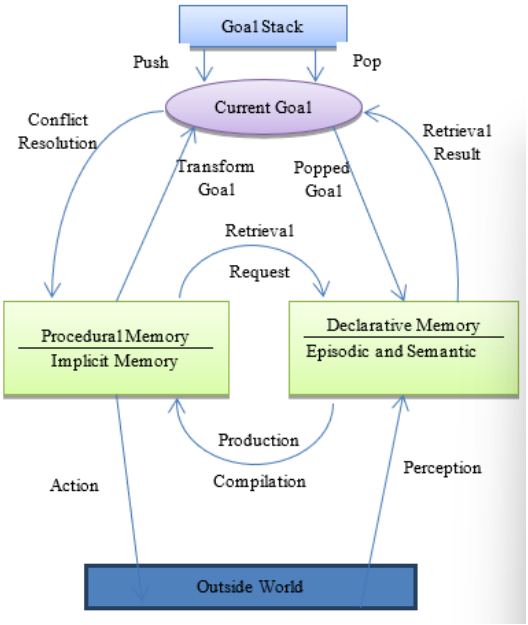

Fig. 1: ACT-R model [10]

PROPOSED APPROACH

The steps of the proposed approach are discussed in this section. The block diagram of the proposed method is exhibited in Fig. 2.

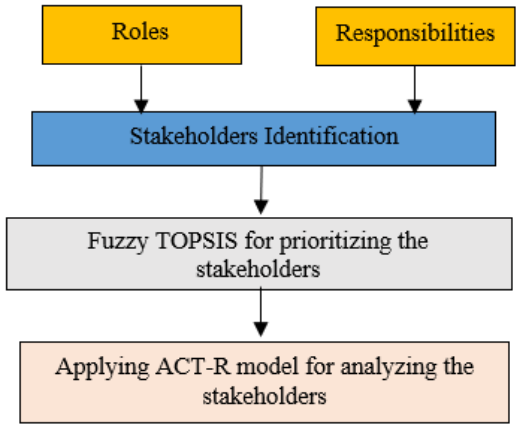

Fig. 2: Block diagram of the proposed method

There are three steps in the proposed method and it is given below:

Step 1: Identification of stakeholders according to their roles and responsibilities

Step 2: Fuzzy approach method for prioritizing stakeholders according to the significance of information system requirements

Step 2.1: Choosing linguistic variable for the process of making decisions

Step 2.2: Evaluation of requirements by the decision makers

Step 3: Stakeholders analysis using ACT-R model

The explanation of the steps of the proposed approach is given below:

Step 1: Identifying of stakeholders according to their roles and responsibilities

The primary sources of an information system's requirements are its stakeholders. Therefore, in order to elicit a complete list of requirements, it is necessary to identify the stakeholders of an information system before eliciting its requirements. The aim of this step is to distinguish the stakeholders according to their responsibilities and duties. Stakeholder roles and duties are determined by the project's requirements. Regarding the various types of quality and non-quality requirements of an information system, the stakeholders are determined in this step.

Step 2: Fuzzy approach method for prioritizing stakeholders according to the significance of information system requirements

Stakeholder analysis is very difficult activity as it involves the participation of multiple stakeholders during the software evaluation process. Decision-makers may employ linguistic variables in real-world applications to get feedback regarding stakeholders.

Consequently, this phase uses fuzzy logic to model the linguistic variable.

Step 2.1: Choosing linguistic variable for the process of making decisions

Linguistic variables are employed for capturing the opinions of decision makers. Following types of the linguistic variables have been employed in our work, i.e., "Very Low" (VL), "Low" (L), "Medium" (M), "High" (H), and "Very High" (VH).

Step 2.2: Evaluation of requirements by the decision makers

Decision-makers opinions about the stakeholders are captured using the linguistic variables chosen in the previous step, allowing for a proper analysis based on the significance of the information system requirements. Thus, in this steps, the requirmeents are evelauted by the decsion makers and their opinions are strored in the preference matrix. Then, fuzzy "Technique for Order Preference by Similarity to Ideal Solution" (TOPSIS) is applied for computing the ranking order of the stakeholders [2].

Step 3: Stakeholders analysis using ACT-R model

The objective of this step is to analyze the stakeholders using ACT-R model and it includes the following steps: (a) research methodology (b) subjects (c) experimental design and (d) data collection methods and data analysis [10].

EXPERIMENTAL WORK

This purpose of this section is to explain the steps of the proposed approach while considering the stakeholders of an Institute Examination System (IES). The IES is an information system which deals with the examination activities of the students and faculty members of an institute [3].

Step 1: In this step, the stakeholders of an IES have been identified based on the roles and responsibilities. The key list of the stakeholders of an IES is given below:

Controller of Examinations: The necessity of digitizing examination processes has grown more apparent in modern educational institutions. The goal is to reduce the number of times students visit the office of the Controller of Examinations by streamlining procedures like the distribution of examination schedules and the submission of end- semester examination forms. This change not only increases operational effectiveness but also greatly enhances the educational experience for students.

IT Company: The stakeholder's responsibility is to develop an Institute Examination System (IES) to meet the requirements of the institution's director, professors, and students. The IES will optimize processes, improve productivity, and offer a consolidated platform for managing examination-related activities, while guaranteeing accessibility, security, and scalability. This stakeholder is tasked with building a proficient team to identify, model, implement, test, and provide a complete set of IES requirements customized to the client's specifications.

Reviewer and Testers: This stakeholder seeks to fully understand the Software Requirements Specification (SRS) document to guarantee that all the requirements of an IES have been identified. Their duty is to meticulously validate each need, guaranteeing the result is precise and devoid of errors.

Step 2: This phase seeks to classify stakeholders according to the significance of IES requirements. We have identified three primary stakeholders, each potentially associated with various sub-stakeholders. In an organization, stakeholders may comprise researchers, requirements modelers, cost estimators, analysts, and developers. We employ the Fuzzy TOPSIS method to efficiently handle several stakeholders. A C program was written to rank the stakeholders into groups based on the following linguistic variables, i.e., VL), L), M), H, and "VH. These variables have been modeled using triangular fuzzy numbers (TFNs). The membership values of the linguistic variables are illustrated in Fig. 3, where μS(x) denotes the membership value (μ) of set S for element x. The C program documents and analyzes the perspectives of decision-makers, allowing the fuzzy TOPSIS method to classify the IES stakeholders. The classification results indicate that the director possesses significant influence and interest in the project developers exhibit minimal influence yet substantial interest, whereas students (end users) demonstrate both low influence and interest. This classification aids requirements analysts in the selection and prioritizing of information system requirements.

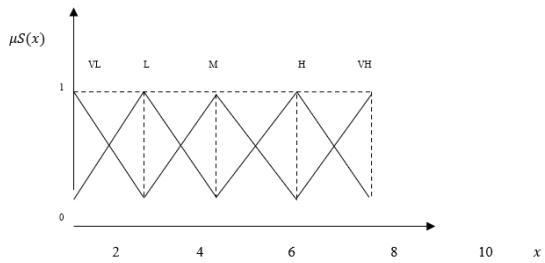

Fig. 3: Membership functions of linguistic values for the classification of stakeholders of an IES

Step 3: The experimental work is carried out using questionnaire and process-tracing method. The process tracing method is an effective way for capturing the data as compared to the input-output analysis. The questionnaire was filled by the subjects based on the proposed method and other selected methods.

(A) Subjects

The subjects in this study were the students of Mangalayatan University Aligarh, Uttar Pradesh, India, and trainees from Indraprastha Institute of Information Sciences Private Limited, New Delhi, who have completed at least one course of Software Requirements Engineering. We invited 45 students to participate in the experimental work.

(B) Designing of Experiment

For analyzing the stakeholders, both dependent and independent variables have been chosen. The information about two domains with focus on the "Institute Examination System" (IES) and "Library Information System" (LIS) is exhibited in Table 1 in which following acronyms are used: PM for proposed method, STKR for StakeRare method, STSN for StakeSoNet method, and STPG for StakePage method. Following are the independent and dependent variables: Independent variables: PM, STKR, STSN, STPG. The dependent variable includes the following: "Subject's performance for analyzing the stakeholders by these methods".

Table 1: Experimental Design

Treatment (T)	Domain	
	Domain 1 (IES)	Domain 2 (LIS)
T-1	Sequence 1: STKR→STKR+PM	Sequence 2: STSN→STSN+STKR
T-2	Sequence 2: STSN→STSN+STKR	Sequence 2: STKR→STKR+PM
T-3	Sequence 3: PM→PM+STSN	Sequence 3: PM→PM+STKR
T-4	Sequence 4: STPG→STPG+PM	Sequence 4: STPG→STKR+PM

(C) Methods of Data Collection and Data Analysis

The verbal protocol analysis [15] was employed by subjects to express their outcomes. The output of experimental sessions was recorded so that it can be coded and analysed. The recorded data was formatted and itemized based on the data identified from proposed method, StakeRare, and StakeSoNet methods. The final data was normalized to qualify consistent comparison of the final data scores.

(D) Problem Domain

Two problem domains have been used in the experiment work. Problem domain-1 was a system analysis of an IES; on the other hand, problem domain-2 was the system analysis of a LIS. The stakeholders of these two systems were adopted from the existing published materials to impose internal reliability of the experimental design. The problem domain-1 was adopted from the work of Sadiq and Devi [16] published in IETE Journal of Research, Taylor and Francis in 2021. The problem domain-2 was adopted from the work of Arif et al. [9] published in International Journal of Information Technology, Springer, in 2022.

(E) Perceived Utility and Perceived Simplicity of Use

The experimental work in this section has been carried out based on two determinants, i.e., "perceived usefulness (PEU)" and "perceived ease of use (PRU)". In this paper, two determinants have been used during the experimental work, i.e., "perceived usefulness" and "perceived ease of use". Perceived usefulness can be defined as "the degree to which a person believes that using a particular system would enhance his or her job performance" [17, p, 320]. It refers to the belief that the system people are using will enhance their ability to perform their tasks more effectively [17]. The perceived ease of use can be explained as "the degree to which a person believes that using a particular system would be free of effort" [13, p. 320]. At the end of the session, the subjects were requested to provide the answers of the questions based on the responses on PEU and PRU by considering the proposed method, StakePage, StakeRare method, and StakeSoNet method. The seven-point scale was used to capture the responses of the subjects based on two determinants, i.e., PEU and PRU: "neutral", "strongly disagree", "moderately agree", "slightly agree", "strongly agree", "slightly disagree", and "moderately disagree".

The following questions were formulated for PEU, i.e., (i) finish stakeholders' analysis more efficiently, (ii) enhances requirements identification process, (iii) handles the linguistic variables, (iv) elicit a comprehensive set of FRs and NFRs, and (iv) simplifies the requirements analysis process. The following questions were designed for PRU: (i) simplifies the identification of stakeholders in an information system, (ii) simple to comprehend, (iii) rigid and difficult to understand, (iv) simple to recall the process of stakeholder analysis, and (v) user-friendly.

RESULTS AND DISCUSSION

The final data was obtained from the counts of matching information elements gathered by 30 subjects during the protocol analysis. A normalization procedure was then used to normalizes the counts which were obtained from the proposed method, StakeRare method or StakeSoNet method. The counts percentile was then employed for every method. Both "T-test" and "Analysis of Variance" (ANOVA) were used during the statistical analysis. The ANOVA test was conducted to elicit the difference between two groups using variance. The means of two groups was compared by applying the T-test. The aim of T-test is to determine whether a treatment (T) has an impact on the target population or whether there is a difference between the two groups. The results of the hypothesis testing are exhibited in Table 2.

Impact of diagrammatic analysis

The ANOVA test is employed for analysing the outcome of the methods on completeness of stakeholders and it shows the statistical difference as ($0.000<p<0.001$), which means that there is a substantial difference between two methods. The result supported the hypothesis HI, i.e., "The completeness of analysing the

StakePage, StakeRare and StakeSoNet methodologies is different".

Impact of the diagram type analysis

The effect on the amalgamation of StakeRare (SR) method and StakeSoNet (SN) method is discussed in this section. Initially, the stakeholders are analyzed by using the StakeRare method. After that both the proposed method and StakeRare method were used for analysing the stakeholders, i.e., STKR STKR+PM (Sequence-1). In the second round, the stakeholders were analysed by using the StakeSoNet method. After that the stakeholders were analysed by using the StakeRare method and StakeSoNet method, i.e., STSN STSN+STKR (Sequence-2). The ANOVA test is then employed for analyzing the effect of both the sequences. Based on the insignificant difference of 0.685, it was found that the hypothesis H2: "Sequence combination of STKR and STSN affects the completeness of stakeholders' understanding" is not supported. The same procedure was adopted to the proposed method, as well as the StakeSoNet and StakeRare methods.

Table 2: Results of hypothesis testing

p-value for Hypothesis	Supported
H1 < 0.001	Yes
H2 > 0.05	No
H3 > 0.05	No
H4 > 0.05	No

Perceived utility and user-friendliness

There is no statistical difference among StakePage, StakeRare, and StakeSoNet methods when analyzed based on PEU and it invalidates the hypothesis H3. We found some differences in PRU between StakeRare and StakeSoNet methodologies. The 0.415 value was produced by the ANOVA test with a p-value outside 0.05. Thus, the hypothesis H4 lack support which proclaims a difference in PRU between StakeRare method and the StakeSoNet method. The participants thought that the proposed method as well as StakeRare and StakeSoNet methods are beneficial for evaluating the different types of the stakeholders. The proposed method only supports fuzzy based classification of stakeholders based on their salience.

CONCLUSION

A method for analysing the stakeholders using fuzzy TOPSIS is presented in this paper. The proposed method classifies the stakeholders based on the importance of the requirements. There three steps in the proposed method, i.e., (i) identification of stakeholders according to their roles and responsibilities, (ii) fuzzy TOPSIS based approach method for prioritizing stakeholders according to the significance of information system requirements, and (iii) stakeholders' analysis using ACT-R model. Our results shows that stakeholders are analysed differently by the proposed method, as well as StakePage, StakeRare, and StakeSoNet methods; and these methods were also applied in sequence. The proposed method analyses the stakeholders based on the importance of the requirements in which fuzzy TOPSIS method was employed for analysing the requirements of stakeholders based on the importance. There is no variation between PEU and PRU among StakePage, StakeRare, and StakeSoNet methods. In future, the StakePage method under rough-set theory environment will be used for the analysis of the stakeholders in addition to StakeRare and StakeSoNet methods.

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