Analytical Hierarchy Process Issues and Mitigation Strategy For Large Number of Requirements—An Experimental Study

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Abstract—Now-a-days most software projects have more candidate requirements. So it is vital for software companies to use different prioritization techniques to select valuable requirements among the candidate requirements. But software companies usually face a lot of challenges in using AHP such as increase in time and complexity with respect to number of comparisons. In this paper, we present previous work carried out in this research area and industrial study to identify the challenges software companies face while prioritizing large number of requirements using AHP. Different types of prioritization techniques have been developed to resolve these challenges. This paper focuses on Numeral assignment technique which groups requirements into three categories: critical, standard and optional and AHP which prioritize requirements based on pair-wise comparisons. In this article we proposed a model i.e., NAcAHP where pair-wise comparison of AHP is applied on critical group of Numeral assignment technique for prioritizing the requirements. The result shows that the proposed model minimizes the time and complexity of pair wise comparison.

Keywords— Requirement Engineering; Analytical Hierarchy Process; Requirement Prioritization; NAcAHP.

I. INTRODUCTION

The quality of software product is often determined by the ability to satisfy the needs of the customers and users [1]. Since most software development projects have more candidate requirements than can be realized within the time and cost constraints. Therefore, it is often problematic to implement all requirements that have been elicited [1] [2].

Requirement prioritization aims at selecting and implementing a subset of the candidate requirements and still produces a technique which meets the most essential requirements of the stakeholders, and thereby providing quality for the customers [2]. Furthermore prioritization of requirements plays an integral role in software development by helping the software companies to plan for system releases and also helps in deciding which requirements to be implemented in each release, according to budget and time constraints coupled with customer expectations [1] [2]. Moreover there are number of prioritization techniques that are available to prioritize requirements with their associated strength and limitations [3]. These includes: Analytical Hierarchy Process (AHP), B-Tree, Commutative Voting (100-dollar), Numeral assignment, Ranking, Top Ten Requirements, and Planning Game, spanning tree matrix, bubble sort [2-5].

According to Wohlin et al. [4], AHP is the most promising method compared to the above mentioned techniques. The authors used AHP as a prioritization technique in industrial follow up study. Consequently AHP provided reliable results, could able to promote transfer of knowledge and also could create a very good accord amongst project members. Though it gives out fruitful results, it still has problems of scaling up which implies AHP technique is complex and time consuming while prioritizing large number of requirements. Even Numeral assignment technique has ample applicability and also helps in grouping up and classifying requirements with respect to stakeholders in a very easy manner. But stakeholders set most of the requirements as critical which leads to greater part of the requirements to be implemented. Furthermore requirements depicted in each group are assigned the same priority which implies Numeral assignment technique fails in assigning unique priority to the requirements.

As both AHP and Numeral assignment technique has pros and cons in prioritizing requirement. An effective amalgamation of different prioritization technique is required.

Objective

In this paper we present the challenges and their solution when Analytical Hierarchy Process (AHP) prioritization technique is applied on large number of requirements. In this study we analyze that even if AHP is more efficient prioritization technique when it is applied for large number of requirements, the number of pair wise comparison will be increased and this makes the prioritization process complex and time consuming. In order to resolve this problem we propose a new model by combining Numeral Assignment with AHP and analyze the results when our proposed model is applied on large number of requirements.
The objective of this study is to help the stakeholders to prioritize large number of requirements by integrating Numerical assignment technique with AHP. The Numerical assignment technique categorize large number of requirements into three priorities groups namely a) critical, b) standard c) optional and then pair wise comparison (AHP) is carried out on requirements present in critical group. The remainder of this paper is organized as follows. In section III we outline the research methodology used for this study, in section-IV the data is analyzed and results are presented according to the described research methods and in section-V we present discussion and validity threats. Finally in Section-VI we describe the conclusion.

II. BACKGROUND/RELATED WORK

Researchers are focusing on different aspects of requirement prioritization techniques and try to evaluate these techniques and some of them propose new models/frameworks to make effective decision in prioritizing large number of requirements. As Muhammad Aasem et al, presents the analysis of different prioritization techniques with their strengths and limitations [3]. Based on their findings they propose a new framework by combining existing prioritization techniques (100 dollar, AHP, B-tree) that can be used to prioritize small, medium, and large number of requirements [3]. Amir Seyed and Rodina Ahmad [2] talks about the evaluation of AHP and Numerical assignment prioritization technique, the result of the study shows that AHP gives more accurate and more informative result than the Numerical assignment technique [2]. Md. Rizwan Beg et al, propose a method called B-tree to reduce the number of comparison in prioritizing large number of requirements by keeping the process simple [6]. This method uses balanced search tree that creates a structure which could maintain easy searching of the requirements, it also could be helpful in keeping the comparison as low as possible [6]. But the limitation of this study is that they assume requirements are independent. Hence, the method should be evaluated in the situation where the requirements are dependent [6]. Previous findings indicate that currently used prioritization methods have limited ability to support decision making in a complex area like requirements prioritization in market-driven product development [5]. Based on those findings Muhammad Atif Iqbal et al, proposes a new model called MDRPM (Market Driven Requirement Prioritization Model) which uses AHP (Analytical Hierarchical Process) [5]. In this model number of comparisons as compared to traditional AHP techniques are significantly reduced which make it practicable and applicable [5]. The limitation of this study is that, it assumes that there is no dependency between the candidate requirements and no conflict between the stakeholders during pair wise comparisons of the requirements [5].

Based on the study done by Karlsson et al, on the differences between Planning Game (PG) and AHP; they stated that it would be interesting to combine PG with AHP, so that this combined method would use the strengths in each method and eliminate their weaknesses [10].

A. Research Questions

RQ1. What are the challenges faced when AHP is applied as a prioritization technique for large number of requirements?

The systematic literature review and survey we conducted depicts, prioritizing large number of requirements using AHP creates high complexity and consumes lot of time from stakeholder(s) point of view. The detail answer is explained in Section III (especially SLR and Survey) and in Section VI.

RQ2. What approaches have been done previously to solve the problems faced when AHP is applied on large number of requirements?

The answer is described in Section III (especially SLR) and Section VI.

RQ3. What new practices are needed in order to minimize time and complexity of pair wise comparison when AHP is applied on large number of requirements?

The detailed answer for this question is explained in section IV especially in experiment result analysis section.

III. METHODOLOGY

Mixed research methodology approach comprising of both qualitative and quantitative methodologies are used in this study. For qualitative research approach, Systematic literature review was carried out according to the guidelines provided by Kitchenham [13] and then we conducted survey with software companies in order to catch up with the trend based on our selected area of research. Finally to prove the hypothesis, an experiment was conducted as part of quantitative research approach.

A. Qualitative Methodology

Systematic literature review proffered us the brief insight on previous work carried out on our selected area of research. Then we conducted survey using questionnaires and interview with software companies to catch up the challenges the industry face when analytical prioritization technique is carried out on large number of requirements.

1) Systematic Literature Review

Implementation of AHP and Numerical assignment technique has a great impact on prioritizing requirements in software industries. Systematic literature review helped us in gathering background knowledge on pros and cons of these prioritization techniques and their implementation in software industries. Our motivation behind complementing the systematic literature review was to extract the challenges and issues faced when AHP or Numerical assignment technique is used for prioritizing requirements especially when prioritizing large number of candidate requirements. We compiled 26 articles based on our research area which include journals, conferences and books published between 1979 and 2011. A gap in the present research area was also figured out via systematic literature review. Systematic literature review
helped us in narrowing down our research for selecting a research topic of our interest. The result of the literature review is depicted in background and related work section. Furthermore systematic review served as the input for quantitative approach.

2) Survey

“Survey aims at the development of generalized suggestions. Survey is a snapshot of a situation to capture the current status.”[7] Our survey was based on explanatory claims about the population. Explanatory survey explained us why software industrial practitioners/professionals prefer one prioritization technique while others prefer a different one. By observation and examination we tried to explain why software industrial practitioners/professionals choose one of the prioritization techniques. We selected survey as qualitative approach to analyze the pros and cons of prioritizing candidate requirements using Analytical Hierarchal Process technique. According to Claes Wohlin, survey may be used as opinion polls and market research [7].

a) Company Selection

Industrial environment is the best place to collect information on prioritization technique because our main focus is on why AHP is not suitable for large number of requirements. Moreover data collected from software companies is like collecting data from a dynamic environment. We selected those software companies who used AHP prioritization technique to prioritize candidate requirements. We acquired information about the software companies via websites.

b) Participant Selection

Participants we selected were the ones who were associated to the company as system analysts, senior software engineer, software developer, designers, business analysts, project managers, SQA managers. Our main agenda was to compile information in a systematic way, so participants who donned different roles and responsibilities in the same company were opted. The above mentioned tactics helped us in effectively review the information. We selected those participants who had a fair amount of knowledge on AHP prioritization technique. This helped us in analyzing the impact and consequence of AHP prioritization techniques.

c) Questionnaire Creation

We used the questionnaire to gather suggestions and opinions at the specific topic. To acquire good results we took pre-test with selected students of master in Software Engineering interrelated to this subject and having diverse cultural background. The questionnaire form contains open-ended as well as close-ended questions, to minimize the risk of missing information and loosing the interest of the respondent. The different types of the questions were included in the questionnaire form such as multiple choice questions, descriptive and Boolean type. We pointed out the problems faced by the selected candidates during the pre-tests and later to improve the questions. Opinions and suggestions of the candidates were collected and in the qualitative phase statistics taken from the survey for in depth answer to the research questions.

d) Data Collection

Primary means of qualitative and quantitative data were compiled via interviews and questionnaires [7]. We send out questionnaires to the participant via email; due to lack of time and budget, sometimes it is not feasible to visit the software companies or conduct meetings [12]. Our participants were employees of software companies who donned different roles and responsibilities, are the sample of developers that answer questionnaires. Before sending the questionnaires form to the entire target participants, we first test the form on few people from the target group. Therefore revised questionnaire form and make again test before sending out the final version.

The collected information were arranged in a specific manner that later be used in a quantitative or qualitative methods [7]. To increase the probability of questionnaires understanding, we contacted the participants and present them the purpose of the study. The process of carrying out an interview helped us in gathering sufficient amount of knowledge about present work in the specific domain and current problems. This is not a good approach in discovering the goals and critical issues; it can extract some future ideas [8]. Interviews gave us a way of establishing trust among the interviewee and also helped us in extracting valuable suggestions from interviewees. We also conducted 5 face to face interviews and 8 telephonic videos conferences.

e) Data Analysis

The data collected from industrial professionals or practitioners is analyzed by tabulation of a questionnaire survey. The list of benefits and challenges of AHP were collected from questioners and interviews are described in the Table I.

<table>
<thead>
<tr>
<th>No</th>
<th>Benefits of AHP</th>
<th>participants Supported</th>
<th>participants not Supported</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Reliability of results increases</td>
<td>19</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>Granularity increases</td>
<td>15</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>Clarification of each requirements increases</td>
<td>21</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>Complexity increases</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>Time consumption increases</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>CR increases</td>
<td>15</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>Number of comparison increases</td>
<td>21</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>Result accuracy decreases</td>
<td>15</td>
<td>6</td>
</tr>
<tr>
<td>9</td>
<td>Effort increases</td>
<td>20</td>
<td>1</td>
</tr>
</tbody>
</table>
B. Quantitative Methodology

Quantitative research is mainly concerned with quantifying a relationship or to compare two or more groups [12]. The aim is to identify a cause-effect relationship [7].

1) Experiment Process

Experiments were carried out in the following steps:

   a) Experiment Definition

   Experiment definition gave us the basic foundation for the experiment.

   Goal of the experiment:

   Our goal is to prove that integration of Numeral assignment technique with AHP will solve the problem of prioritizing large number of requirements. It reduces time consumption and the complexity in terms of calculating pair wise comparison of requirements with main focus on estimating importance and informative level of each requirement.

   Motivation:

   Quantitative approach is known for fetching quantitative data from controlled experiments which promotes comparison and statistical analysis [7]. Previous work on AHP suggested us that AHP has a problem in scaling up i.e., AHP is not suitable for prioritizing large number of requirements [1-5]. This problem in AHP motivated us to carry out a research on how AHP can be used in prioritizing large number of requirements. We proposed that it would be interesting to combine AHP with Numeral Assignment prioritization technique; so that this combined method would use the strengths in each method and eliminate their weaknesses. Our modus operandi is to prove that integration of Numeral Assignment technique with AHP can give better result in terms of reducing time consumption and complexity than carrying out AHP technique individually on large number of requirements. Since we need to carry out the statistical analysis and comparison on the above mentioned techniques we selected quantitative approach.

   b) Experiment Planning

   Planning phase of our experiment helped us in preparing for how the experiment has to be conducted.

   Context Selection:

   Since our experiment needs large number of requirements, industrial context was suitable because industries can provide large number of requirements. Due to limitations in number of subjects moreover their availability and cost associated in conducting the experiment, we selected academic environment/context with M.Sc in Software Engineering students as subjects to carry out the experiment. Our experiment was carried out in offline situation. The problem we worked on is a real problem which industry experts are very keen to know the results of our experiment. Our experiment is valid to specific Software Engineering domain.

   Hypothesis Formulation:

   Hypothesis testing forms the basis for statistical analysis of the experiment [7]. Experiment definition was formalized into hypothesis during planning phase. Our hypothesis includes:

   I) Null Hypothesis: Integration of Numeral assignment technique with AHP i.e., our proposed model NAcAHP will not result in reduction with respect to time and complexity of calculating pair wise comparison as compared to AHP on large number of requirements.

   \[ H_0: \mu_{\text{old}} = \mu_{\text{new}} \]

   II) Alternative Hypothesis: Integration of Numeral assignment technique with AHP i.e., our proposed model NAcAHP will result in reduction with respect to time and complexity of calculating pair wise comparison as compared to AHP on large number of requirements.

   \[ H_1: \mu_{\text{old}} < \mu_{\text{new}} \]

   Different types of risks can be associated while testing the hypotheses

   • Type-I-Error: The conditional probability of rejecting the null hypothesis even though null hypothesis is said to be true [7].

   \[ P (\text{type-I-error}) = P (\text{reject } H_0 | H_0 \text{ true}) \]

   • Type-II-Error: The conditional probability of not rejecting the null hypothesis even though null hypothesis is said to be false [7].

   \[ P (\text{type-II-error}) = P (\text{not reject } H_0 | H_0 \text{ false}) \]

   To evaluate these errors we have used statistical test depicted in analysis section which reveals the true pattern if integration of Numeral assignment technique with AHP i.e. our proposed model NAcAHP will not result in reduction with respect to time and complexity of calculating pair wise comparison as compared to AHP on large number of requirements is false.

   We chose a test with very high power as possible.

   \[ \text{Power} = P (\text{reject } H_0 | H_0 \text{ false}) = 1 - P (\text{type-II-error}) \]

   Variables Selection:

   We chose independent and dependent variables which were required for the experiment.

   • Independent Variables: are variables which can be controlled by us in the experiment [7].

   ➤ Participants in the experiment
   ➤ Location (decide where the experiment was carried out with the involvement of participants)
   ➤ Time (decide when to start the experiment with the involvement of participants)
   ➤ Guide line (for participants on how to carry out the methods)

   • Dependent Variables: are variables which need to be evaluated by us during our experiment [7].

   ➤ Complexity of the method
   ➤ Time to execute a method
Selection of Subjects:
We chose “Convenience Sampling” non-probability sampling technique for selection of subjects. Here the most convenient and nearest people are selected as subjects [7]. The subjects were students who had taken “Master of Science in Software Engineering” program in Blekinge Tekniska Högskola. For optimized result we followed certain protocols while selecting the subjects. The selections of Software Engineering students were based on the following criteria:
- Students should have very good grades (A/B) in requirement engineering course.
- Students should have 1-3 years of industrial experience in software companies.
Since population of subjects selected were only eight, Subjects should have a very clear idea on Analytical Hierarchy Process (AHP) and Numeral Assignment prioritization techniques.

c) Experiment Design
Design phase in experiment helped us in applying the statistical analysis. Because statistical analysis depends on the chosen design and measurement scales used [7].

Design Principle
We used “Randomization” as our design principle to carry out the experiment. Randomization helped us in selecting subjects which were the representative of the population of similar interest and had good knowledge on prioritization techniques such as AHP and Numeral Assignment. Moreover randomization averages out the effectiveness of our factor [7].

Design Type
We selected “Paired Comparison Design” as a design type for carrying out the experiment. We had one factor and two treatments.
- One Factor: Time taken in prioritizing 40 requirements
- Treatment 1: AHP prioritization technique
- Treatment 2: Our proposed model NAcAHP i.e., the combination of Numeral Assignment with AHP prioritization technique.

Here each subject was assigned both treatments on the same object [7]. Our experiment was suitable for paired comparison design type because the mean of the differences between two treatments were either greater or lesser than zero i.e. not equal to zero.

d) Experiment Instrumentation
According to Wohlin, there are 3 types of instruments for an experiment namely:
- Objects: The objects needed for conducting the experiment are a seminar hall with good infrastructure, requirements specification document, calculator, and control members to guide the participants.
- Guidelines: Process descriptions on how to apply AHP and the proposed model NAcAHP which is the combination of Numeral Assignment with AHP technique in prioritizing requirements.
- Measurement Instruments: After the completion of the experiment interview was conducted by using questionnaires.

e) Experiment Preparation
We alerted the subjects a week before the actual test. For subjects to feel like test was conducted in industry like atmosphere, we assigned toy problems which also served as a practice ground for subjects to work on before the actual test. A brief and concise purpose was stated a day before conduction of experiment. We did not reveal the complete motivation and description of the experiment thoroughly to the subjects because of construct validity such as hypothesis guessing and evaluation apprehension. We carried out the briefing and experiment on weekend so that neither the assignment nor lecture should hinder subjects’ involvement in the experiment.

f) Experiment Execution
We conducted the experiment at once. We made sure all participants were present on the day of experiment. We selected seminar hall as a meeting point for conducting the experiment. The advantage of gathering people at once
- Helped us in collecting data with ease.
- When questions rose up, we experimenters were present to resolve the questions directly.

Data Collection
Data were collected manually from the participants in the form of fill out forms. Subjects had to fill out the assigned priority of each requirement and time the participants took to carry out the comparison of requirements using AHP and NAcAHP.

Experimental Environment
We conducted the experiment in a seminar hall. The experiment is conducted in stages:
- Stage 1: Eight participants were given the requirements specification document, guide line, calculator, and forms to calculate the comparison on 40 requirements using AHP prioritization technique.
- Stage 2: The same eight participants were given the same requirements specification document, guide line, calculator, forms to calculate the comparison on 40 requirements using Numeral Assignment prioritization technique by grouping 80% of the requirements as critical.
- Stage 3: Once again those eight participants were given the same requirements specification document,
guide line, calculator, and forms to calculate the comparison on 32 (80% of 40 requirements) critical requirements using AHP prioritization technique.

IV. ANALYSIS OF EXPERIMENTAL RESULTS

A. Descriptive Statistics

Numerical processing and presentation of data set were carried out in descriptive statistics section. Descriptive statistics were used to describe and graphically represent very interesting aspects of the data sets. This is carried out after collecting experimental data [7].

We have plotted a two dimensional bar graph as shown in Figure I.

![Fig. 1. Experiment configuration](image)

This graph helped us in analyzing how experimental data set were distributed. We also could analyze the complexity level of prioritizing 40 requirements using AHP and NAcAHP. The experimental data we collected from the experiment was depicted in Table II. Since standard deviation did not go beyond seven minutes [9]. Our experiment successfully handled the threat of hypothesis guessing.

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Treatment 1</th>
<th>Treatment 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>337</td>
<td>279</td>
</tr>
<tr>
<td>2</td>
<td>325</td>
<td>271</td>
</tr>
<tr>
<td>3</td>
<td>328</td>
<td>272</td>
</tr>
<tr>
<td>4</td>
<td>327</td>
<td>273</td>
</tr>
<tr>
<td>5</td>
<td>320</td>
<td>274</td>
</tr>
<tr>
<td>6</td>
<td>325</td>
<td>272</td>
</tr>
<tr>
<td>7</td>
<td>323</td>
<td>269</td>
</tr>
<tr>
<td>8</td>
<td>327</td>
<td>265</td>
</tr>
<tr>
<td>Mean</td>
<td>326.5</td>
<td>272.27</td>
</tr>
</tbody>
</table>

The total number of comparisons carried out in each treatment is depicted Table III.

<table>
<thead>
<tr>
<th>Number of comparisons</th>
<th>Treatment 1</th>
<th>Treatment 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>780</td>
<td>664</td>
</tr>
</tbody>
</table>

The result of the two treatments shows that, when 80% of the total requirements grouped under critical category our new proposed model (NAcAHP) produced less number of pair wise comparison than AHP prioritization technique.

B. Hypothesis Testing

“The impartial of hypothesis testing is to see if it is possible to reject a certain null hypothesis, $H_0$, based on a sample from some statistical distribution.” [7]. Since our aim was to reject the null hypothesis, we used one of the parametric test i.e., paired t-test hypothesis testing.

- **Paired T-Test**

Our test has to be carried out on paired comparison design. Furthermore only one group of eight subjects was selected and every subject used both the treatments which result in repeated measures. To compare these repeated measures paired t-test was used.

The expected result from paired-t test is depicted in Table IV:

<table>
<thead>
<tr>
<th>Pairing t-test</th>
<th>Input</th>
<th>Paired samples $(x_i, y_i)$ for instance, $(337,279), (325,271),...,(327,265)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ho</td>
<td>$\mu_d = 0$, where $d_i = x_i - y_i$</td>
<td></td>
</tr>
<tr>
<td>Calculations</td>
<td>$SD = \sqrt{\frac{\sum_{i=1}^{n} (d_i - \bar{d})^2}{n-1}}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$SD_d = 4.565$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$t_0 = \frac{d}{SD/\sqrt{n}}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$t_0 = 54.625/(4.565/2.828) = 33.839$</td>
<td></td>
</tr>
<tr>
<td>Criterion</td>
<td>Two sided ($H_1: \mu_d \neq 0$): Rejected $H_0$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Because $</td>
<td>t_0</td>
</tr>
<tr>
<td></td>
<td>$</td>
<td>t_0</td>
</tr>
<tr>
<td></td>
<td>$33.839 &gt; 2.365$</td>
<td></td>
</tr>
</tbody>
</table>

$\mu_d$ = expected mean of the difference  
$n$ = number of samples i.e., subjects used  
$SD_d$ = Standard deviation
\[ d_i = \text{expected mean of the differences} \]
\[ d' = \text{mean of the difference } d_i \]

Henceforth, we rejected \( H_0 \) i.e. NAcAHP resulted in reduction with respect to time and complexity of calculating pair wise comparison as compared to AHP on large number of requirements.

V. DISCUSSION AND VALIDITY THREATS

A. Validity Threats

Validity threats are those which affect the validity of the experiments.

1) Internal Validity

Threats to internal validity are those kinds of threats without the researcher’s knowledge; it can affect the independent variables with regards to causality [7].

a) Maturation

As time pass, subjects have the tendency to react differently [7]. For subjects to participate actively in the experiment we offered food and fruit juice during break between each stage of the experiment.

b) Instrumentation

Incorrect process description and ambiguous requirement specification given to the participants can affect the execution of experiment. So we carefully prepared those documents by consulting the professor to review process description and requirement specification document.

2) Construct Validity

Construct validity focus on generalization of the result extracted from experiment to the theory or concept concerning the experiment [7].

Social threats to construct validity include:

- **Hypothesis Guessing**: When subjects base their behavior on guesses either positively or negatively about the hypothesis, and then it is termed hypothesis guessing [7]. We calculated the standard deviation extracted from eight subjects. If the value deviates more than seven minutes [9] then we once again carried out the experiment.

- **Evaluation Apprehension**: Human beings have the tendency to answer in a favorable way when being evaluated and jumble up the outcome of the experiment [7]. We advised subjects to be honest and not to worry about the outcome of the experiment.

3) External Validity

Threats to external validity are those conditions that limit our potential to generalize the experiment results to industrial practice [7]. There are three types of interactions which are associated with the treatment namely: people, place and time.

- **Interaction Of Selection And Treatment**

This threat comes into effect when wrong people participate in the experiment. We overcome this threat by selecting those subjects who had a good knowledge on both AHP and Numeral assignment prioritization techniques.

4) Conclusion Validity

a) Few persons involved in the experiment:

Minimize threat: if the requests to attend the experiment are going to a large population, there is a greater chance that the risk would be minimized.

b) Violating assumptions of statistical tests:

Minimize threat: The test subjects who have similar knowledge and background will be used as subjects and this reduces the external validity of the experiment.

c) Random heterogeneity of subjects:

Minimize threat: The test subjects who have similar knowledge and background will be used as subjects and this reduces the external validity of the experiment.

d) Random irrelevancies in experimental setting:

Minimize threat: Creating a setting that is similar to the software project environment.

e) Reliability of measures

Minimize threat: The validity of an experiment is highly dependent on the reliability of the measures [7]. There is a moment in the experiment where the test subject should conduct a subjective judgment about each method. To minimize this threat the test subjects must be given an option for answers in an ordinal scale, except for time which is measured in ratio scale.

B. Limitations and Future Work

Though the authors highlighted the pros of integrating Numeral assignment technique with AHP for prioritizing large number of requirements, we in fact observed few flaws in using the new model i.e. NAcAHP.

Mathematically it is more suitable to apply NAcAHP, if and only if, the amount of requirements is more than 11 and if we believe that the number of very important requirements falls within 80%.

If the number of requirements is less than 80% it is better to use AHP. However, this is purely mathematical. In real life, we do not know how important the requirements are before we prioritize them against each other. Hence, it is not possible to say if the 80% level is applicable to our problem(s).

If more number of stakeholders involved in prioritizing large number of requirements using Numeral...
assignment technique this consumes time because there is a probability of debate that might arises among subjects while assigning priority to each requirement.

For future enhancement, since NAcAHP model is not evaluated based on consistency ratio, so we will look forward to work on how consistency ratio can be improved using NAcAHP.

Secondly the proposed model can be further extended to compare it with the other approaches and enhancements made by other researchers to the AHP.

However our study has few limitations. We conducted experimental study by taking university students who were associated to the company as system analysts, senior software engineer, software developer, designers, business analysts, project managers, SQA managers and not with the industrial environment. But the involvement of industry was taken into consideration during survey section which acted as a stepping stone for carrying out the experiment.

VI. Conclusion

Our conclusion could be termed as a blend of both research and summary conclusion.

Firstly, from the systematic literature review and survey we extracted a lot of challenges when AHP is applied on large number of requirements such as pair wise comparison is complex and very time consuming.

Secondly, from the systematic literature review we observed that different researchers proposed different methods by combining AHP with other prioritization techniques to solve the challenges faced in prioritizing large number of requirements using AHP.

Thirdly, we proposed a new model that composes Numeral Assignment and AHP prioritization techniques (called NAcAHP) to reduce the time and complexity of pair wise comparison. The result of the experiment shows that NAcAHP model solves the scalability challenges in AHP by reducing the time and complexity in pair wise comparison.

Since the total number of requirements varies from companies to companies, it is very hard to predict and identify the baseline for AHP and NAcAHP has been proved to be beneficial when the threshold value of 80% of the total requirements are taken into consideration.

Finally, we concluded that industry can use our model in order to reduce their time and effort needed to prioritize large number of requirements.

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References