A TRIAD-BASED INCONSISTENCY DETECTION MECHANISM FOR ELICITING TACIT KNOWLEDGE

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ABSTRACT

In conventional online questionnaires, the respondents are always provided with a complete set of static questions, for determining both the relative importance and the degree of relative importance between two criteria in one single question showing a symmetric agree-disagree Likert scale. It can be tiring to perform two different tasks at the same time. As the number of questions increases, it takes a toll on the concentration span of the respondents. In addition, it defeats the purpose of computing a consistency ratio of the responses if it is only performed when all questions have been responded, as in most online questionnaires. This research attempts to explore a novel way for generating the questions dynamically, where only the relative importance of each pair of criteria is required. The inconsistent responses are highlighted as and when they arise, as opposed to the computation of consistency ratio at the end. Effectively, an attempt is made to explore a possible inconsistency detection mechanism with the intention of studying the trends and patterns of detected inconsistencies. Various issues have been investigated including question generation, formation of triads, and identification of logical rules, as well as deliberation on whether a detected inconsistent response should be rectified. If ever an inconsistent response is rectified, what are the reasons behind the detected inconsistency? Can these reasons be meaningfully elicited, stored, analyzed and reused in similar multi-criterion decision-making (MCDM) processes?

KEYWORDS

Inconsistency detection mechanism, logical rules, multi-criterion decision making (MCDM), formation of triads, reasons behind inconsistent responses

1 INTRODUCTION

As an established sub-discipline of operations research, multi-criterion decision making (MCDM) techniques have been adopted in software requirements prioritization [1] [2], risk factors prioritization [3], and academic library service quality indicators prioritization [4]. Two commonly used quantitative methods in MCDM are point allocation and direct rating. However, it has been proven that these two methods are non-deterministic, biased and unreliable [5] [6]. They also tend to cause systematic “underweighting” of unimportant attributes, and “overweighting” of important ones, when used by different types of respondents [5]. Other highlighted research problems include the weaknesses of consistency ratio (CR) leading to scalability problems and limitation of scales for large number of criteria [6]. These drawbacks have inhibited the wide spread acceptance of quantitative methods in the research and application domains [6].

Many researchers have instead chosen to study the qualitative methods by adopting triad comparison [7] [8] and quad comparison [9], for detecting logical inconsistency. However, it is observed that the state of the art for logical inconsistency detection methods has not reached an acceptable level for its wide spread use. As such, we choose to embark on a detailed study of various aspects related to logical inconsistency detection mechanisms. Based on the outcomes of our survey and analysis, we decide to explore a possible triad-based logical inconsistency detection mechanism by focusing on question generation, choice of logical rules, and formation of triads. The consequences and the reasons behind each inconsistent response would also be studied for possible deployment in similar MCDM settings.

2 LITERATURE REVIEW ON EXISTING TRIAD-BASED APPROACHES AND METHODS

Although triad-based comparisons had been proposed in 2003 as described in [10], there has not been any significant research on triad-based inconsistency detection since then. In 2011, however, the researchers of IDOT [7] resumed the research by assuming that *the first (n-1) responses were consistent*. It is found in IDOT [7] that triad-based detection tend to out-perform other methods because its inconsistency detection can commence as soon as (n-1) questions have been correctly responded, where n refers to the number of criteria. It is felt that the triad-based inconsistency detection method proposed in IDOT has great potential for further research.

2.1 Online Question Generation

In a MCDM online questionnaire with n criteria, there are $n(n-1)/2$ (or ${}^{n}C_2$) questions to be answered by the respondents. Each question contains a pair of criteria. In IDOT [7], the questions are generated in a row-wise fashion as shown in the Figure 1. The cell indicated with Q1 is the first generated question which compares the relative importance between criterion C1 and criterion C2. The second question Q2 compares the relative importance between criterion C1 and criterion C3, the same procedure can be repeated until the generation of the sixth question Q6, which compares the relative importance between criterion C3 and criterion C4. The typical question layout is shown in Figure 2.

	C1	C2	C3	C4
C1		Q1 →	Q2 →	Q3
C2			Q4 →	Q5
C3				Q6 ↓
C4				

Figure 1. Question generation for four criteria

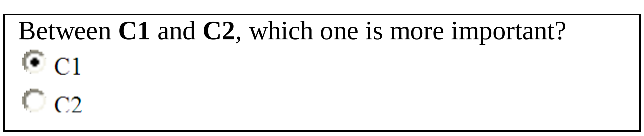

Figure 2. Layout of a generated question

2.2 General Logical Rules

In IDOT [7], logical rules are used to detect inconsistent responses within each triad. Responses are validated in each triad based on a common transitivity definition:

> *A positive reciprocal matrix A is transitive if it satisfies the qualitative transitivity property that $C_i > C_j$ and $C_i > C_k$ imply $Cj > C_k$ for any i, j, k $\in\{1, 2, . . . , n\}$. Otherwise, A is intransitive* [11].

By applying the logical operators of "more important than (>)", "less important than (<)", and "equally important with (=)" on a set of triads with three criteria C1, C2 and C3, a total of nineteen (19) logical rules could be derived, as shown in Table 1. These rules are derived from the digraphs in Keri [11] and Yadav [7]. The current response in a triad is considered inconsistent if it violates any of the nineteen (19) rules.

Table 1. Logical rules for inconsistency detection

Rule No.	**Rule Components**
1	$C_1 > C_2$ AND $C_1 > C_3 \Rightarrow C_2 > C_3$
2	$C_1 > C_2$ AND $C_1 > C_3 \Rightarrow C_2 < C_3$
3	$C_1 > C_2$ AND $C_1 > C_3 \Rightarrow C_2 = C_3$
4	$C_1 > C_2$ AND $C_1 < C_3 \Rightarrow C_2 < C_3$
5	$C_1 > C_2$ AND $C_1 = C_3 \Rightarrow C_2 < C_3$
6	$C_1 > C_2$ AND $C_1 = C_3 \Rightarrow C_2 = C_3$
7	$C_1 < C_2$ AND $C_1 > C_3 \Rightarrow C_2 > C_3$
8	$C_1 < C_2$ AND $C_1 < C_3 \Rightarrow C_2 > C_3$
9	$C_1 < C_2$ AND $C_1 < C_3 \Rightarrow C_2 < C_3$
10	$C_1 < C_2$ AND $C_1 < C_3 \Rightarrow C_2 = C_3$
11	$C_1 < C_2$ AND $C_1 = C_3 \Rightarrow C_2 > C_3$
12	$C_1 < C_2$ AND $C_1 = C_3 \Rightarrow C_2 = C_3$
13	$C_1 = C_2$ AND $C_1 > C_3 \Rightarrow C_2 > C_3$
14	$C_1 = C_2$ AND $C_1 > C_3 \Rightarrow C_2 = C_3$
15	$C_1 = C_2$ AND $C_1 < C_3 \Rightarrow C_2 < C_3$
16	$C_1 = C_2$ AND $C_1 < C_3 \Rightarrow C_2 = C_3$
17	$C_1 = C_2$ AND $C_1 = C_3 \Rightarrow C_2 > C_3$
18	$C_1 = C_2$ AND $C_1 = C_3 \Rightarrow C_2 < C_3$
19	$C_1 = C_2$ AND $C_1 = C_3 \Rightarrow C_2 = C_3$

2.3 Basic Triad Formation

A triad is derived from a set of three responded questions which comprise of three unique criteria. Basically, inconsistency detection could commence after the first (n-1) questions have been responded, for n criteria. The response for the n^{th} question can be validated by forming a triad. In Figure 3, if Response (C2, C3) is the current response, a triad can be formed together with two previous responses, such as Response (C1, C2) and Response (C1, C3). For any current response, there exists a formula for selecting the appropriate previous responses. In this case, the previous responses are all in the first row, indicated as first (n-1) responses in Figure 3.

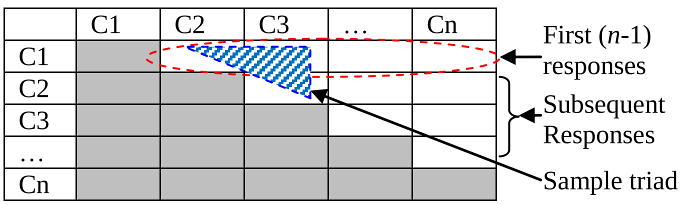

Figure 3. First (n-1) responses for triad formation

3 ANALYSIS OF TRIAD-BASED INCONSISTENT DETECTION

As reviewed in the last section, IDOT [7] stops at the detection of inconsistency. It does not consider whether the cause of the inconsistency is intentional or unintentional. Should it be rectified or otherwise? If it is rectified, what are the reasons behind the rectification? If it is not rectified, are there any valid reasons? This section elaborates on the choice of question generation, logical rules and triad formation for eliciting the reasons behind the detected inconsistent responses.

3.1 Question Generation

The questions which can be generated for four (4) criteria reviewed in Section 2.1 is shown in Table 2.

Table 2. Generated questions for four criteria

No	Question
1	Between **performance (C1)** and **functionality (C2)**, which one is more important?
2	Between **performance (C1)** and **maintainability (C3)**, which one is more important?
3	Between **performance (C1)** and **reliability (C4)**, which one is more important?
4	Between **functionality (C2)** and **maintainability (C3)**, which one is more important?
5	Between **functionality (C2)** and **reliability (C4)**, which one is more important?
6	Between **maintainability (C3)** and **reliability (C4)**, which one is more important?

3.2 Logical Rules for Triad-based Validation

In our study, we have optimized the response validation in triads by focusing on only two logical operators, as in “C1 more important than C2” and “C1 less important than C2”, while the logical comparison operator for “C1 and C2 are equally important” has been eliminated. After the elimination, the remaining logical rules are shown in Table 3.

Table 3. Logical rules for the proposed mechanism

Rule No.	Rule Components
1	If $C_1 > C_2$ AND $C_1 > C_3$, $\Rightarrow$ $C_2 > C_3$
2	If $C_1 > C_2$ AND $C_1 > C_3$, $\Rightarrow$ $C_2 < C_3$
3	If $C_1 > C_2$ AND $C_1 < C_3$, $\Rightarrow$ $C_2 < C_3$
4	If $C_1 < C_2$ AND $C_1 > C_3$, $\Rightarrow$ $C_2 > C_3$
5	If $C_1 < C_2$ AND $C_1 < C_3$, $\Rightarrow$ $C_2 > C_3$
6	If $C_1 < C_2$ AND $C_1 < C_3$, $\Rightarrow$ $C_2 < C_3$

3.3 Triad Formation and Validation

As reviewed in Section 2.3, the current response is combined with two previous responses in the first row to form a triad [8]. Assuming that the first (n-1) responses are correct and further verified with the verification mechanism proposed in [12], inconsistency can be detected on the current response in each triad, for all remaining responses in a questionnaire.

In order to avoid possible conflicts in a detection process, a corollary from Bozoki [8] can be adopted. The corollary states that it is sufficient to detect inconsistency with ${}^{(n-1)}C_2$ triads in a questionnaire. A condition (E.1) is employed such that “*each unique pair of criteria, expect those in the first (n-1) responses, should be validated once and only once*”.

$$\sum_{k=j+1}^{n} t_{ijk} + \sum_{\substack{k=i+1 \\ j-1>1}}^{j-1} t_{ijk} + \sum_{\substack{k=1 \\ i>1}}^{i-1} t_{ijk} = 1 \ldots\ldots (E.1)$$

If a stakeholder knows exactly what criteria are of utmost importance, only triads containing those criteria in the current responses will be considered. In this case, the number of questions to be responded will correspondingly be reduced, which will lighten the burden of the respondents.

3.4 Basic Application of the Mechanism

In a software house, suppose the R&D manager needs to seek some important information from the software engineers on the relative importance among the major software design factors, together with the underlying reasons. The proposed inconsistency detection mechanism can be adopted for generating an online questionnaire containing questions which compares four design factors namely "performance", "functionality", "maintainability", and "reliability".

The questionnaire would have a total of six questions, each of which compares two factors at a time among the four factors. The first (*n*-1) questions, Questions 1 to 3 in Table 4, must first be correctly responded and verified. For each subsequent responded question, the inconsistency detection mechanism can be executed. In Table 4, the 4th response will be validated first.

It is shown that an inconsistency has been detected in the 4th response, in the triad which contains response 1, response 2, and response 4. At this point, the responding software engineer would be prompted to make a decision on whether to correct or not to correct the inconsistency detected in the relative importance between "functionality" and "maintainability". Whatever decision he or she makes, a valid reason is expected. The elicited reasons would then be compiled in some knowledge repository for future references. The elicited knowledge could be further analysed and displayed in a dashboard or some charts for the R&D manager to make better-informed R&D decisions and research directions.

Table 4. Triad-based inconsistency detection among four software design factors

No	Question	Response
1	Between **performance (C1)** and **functionality (C2),** which one is more important?	C1 > C2
2	Between **performance (C1)** and **maintainability (C3)**, which one is more important?	C1 > C3
3	Between **performance (C1)** and **reliability (C4)**, which one is more important?	C1 > C4
4	Between **functionality (C2)** and **maintainability (C3),** which one is more important?	C2 < C3 (Inconsistent)
5	Between **functionality (C2)** and **reliability (C4)**, which one is more important?	C2 < C4
6	Between **maintainability (C3)** and **reliability (C4)**, which one is more important?	C3 > C4

4 DISCUSSIONS

4.1 Effects of Different Triad Formation Techniques

Interested stakeholders may choose different combinations of triads based on their own needs. In this paper, an example has been given in Section 3 for deriving a set of triads free from any conflicts with the validation of each response once and only once. In this case, the same pair of criteria must not appear in more than one triad. However, from a different perspective, triads can be formed such that a pair of criteria may be repeatedly validated in several triads with respect to different responses. The possible conflicts and deadlocks among these triads may give rise to more hidden reasons, which may be the primary objective of some stakeholders. Other stakeholders may choose to work on a small number of questions. In this case, the stakeholders must know exactly what criteria are required to form a subset of triads with the omission of some irrelevant questions.

4.2 Effects of Different Question Generation Techniques

Different sets of triads require different question generation techniques. Two question generation techniques for six (6) questions with four (4) criteria are shown in Table 5. Example 1 adopts a systematic order of generating the questions, where a base criterion is compared with all other criteria before another base criterion is chosen. In Example 2, the mechanism adopts a random order of criteria selection. In this case, it is felt that the number of inconsistencies detectable in Example 1 may be less than that of Example 2, because the generated questions are more structured, thus there will be fewer mistakes.

In general, the decision to choose an appropriate technique would highly depend on the objective of the stakeholders. Nevertheless, once a question generation technique has been determined, it should be used consistently for the same purpose. This is aimed at preserving the deterministic property of the mechanism.

Table 5. Two examples of question generation mechanisms

Example 1			Example 2		
Question No:	Criterion 1	Criterion 2	Question No:	Criterion 1	Criterion 2
1	C1	C2	1	C2	C3
2	C1	C3	2	C1	C3
3	C1	C4	3	C3	C4
4	C2	C3	4	C1	C2
5	C2	C4	5	C2	C4
6	C3	C4	6	C1	C4

5 CONCLUSION & FUTURE WORK

In this paper, a study has been conducted on a triad-based inconsistency detection mechanism by considering various issues pertaining to question generation, logical rules selection, and triad formation. The settings have been chosen for the consideration and deliberation of rectifying the inconsistent responses, and also elicitation of the reasons behind the genuine inconsistent responses, less the careless mistakes.

Ideally, the mechanism should aim to attain the minimum set of triads that could give rise to the maximum number of inconsistent responses. Having explored the detection mechanism, it is felt that many outstanding issues still remain for future research. Among others, they include:

- Does question generation depend on triad formation and vice versa?
- Is there a need to deal with redundancy in question generation and triad formation?
- Is there a way to prove that a certain set of rules is necessary and sufficient for validating the consistency of each response with respect to a triad?

Once the above-mentioned issues have been investigated, it will path a different way of thinking for eliciting useful tacit knowledge for both personal and organisational deployment.

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