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Identification, Assessment and Automated Classification of Requirements Engineering Techniques

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Abstract. Selection of suitable techniques to be used in requirements engineering or business analysis activities is not easy, especially considering the large number of new proposals that emerged in recent years. This paper provides a summary of techniques recommended by major sources recognized by the industry. A universal attribute structure for the description of techniques is proposed and used to describe 33 techniques most frequently quoted by reviewed sources. A pilot study of automated classification of techniques based on attribute values is also reported. The study used fuzzy c-means clustering algorithm and produced pairings of complementary techniques, most of which successfully passed validation conducted by business analysis practitioners.

Keywords: Requirements Engineering, Business Analysis, Techniques, Clustering, Industrial Standards.

1 Introduction

Requirements Engineering (RE) aims at establishing stakeholder's viewpoints and determining requirements that reflect the purpose of software system to be developed. It is considered a crucial factor of software development project, as it strongly influences software quality and final project outcome [1, 2]. RE is recognized as an important topic in research and industrial practice since many years [3, 4]. Several books (e.g. [5, 6]) and international standards (e.g. [7, 8]) describing recommended processes and practices are available.

In recent years, however, two new observations can be made. One is the emergence of Business Analysis (BA), which, while being closely related to RE, has a broader scope and puts more emphasis on facilitating business change [9]. Another observation is an increased interest of industrial community, which resulted in founding professional associations e.g. International Institute of Business Analysis (IIBA) or International Requirements Engineering Board (IREB) and their subsequent activity in the fields of Requirements Engineering and Business Analysis (RE/BA). Such activities include education, certification and publishing standards and other guidelines. As result, several new sources of knowledge became available, including industrial standards (BABOK [9], PMI Guide [10]) and training materials associated with certification schemes (IREB [11], REQB [12]).

Such sources usually cover various RE/BA aspects e.g. definitions of processes and activities, good practices, competencies expected from an analyst and RE/BA techniques. There are differences between particular sources with respect to most of mentioned aspects. In this paper, however, we will focus solely on RE/BA techniques. Adopting the corresponding definition from BABOK glossary [9], we define RE/BA technique as a manner or method for conducting a particular RE/BA task or for shaping its output. For example, interview, observation and document analysis are techniques used for requirements elicitation, while use cases, business process modeling or user stories belong to requirements specification (documentation) techniques.

As mentioned, particular sources propose different sets of techniques. Consequently, a large number of techniques is included in the collective body of knowledge available. An analyst looking for tools to do his/her work has a potentially wide choice of techniques, but this can also become a problem. It may be difficult to pick a technique (or a combination of techniques to be used together) that is appropriate for a given task in a given context of software project from so many candidates. Moreover, differences in techniques' names and levels of abstraction can increase confusion. As result, it is likely, that such selection would be based on personal preferences and (limited) knowledge about available techniques. Unfortunately, there are no clear and comprehensive summaries of techniques recommended by state of the art sources nor methods guiding analysts in selection of those techniques.

In this paper we aim to provide a solution. We made a thorough review of four sources published by industrial professional associations and one additional source being an international standard. We extracted RE/BA techniques from them and created a unified summary, matching corresponding techniques appearing under different names and/or abstraction levels. We selected 33 techniques recommended by at least 2 sources for further consideration. Next, we proposed a set of attributes describing techniques and their applicability. For each of 33 techniques we assessed them by assigning values to attributes.

Apart from providing summary of techniques together with their structured descriptions, we made an initial attempt to use it as a dataset for automated analysis (clustering algorithm) to group similar techniques and to identify complementary techniques i.e. those recommended to be used jointly. Recommendations given by the algorithm were validated by two experienced business analysts and results can be considered promising.

Hence, the main contributions provided by this paper are:

- A summary of RE/BA techniques recommended by present industrial standards;
- A set of attributes for technique's description (which can be used both by humans and as input of automated analysis) and attribute values for 33 techniques;
- A pilot study applying automated analysis aiming at identifying complementary RE/BA techniques.

The remainder of this paper is structured as follows. In Section 2 we describe related work. In Section 3 we present the processes of: techniques identification (through reviewing the sources) and techniques assessment (using a pre-defined attribute structure), as well as outcomes of both those processes. Section 4 outlines the study of automated classification of techniques and the validation conducted afterwards. We conclude the paper in Section 5, by summarizing contributions, discussing limitations of our work and sharing ideas on future research directions.

2 Related Work

There are several studies on defining attributes or criteria of particular RE/BA techniques, in order to compare them and/or provide guidelines about the context a given technique should be used in.

Hickey and Davis [13] provided a formalized process model for selection of requirements elicitation techniques. Their proposal lacks particular selection criteria but the process described by them sets a foundation for further works. Escalona and Koch [14] assessed several techniques (for elicitation, specification and validation of requirements) with respect to their ability to be used in particular methods of web application development and to be applied to various categories of requirements.

Jiang et al. [15] developed a framework for selection of requirements engineering techniques. They compiled an extensive list of 46 techniques and described each one using a set of attributes reflecting technique's abilities. They also used fuzzy clustering algorithms to group similar techniques. On the basis of work by Jiang et al., other research studies were conducted [16, 17]. Kheirkhah and Deraman [16] slightly modified the set of attributes and extended it by organizational viewpoint. Tiwari and Rathore [17] developed a framework based on characteristics of 3 aspects (project, people and process) to select requirements elicitation techniques most suitable in a given context defined by those 3 aspects.

des Santos Soares et al. [18] defined an attribute structure for requirements documentation techniques expressing mainly technique's abilities, but also e.g. maturity or popularity and assessed 8 techniques with respect to such criteria. Besrour et al. [19] conducted an experiment in academic setting to assess 3 popular requirements elicitation techniques in several dimensions e.g. usability or communicating ability. Darwish et al. [20] used a set of 42 attributes grouped 8 categories to characterize 14 techniques and applied an artificial neural network as a tool for techniques selection.

For other related research studies (limited to requirements elicitation techniques) a reader can also be referred to a systematic mapping study by Carrizo et al. [21]. The research gap that can be identified is based on the following observations:

- No research study is based on the comprehensive review of state of the art techniques recommended by current industrial standards. The only exception is the previous work of one of us [22], which however was based on smaller number of standards and in some cases their older versions were used.
- Most studies are limited to a relatively small subset of techniques (e.g. dedicated to requirements elicitation or documentation only).

- Only two studies ([15, 20]) use automated methods of selecting most effective techniques for a given context (despite the fact that a large number of attributes and their values is difficult to comprehend for humans).

3 Selection and Description of RE/BA Techniques

The following sources were selected and reviewed to extract RE/BA techniques from their contents:

1. A Guide to the Business Analysis Body of Knowledge (BABOK Guide v3, 2015) [1] – It is a widely recognized industrial standard published by International Institute of Business Analysis. Its purpose is to define the profession of business analysis and provide a set of commonly accepted practices. It aims to help practitioners discuss and define the skills necessary to effectively perform BA.
2. PMI Business Analysis for Practitioners: A Practice Guide (2015) [10] – Another recognized standard issued by Project Management Institute (PMI), known from other standards and methodologies e.g. PMBOK. The intent of this publication is to provide o comprehensive guidance on how to apply BA practices to projects.
3. IREB Certified Professional for Requirements Engineering Syllabi – International Requirements Engineering Board (IREB) is a non-profit organization focusing on certification of RE practitioners. A 3-level certification scheme is available. IREB published several syllabi summarizing the scope of knowledge required on certification exams. In our study we used the following syllabi from Foundation and Advanced levels: [3, 23, 24].
4. REQB Certified Professional for Requirements Engineering Syllabi - Requirements Engineering Qualification Board (REQB) was another organization, which developed a certification scheme for requirement engineers. In January 2017 it was merged with IREB. However, as REQB certificates were recognizable for many years and associated syllabi were available, we decided to use the following documents: [4, 25].
5. IEEE Guide to the Software Engineering Body of Knowledge (SWEBOK Guide v. 3.0, 2014) [8] – SWEBOK is a guide developed by IEEE and later adopted as an international standard (ISO/IEC TR 19759:2015). It defines Software Engineering discipline and 15 knowledge areas summarizing the expected knowledge of a qualified software engineer. One of these areas is Software Requirements and its description by SWEBOK provided input to our study.

It should be stressed that all of these sources were most up to date versions at the time of conducting our review and search for RE/BA techniques (and no updated versions have been published till present day). The only exception was REQB – as already mentioned, despite the fact that in January 2017 REQB and IREB merged under unified IREB brand, we decided to include it, because REQB certificates were recognizable for many years. It is also worth mentioning that at the time of writing this paper still no new source incorporating IREB's and REQB's approaches and ideas was available.

Table 1. A list of sources used to extract RE/BA techniques from their contents.

#	Technique	Sources
1	Activity Diagram	IREB; REQB
2	Approval Levels	PMI; REQB
3	Benchmarking	BABOK; PMI
4	Brainstorming	BABOK; PMI; IREB; REQB
5	Business Rules Catalog and Analysis	BABOK; PMI
6	Class Diagram	BABOK; IREB; REQB
7	Communication Diagram	IREB; REQB
8	Cost-Benefit Analysis	PMI; IREB
9	Data Dictionary	BABOK; PMI
10	Data Flow Diagram	BABOK; PMI; IREB; REQB
11	Dictionary (Glossary)	BABOK; IREB
12	Document Analysis	BABOK; PMI; IREB; REQB
13	Entity Relationship Diagram	BABOK; PMI; REQB
14	Facilitated Workshop	BABOK; PMI; IREB; REQB; SWEBOK
15	Focus Groups	BABOK; PMI
16	Interviews	BABOK; PMI; IREB; REQB; SWEBOK
17	Lessons Learned	BABOK; PMI
18	Maintaining Product Backlog	BABOK; PMI
19	Observation	BABOK; PMI; IREB; REQB; SWEBOK
20	Organizational Charts	BABOK; PMI
21	Peer Review	BABOK; PMI; IREB; REQB; SWEBOK
22	Prioritization	BABOK; PMI; REQB; SWEBOK
23	Process Modeling	BABOK; PMI; IREB; REQB
24	Prototyping	BABOK; PMI; IREB; REQB; SWEBOK
25	Questionnaires	BABOK; PMI; IREB; REQB
26	Scope Modeling	BABOK; PMI
27	Sequence Diagram	BABOK; IREB; REQB
28	Stakeholders List, Map or Personas	BABOK; PMI; IREB; REQB
29	State Table/Diagram	BABOK; PMI; IREB; REQB
30	SWOT Analysis	BABOK; PMI
31	Traceability Matrix	PMI; REQB
32	Use Cases	BABOK; PMI; IREB; REQB; SWEBOK
33	User Stories	BABOK; PMI; IREB; REQB; SWEBOK

We reviewed all sources to identify RE/BA techniques described or even mentioned by them. In some cases (BABOK) such task is rather easy, as techniques are indexed and presented in a separate section. In other cases the task required reading all contents of sources. The next step was to unify different sets originating from various sources. This task included the following actions:

- Resolving simple name differences e.g. Backlog Management (BABOK) vs. Maintaining Product Backlog (PMI);
- Unifying different but closely related techniques (including cases when one technique extended other with additional tasks/tools) e.g. Persona (IREB) and Stakeholder List, Map, or Personas (BABOK);

- Providing a common level of abstraction as some sources distinguish more specific variants of a given technique e.g. there is a number of various collaborative games (IREB) that can be treated as more specific forms of Brainstorming.

Table 2. Attributes used to describe RE/BA techniques and their possible values.

Group	ID	Attribute	Values
Resources	A1	Required skill level	1 – low; 2 – medium 3 – high
	A2	Required effort	
	A3	Required involvement of stakeholders	0 – none; 1 – low; 2 – medium; 3 – high
Abilities	A4	Ability to identify functional requirements	0 – lack of ability 1 – to a small extent 2 – to a moderate extent 3 – to a large extent
	A5	Ability to identify non-functional requirements	
	A6	Ability to identify stakeholders, their roles and relationships between them	
	A7	Ability to support verification and validation	
	A8	Ability to support communication with stakeholders	
	A9	Ability to support requirements management, traceability and monitoring	
Inherent characteristics	A10	Availability of graphical representation	0 – no representation 1 – limited representation 2 – complex graphical representation
	A11	Availability of precise guidelines/procedure of use	1 – requires analyst's interpretation 2 – generic/partial procedure defined 3 – detailed procedure defined
	A12	Degree of creativity enabled	1 – low; 2 – medium 3 – high

As result, we obtained a list of 82 techniques, which we considered too extensive to be processed in next steps of this study. We decided that only techniques mentioned by at least two of the reviewed sources would be considered further and consequently we were left with 33 techniques. The final set of RE/BA techniques is given in Table 1. The table also shows the sources in which a given technique is found. For detailed description of techniques, readers are referred directly to the sources, due to space limitations of this paper.

Next, we proposed a structure of attributes to describe each technique. The attributes and their value scales are shown in Table 2. The values are given in two forms: descriptive and numerical (the latter is for the purpose of automated analysis). Attributed are also divided into 3 groups, but it is for clarity sake only, it does not influence automated classification described in later sections.

The set of attributes was kept relatively small for two reasons. The first is the intent to have a common set of attributes to describe all RE/BA techniques, regardless of the tasks they are used for (elicitation, analysis, validation etc.). The second reason was a practical one – to reduce the effort necessary to assess all 33 techniques. We treated it as a first trial and intended to refine this set of attributes, in case results of next steps (automatic classification and validation) suggest it.

Using the set of attributes given in Table 2, 33 techniques from Table 1 were assessed by assigning attributes with values. Two persons completed this task independently and later met to discuss their assessments and the rationale behind them. In most cases the discussion allowed them to reach consensus. In the remaining cases some disagreement remained, however the difference between assigned attribute's values was never greater than 1. If differences between assessors could not be resolved, then a mean arithmetic value was assigned to the attribute e.g. the disagreement whether Maintaining Product Backlog requires low (1) or medium (2) skill level, led to assigning 1.5 value. Examples of attribute values for 3 techniques used in different RE/BA areas and for different purposes are given in Table 3.

Table 3. Attribute values for example techniques.

Technique	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12
Interviews	2	2.5	2.5	3	2.5	3	2.5	2.5	0.5	0	2	2
User Stories	1	1	1.5	2.5	1.5	1.5	1	3	0.5	0.5	3	2
Maintaining Product Backlog	1.5	1.5	0.5	2	0.5	0	1.5	2	3	0.5	2.5	1

4 Automated Classification

We decided to apply data clustering approach for automated classification of RE/BA techniques. Clustering is a generic concept of unsupervised classification intended to identify natural groupings of data from a larger data set. Several methods based on this concept were proposed e.g. hierarchical, c-means or fuzzy clustering [26]. We acknowledge that our approach is similar to the one used in [15] and was inspired by that work.

We used Fuzzy C-Means Clustering algorithm implemented in Fuzzy Logic Toolbox library [27] for Matlab 2012. This algorithm was chosen because it provided additional information as its output – not only RE/BA technique's final classification into a given cluster, but also the degree the technique belongs to each cluster specified by a membership grade. As it was our first attempt of classifying RE/BA techniques, we intended to experiment with e.g. various numbers of clusters and such additional output information proved valuable. The *fcm* function available in Matlab's library requests as input: the data set, number of clusters and optionally parameters like maximum number of iterations or improvement of objective function. Its output includes: cluster centers, fuzzy partition matrix (indicating the degree of membership of each data point to each cluster) and objective function values. The objective function is defined as in equation (1) [27].

$$J_m = \sum_{i=1}^{D} \sum_{j=1}^{N} f_{ij}^m ||x_i - c_j||^2 \qquad (1)$$

The symbols used in equation (1):

- D is the number of data points.
- N is the number of clusters.
- m is fuzzy partition matrix exponent for controlling the degree of fuzzy overlap, with m > 1. Fuzzy overlap refers to how fuzzy the boundaries between clusters are, that is the number of data points that have significant membership in more than one cluster.
- x_i is the i-th data point.
- c_j is the center of the j-th cluster.
- f_{ij} is the degree of membership of x_i in the j-th cluster. For a given data point, x_i, the sum of the membership values for all clusters is one.

We run *fcm* function several times, using different input values for the number of clusters (3-10) and finally we decided to use the classification based on 8 clusters. It was a subjective decision based on our experience in RE/BA as we rejected classifications that grouped very different RE/BA techniques in one cluster. The resulting classification for 8 clusters is shown in Table 4 and indicates sets of “similar” RE/BA techniques as determined by the algorithm.

Table 4. Classification of RE/BA techniques into clusters.

Cluster	**Techniques**
A	Benchmarking; Document Analysis; Lessons Learned; Questionnaires
B	Cost-Benefit Analysis; Data Dictionary; Maintaining Product Backlog; Prioritization
C	Focus Groups; Prototyping
D	Business Rules Catalog and Analysis; Process Modeling; Use Cases; User Stories
E	Approval Levels; Peer Review; Traceability Matrix
F	Brainstorming; Facilitated Workshop; Interviews; Observation
G	Activity Diagram; Class Diagram; Communication Diagram; Data Flow Diagram; Entity Relationship Diagram; Sequence Diagram; State Table/Diagram
H	Dictionary (Glossary); Organizational Charts; Scope Modeling; Stakeholders List, Map or Personas; SWOT Analysis

After assigning techniques to clusters, we proceeded to find out which pairs of techniques could be considered as complementary i.e. recommended to be used together, because they complement each other, as advantages of one technique counter-balance limitations of the other. We define complementary techniques M and N as:

1. Belonging to different clusters;
2. Satisfying the condition:
   $5 \leq \sum_{k=1}^{12} t_M(k) - t_N(k) \leq 5{,}5$, where $t_I(k)$ is value of k-th attribute of technique I (where I belongs to {M, N});

The values 5 and 5,5 were determined considering the number of attributes and their value scales. It reflects the concept of complementary techniques which is a mix of similarities and differences (completely different techniques, having nothing in common would be difficult to use jointly). It is worth to mention that this complementarity relation between techniques is symmetric but not transitive. Based on this definition we identified 35 pairs of complementary techniques. They are listed in Table 5.

Table 5. Complementary RE/BA technique pairs and associated validation results.

Technique 1	Technique 2	Validation
Activity Diagram	Observation	Y
Activity Diagram	Use Cases	Y
Approval Levels	Process Modeling	Y
Benchmarking	Focus Groups	Y
Benchmarking	Organizational Charts	N
Brainstorming	Peer Review	N
Business Rules Catalog and Analysis	Peer Review	Y/N
Cost-Benefit Analysis	Document Analysis	Y/N
Cost-Benefit Analysis	Scope Modeling	Y
Cost-Benefit Analysis	Stakeholders List, Map or Personas	Y
Cost-Benefit Analysis	State Table/Diagram	Y/N
Data Dictionary	Peer Review	Y
Data Flow Diagram	Prioritization	N
Dictionary (Glossary)	Prioritization	N
Document Analysis	Observation	Y
Document Analysis	Process Modeling	Y
Document Analysis	Use Cases	Y
Facilitated Workshop	Process Modeling	Y
Focus Groups	User Stories	Y
Interviews	Prioritization	Y/N
Lessons Learned	Peer Review	Y
Maintaining Product Backlog	Process Modeling	Y/N
Observation	Scope Modeling	Y/N
Observation	Stakeholders List, Map or Personas	Y
Observation	State Table/Diagram	Y
Organizational Charts	User Stories	N
Peer Review	Prototyping	Y/N
Prioritization	SWOT Analysis	Y/N
Prioritization	Traceability Matrix	Y/N
Process Modeling	Questionnaires	Y/N
Process Modeling	Scope Modeling	Y
Process Modeling	Stakeholders List, Map or Personas	Y
Scope Modeling	Use Cases	Y
Stakeholders List, Map or Personas	Use Cases	Y
State Table/Diagram	Use Cases	Y

This result was a subject of validation through interviews with industry professionals working as business analysts. Two professionals participated in validation, none of them had been involved in earlier steps of research described here, thus they presented an independent viewpoint. One of them had 11 years of experience in RE/BA and was employed as Senior Business Analyst. The second person reported 5 years of experience in RE/BA and at that time held position of Business Analyst.

Each of two analysts was interviewed separately. Their main task was to review pairs of techniques (documented in Table 5) and for each one give a definite answer – to confirm or deny that such two techniques are really complementary and worth using in a joint manner. Additionally they provided some remarks about possible or preferred ways techniques could be used together, but we skip it here, focusing on main validation results, which are shown in “Validation” column of Table 5. The following possible outcomes are reported in this column: both analysts confirmed the pair of techniques is complementary (Y), they both rejected such proposal (N), or their opinions differed (Y/N). In total, 20 pairs (out of 35) were confirmed by both analysts, 10 pair by one analysts only and 5 proposals were unanimously rejected.

5 Conclusions

This paper identified a set of RE/BA techniques recommended by present industrial standards and certification schemes. It also proposed a description structure to represent technique’s abilities, required resources and other characteristics. Describing a technique by determining values of attributes can both support humans in decision-making (selecting a technique to be used in a given project) and provide input for automated classification. We conducted an initial exploration of the second possibility by applying fuzzy c-means clustering algorithm to group similar techniques and then we identified pairs of complementary techniques. That this initial attempt was promising – the majority of generated proposals were confirmed by at least one of experiences business analysts participating in validation.

Our research study had obviously several limitations that could influence its validity. The set of RE/BA techniques we collected does not necessarily have to reflect industrial practice, despite our effort to use sources recognized by industry practitioners. We also cannot exclude the possibility of omitting some techniques – our review was rather thorough, but there are cases that a technique is only briefly mentioned by a source, so overlooking, however unlikely, is still possible. Our attribute structure can be challenged, especially that we deliberately kept the number of attributes limited. Also, assessment of attribute values for particular techniques is based on experience and judgement of two people only. Finally, selection of parameters used in automated classification like number of clusters or the numbers used in the inequality in definition of complementarity was to some extent arbitrary. As for validation, we consider it as an initial step - for a more convincing confirmation a larger group of analysts should be involved.

As mentioned, it was the first trial of using automated classification. There are several opportunities of follow up work. It is possible to improve descriptions of techniques by expanding the attribute set and by “tuning” values of attributes e.g. by involving a larger group of assessors. More attributes reflecting the context a particular technique is best applied (software project constraints, developed product type, stakeholders’ attitude etc.) can enable new possibilities. Moreover, knowledge and experience of analysts who are supposed to use RE/BA techniques can be considered more thoroughly instead of using a simplified “Required skill level” attribute. Finally, various relations between techniques (complementary, equivalent in general or with respect to a given characteristics etc.) can be defined and explored using automated classification.

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