A Methodology for Requirements Engineering Process Development

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Abstract

Adoption of the most suitable Requirements Engineering (RE) process and selection of the most appropriate RE techniques for a given project is a common challenge faced by industry. This paper presents a methodology for RE process development for a given project. The novelty of this work is four-fold. First, a RE Process Knowledge Base (REPKB) is established and it helps during RE process development. Second, a decision support mechanism is provided during RE process development. Third, this methodology uses three components: process building blocks, standard templates of the RE process and development guidelines, to help process development. Fourth, it explicitly links project characteristics with RE process development so that the most suitable RE process can be developed. The theory behind this methodology is described in the paper. Preliminary results suggest that the methodology is of valuable help to requirements engineers during RE process development and process customization.

Keywords: Requirements engineering, process model, process development

1. Introduction

The importance of requirements engineering (RE) has been stressed numerous times in RE literature. Some literature provides empirical evidence of the benefits of RE [1-2], while others give case studies [4-5] and statistical results showing that improving the RE process will likely lead to improvements in the productivity in large and medium sized software organizations [6]. Most people agree that following a well defined RE process and using appropriate RE techniques has a positive impact on software quality. Nevertheless, there is still a big gap between RE theory and practice [7, 23].

Currently, numerous RE process models are available and each one uses various techniques to address different issues of software development. In our previous research, we identified about twenty-six RE process models and fifty-six techniques that can be used in RE processes for various domains [7, 20]. There are a number of factors, which make the application of RE processes different from organization to organization, and from project to project [8]. These factors include technical maturity of the organization, the involvement of engineering and managerial disciplines, organizational culture, application domain, specific characteristics of the project, etc. Therefore, different projects have different needs that require different RE process models. Based on our previous research results and observations of our current research, a framework of RE process development was developed and is described in this paper. The framework is a step towards bridging the gap between RE theory and practice. This is done by providing comprehensive help to requirements engineers for the development and customization of RE process models as well as for selecting the most suitable RE techniques for a given project in an incremental, iterative, and efficient way supported by a tool. A RE process model developed with our framework will be more suitable for the project it was designed for; therefore, leading to higher project success. The methodology proposed in this paper is a cornerstone of the framework that we have developed in recent years. This methodology is complementary to the N-dimensional process development methodology [9] developed in our earlier research.

This paper is organized as follows: section 2 discusses an overview of the framework. The RE process development methodology is presented in section 3. A simple case study is given in section 4. Conclusions and ideas for future research are discussed in section 5.

2. Framework Overview

The objectives of our framework are three-fold:

- Help requirements engineers to develop the most suitable RE process for a specific project in a particular company in an incremental and iterative way supported by a tool.
- Provide a mechanism to assess RE process models.

- Provide a knowledge base for requirements engineers to learn and access various RE process models and techniques. Due to the high number of process models and techniques available for RE, it is difficult even for an expert to know them all, so a database containing such knowledge is an asset.

In order to achieve these objectives, we have developed a RE process knowledge base (REPKB), several models and a methodology within the framework. The conceptual diagram of the framework is given in Fig. 1. The following provides brief introductions to each of the components:

- *A RE process knowledge base (REPKB).* In this research, all identified RE models and techniques were classified, analyzed, compared and stored in the REPKB according to the templates we defined.
- *Decision support models.* Case-based reasoning and rule-based reasoning models are used to help the process engineer decide which RE process models and techniques are most suitable for a given project. A description of these models can be found in [10].
- *A RE process development methodology.* Three major components are used in this methodology: the RE process template, RE process building blocks and RE process development guidelines. These components provide information on how to define a RE process model and select the most appropriate techniques. The suggestions for the selection of building blocks and guidelines depend on the project and product attributes of the given project. The discussion about this methodology is the focus of this paper.
- The evaluation models. These models provide information for the evaluation of user developed RE process models and the selected techniques within the context of the given project and product attributes. The major evaluation models are the model for major concerns of RE [18, 22], a revised RE process CMM assessment model [3] and a suitability assessment model.

3. Process Development Methodology

Developing a general software process model has been extensively discussed in literature [8, 11-13, 24, 25]. The methods and techniques proposed in the literature have certain limitations and cannot be used for RE process development for the following reasons:

- Most process development is done at the organizational level rather than at the project level. In this case, the developed process might not be well-suited for a specific project.
- Existing international standards, used as templates, are tailored towards specific project. The advantage of this method is that it is possible to know the maturity level of a particular software process model. On the other hand, the problem with this method is that the tailoring process is too tedious and time consuming because of the possibly large size of the template. For this reason, this method is rarely applied in project-based process development.
- With the exception of maturity assessment, no other

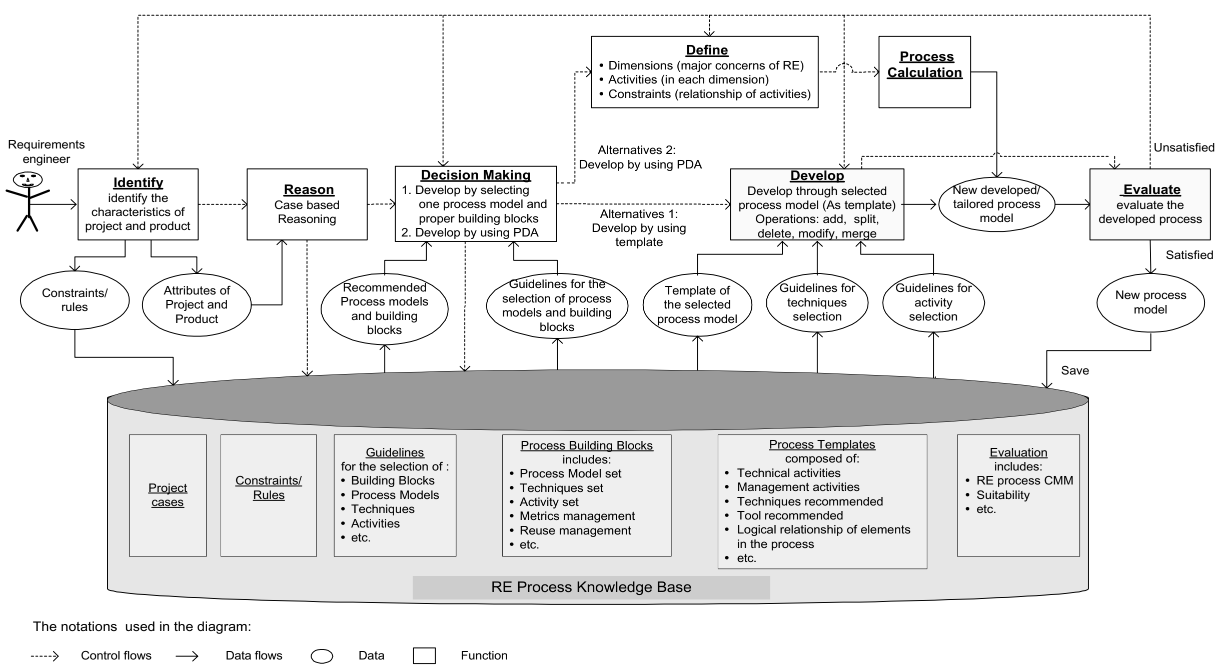

Fig. 1. Conceptual framework of RE process development

means have been used to evaluate user-developed software process models.

- Currently available international standards for a software process have limited guidance for RE process development. For example, all existing international standards, such as the CMM model, have very little guidance related to RE practice.

Based on these observations, we developed a methodology specifically for RE process development. The following subsections provide a more detailed discussion on this methodology.

Requirements volatility: This attribute is defined as the percentage of requirements change (Y). The attribute can have the following values: very high (Y>=50%), high (50%>Y>=30%), average (30%>Y>=10%), low (10%>Y>=1%) and very low (1%>Y).

Project category: This attribute defines the type of project. The possible values are: Communication, embedded, semi-embedded and dynamic. Some of these possible values are borrowed from the COCOMO model [21].

Degree of safety criticality: This attribute is defined as the degree of safety required by the system with regards to the

Table 1. The rules for technique selection (partial list)

Rules	Condition attributes									Decision attributes
	Attributes of Project and product									**Technique sets** (recommended)
	The size of the project	Team Size	Requirements Volatility	Organization and Customer relationship	Project Category	Degree of safety criticality	Quality Standard	Product Type	…	
1	small	10	high	ITT (stands for the software company getting an invitation from customer to tender)	Organic	Low	middle	New	…	**Elicitation:** 1. Customer online 2. Prototyping 3. Concept Map 4. Focus groups **Analysis and Negotiation:** 1. OO analysis 2. AHP 3. UML 4. SASD **Documentation :** 1 UML based 2. Text-based **Verification and Validation:** 1.Customer online 2.Technical Review **Tool support:** Any documentation tool
2	Middle	40	low	ITT	Embedded system	high	High	New	…	**Elicitation:** 1. Interviewing 2. Focus groups 3. JAD 4. Observations **Analysis and Negotiation:** 1. QFD 2. Formal Modeling 3. OO Modeling 4. Goal based analysis 5. Viewpoints analysis 6.Use case Modeling **Documentation :** 1. Formal notation 2.Viewpoints-based 3. Use case-based **Verification and Validation:** 1. Technical review 2. Scenario checking 3. Verification with formal language 4. Requirements testing **Tool support:** 1. Tool for documentation, such as DOORs, Requisite Pro. 2. Tool for verification (if formal notations are used).
3	Big	100	Low	ITT	Semi-detached	high	High	New	…	**Elicitation:** 1. Interviewing 2. Focus groups 3. JAD 4. Observations **Analysis and Negotiation:** 1. Use case Modeling. 2. QFD 3. OO Modeling 4. E-R modeling 5. Goal based analysis. 6. Viewpoints analysis 7. Formal Modeling **Documentation :** 1. UML-based 2. Formal Notation 3. Structured Language **Verification and Validation:** 1. Technical review 2. Requirements testing 3. Scenario checking 4. Checklist **Tool support:** 1. Good RE Tool for documentation, such as DOORS. 2. Tool for verification (if formal notations are used).
…	…	…	…	…	…	…	…	…	..	…

3.1 RE Process Knowledge Base (REPKB)

3.1.1 Project and Product Attributes. Based on our research on the relationship between software projects and RE processes, we have developed a set of software project attributes and organized them into two categories. The attributes in the first category are considered to be more important factors during decision-making and are therefore used more frequently. They provide a means to characterize projects, RE process models, techniques, and methodologies and to establish links between them. Each of these attributes has been defined in detail in [18]. A brief description is given here:

Project size: This attribute is defined as the size of the project (X) in terms of number of requirements. The possible values are: Very big (X>=4000 requirements), big (4000=>X>=2500), medium (2500=>X>=1000), small (1000=>X>100), very small(X<100).

loss of human life or property. The values are defined as follows: very high, high, average, low and very low.

Similarly, we define other attributes such as *Product Type*, *Team Size*, *Project Complexity*, *Time Constraints*, *Organization and Customer relationship* [2], *Acquaintance of the domain*, *Product Quality Standard*, etc. The various values of these attributes provide helpful information for the selection of RE models and techniques.

3.1.2 REPKB. The REPKB includes information related to the development of a RE process, such as

- software project cases
- RE process models
- RE technique and methodologies
- RE process building blocks
- RE process tailoring guidelines
- RE process activity sets ("best practices")
- major concerns of the RE process

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The rules define when to use certain RE process models, techniques, methodologies, process building blocks and process tailoring guidelines. The rules are based on information from two sources:

Table 2. Guidelines for RE process developments

Key attributes	Quantification	Heuristics	Suggested Building Blocks	Suggested Models	Suggested Techniques
Size and Complexity	Project size: Large+ Complexity: complex+.	• Models with complete definition are recommended • More Rigor Models are recommended (Formal Spec definition) • Share RE tools across organization where they are appropriates • Every major concerns of requirements engineering should be addressed among the model construction Other description: • Many hardware and software elements interact with each other need to be considered • These kinds of projects, generally built by many distinct organizations, so identify the relationship among these organizations and make requirements consistent with each other are strongly recommended.	all building blocks are recommended	Process Template SREM Goal-oriented Viewpoints-oriented	**E: Group Session approach** **A&N:** **Rigours Modelling**: **Semi-formal** (when system is not a safety-critical system) or **Formal Techniques** (when system is safety-critical system) . **D: Semi-Formal notation or Formal notation** or **Structured Text**. **V&V: Formal inspection or Formal Methods**
Size and Complexity (Cont.)	Project size: Medium Complexity: Medium	• Use standardized documents • Formalize requirements traceability and cross-org. communication • Where possible combine documentation and testing across organization. • Share RE tools across organization if it is available • If requirements volatility is high, lightweight model be considered	all building blocks are recommended	Goal-oriented Viewpoints-oriented	**E: Group Session approach** **A. Formal analysis, UML, SASD like techniques** **D. Semi-formal documentation or formal** **V&V: Formal inspection,**
Size and Complexity (Cont.)	Project size: small- Complexity: low-	• If time to market pressure is high, then a lightweight process model is recommended (incremental RE process) • Basic documentation of requirements is recommended • If domain is unclear, then incremental prototyping • Communication within group will be highly recommended • Analysis method should be consistent with the whole design process, i.e. if you use OO analysis, then should use OO language in the later design phrases	Elicitation Analysis Documentation Conflict Identification	RUP RAD, Scrum XP	**E: customer on line communication** **A&N. Any** **D: Textual use case, text** **V&V: customer on line verification, informal inspection, technical review**

Keys: E: stands for Elicitation. A&N: stands for analysis and negotiation. D: documentation. V&V: stands for verification and validation

- A thorough review and analysis of RE literature on currently available RE process models, techniques and methodologies was conducted. Firstly, the characteristics of those RE models, techniques and methodologies are identified. Secondly, the applicability of certain RE process models, techniques and methodologies to a certain type of project is identified and documented as rules.
- A survey of people from academia and industry was carried out. The experience and knowledge of experts was identified and documented as rules.

Some sample rules for the selection of RE techniques are presented in Tables 1 and 2.

In Table 1, the column of decision attributes shows the recommendations regarding the suitability of various RE techniques for different types of projects based on the different condition attributes listed in the table. All recommended RE techniques are organized into four main activities of the RE process (Fig. 2), namely elicitation, analysis & negotiation, documentation and verification & validation. All these rules are stored in the REPKB. The recommendations for different categories of activities are as shown in the decision attribute column. The decision support for choosing a particular set of techniques for a project is based on similarity reasoning. Similarity reasoning is carried out according to the attributes and rules in Table 1 though the values of the attributes of the given project might not be exactly the same as that provided in the table.

Tables 1 and 2 only show a few examples of the cases and rules. The REPKB contains a more extensive collection. More rules to support the decision making process will be added as the work progresses.

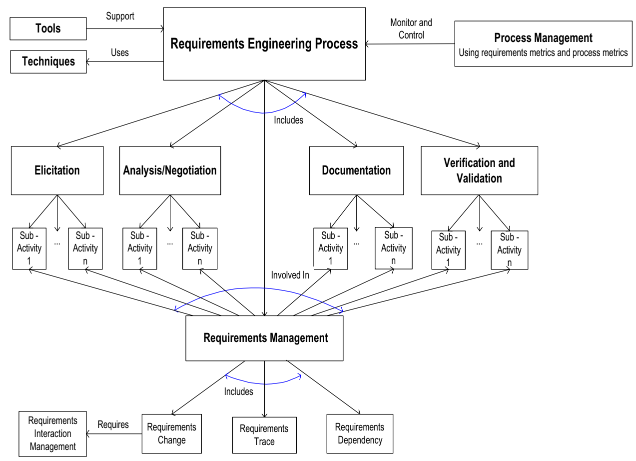

Fig. 2. RE process template

3.2 A Conceptual Framework for RE Process Development

The conceptual framework of RE process development is shown in Fig. 1. The general development process is summarized as follows:

1. *Define the context of the project.* In this step, the user needs to define the values of the project attributes and the weight of each attribute according to his/her perception of the project. The values of these attributes determine the selection of the RE process building blocks, process model, techniques as well as the higher level guidelines for process development.
2. *Case-based reasoning based on the decision support model.* Case-based reasoning is carried out based on the values of the project attributes defined in step 1. The purpose of case-based reasoning is to look for those cases that have similar condition attribute values to the ones defined for the given project. The similarity between the condition attributes (Table 1) of the existing rules and the attributes of the given project is calculated using the weighted Euclidean distance metrics calculation model [20]. The values of the decision attributes of the existing (cases) rules that are very similar to the given project are taken as the results of this step. Let's assume that:
   - R is the existing set of rules contained in REPKB;
   - $\gamma_i = (X_i , D_i)$ represents the existing rules (cases); i=1, ···, n, with n being the number of the rules; all

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the existing rules have k condition attributes and m decision attributes.

- $X_i = (x_{i,1}, x_{i,2}, ..., x_{i,k})$ denotes the values of the condition attributes of the *i*th rule in REPKB; $x_{i,j}$ represents the value of the *j*th condition attribute for the *i*th rule; *j*=1,···,k;
- $D_i = (d_{i,1}, d_{i,2}, ..., d_{i,m})$ denotes the values of the decision attributes of the *i*th rule in REPKB; $d_{i,p}$ represents the value of the *p*th decision attribute for the *i*th rule; *p*=1,···,m;
- $Y = (y_1, y_2, ..., y_k)$ denotes the attributes of the given project; y_j represent the value of the *j*th attribute for the given project; j=1,···,k;
- W_j denotes the weight for each condition attribute; j=1,···,k;

Then, the similarity result is given as:

$$Sim(X_i,Y) = \frac{1}{\sqrt{\sum_{j=1}^{k} w_j (x_{i,j} - y_j)^2}} \qquad i=1,\cdots,n. \qquad (1)$$

The recommended techniques and/or process models for the given project will be:

$$\{ d_{i,1}, d_{i,2}, ..., d_{i,n} \mid \gamma_i \in R \wedge Max(sim(X_i, Y)),\ i=1,\cdots,n, \} \qquad (2)$$

$Max(sim(X_i, Y))$ indicates the maximum value of the similarities calculated among all existing rules according to equation (1).

In this similarity calculation, we assume that no two existing rules have exactly the same value of overall similarity with the given project, i.e. no X_j exists, such that $Sim(X_i,Y) = Sim(X_j,Y)$. If X_j exists then additional attributes must be considered that help differentiate between those cases.

3. *Information retrieval.* According to the results of case-based reasoning and the constraints that the user defined, a set of RE process building blocks, RE process models, techniques and/or methodologies, and higher-level process development guidelines are selected from the REPKB and recommended to the process engineer. The recommendations given in this step are not decisions by themselves but critical information which helps the requirements engineer make qualified decisions.
4. *RE process model comparison.* A comparison among the recommended process models is conducted based on several criteria such as level of completeness of the process model, RE CMM level, the major concerns of RE addressed [18, 22], level of complexity, introduction cost and application cost, etc.
5. *Comparison of methodologies and techniques.* A comparison between recommended techniques and methodologies is conducted based on certain criteria, such as introduction cost, application cost, complexity, strengths, weaknesses, and suitability of techniques for certain projects.
6. *Decision making.* Based on the recommendations given in step 3 and the comparisons in step 4 and 5, requirements engineers select one RE process model, a subset of techniques and methodologies and a subset of RE process building blocks from the recommendations given in step 3. Once a RE process model is selected, further queries are conducted and more detailed information about the selected RE model as well as process development guidelines can be retrieved. The information is ready to be used in the next step.
7. *Process development.* Based on the decision made in the last step, process development is carried out in one of three possible ways:
   i. Using the selected existing process model as a reference process model, requirements engineers develop a new RE process model by using building blocks, techniques and guidelines through the following operations: adding, splitting, deleting, merging and modifying.
   ii. Using the RE process template defined in our framework [20], requirements engineers develop a new RE process model by tailoring the RE process template and using the building blocks, techniques and guidelines.
   iii. Requirements engineers develop a RE process by using the Process Development Assistant (PDA) of our previous work [9].

It is worth mentioning that process development is an iterative process. Several iterations might be necessary based on the situation and the judgment of the requirements engineer. After completion, the new user-defined process can be assessed using the assessment models we developed. The discussion of the assessment models is beyond the scope of this paper; interested readers can refer to [20] for more details.

3.3 Templates

In order to facilitate RE process development, six templates were developed: the RE process template, the process model definition template, the techniques definition template, the activity definition template, the rules template and the guidelines template. In the following we will discuss four of the six templates in more detail.

3.3.1 The RE Process Template. The RE process template serves as a standard RE process template and/or reference model for the development of a RE process. The high-level components of this template are shown in Fig. 2. The following provides the definition of the RE process template and a brief explanation of each component of the template:

- Based on Kotonya & Sommerville's RE process model [8], we defined the RE process template shown in Fig. 2. The template includes four main activities: Elicitation, Analysis/Negotiation, Documentation and Validation & Verification. Each main activity can also be considered as a process since they include a lot of sub-activities that implement part of the tasks defined in the main activity. A sub-activity is defined as the smallest element in a RE process model in our RE process template. This means the activity is at the lowest level of a RE process template. Requirements management is involved in all four activities as illustrated in Fig. 2. Which techniques will be selected in a RE process depends on the evaluation of the suitability of each technique for a given project based on its characteristics.
- RE process management includes a wide variety of topics. It is mainly related to the issues of RE process planning, requirements and process metrics with a focus on monitoring and controlling the RE process.

Table 3. Templates for the process model, technique and activity

Process Model Template	Technique Template	Activity Template
Process Model Name	Technique Name	Activity ID
Activities:	Techniques Category	Activity Name
Techniques Used	Capability:	Actors
Tool Support	Tool Support	Category
Introduction Cost:	Introduction Cost:	Major COREs Addressed
Application Cost:	Application Cost:	Pre-Activity
Strengths:	Strengths:	Post-Activity
Weaknesses:	Weaknesses:	RE CMM Level
Complexity of the model	Complexity of the Technique	Introduction Cost
Major COREs addressed	Applicable Project Type	Application Cost
Maturity Assessment Results	Recommended project	Artifacts
Applicable Project Type	Detail description:	Candidate Techniques
Recommended system	Reported Case	Detail Description
Detail description:		
Post-mortem Assessment*		

3.3.2 Other Templates. In order to help the RE process developer, several other templates have been defined. The most important ones are the process model definition template, the techniques definition template and the activity definition template. The basic elements of these three templates are shown in Table 3. The following provides only brief explanations of these templates; more detailed descriptions can be found in [20]:

1. The underlined elements (see Table 3) such as *Activities, Techniques Used, major COREs (*COncerns of RE*) addressed* are composite data types. For example the element *Activities* is organized according to the four main activities of the RE process and each main activity has several sub-activities.
2. The elements that are not underlined are primitive data types; most of them are self explanatory. Some attributes that are worth mentioning are:
   - *Introduction Cost*. This element represents the cost of introducing the technique or activity into the process if this activity or technique has never been used before in the organization. In this case, training for using the technique is needed.
   - *Application Cost*. This element represents the cost of carrying out the activity or using the technique during the RE process.
   - *Capability*. This element indicates the effectiveness of a certain technique. It could mean different things for different techniques. For instance, in the case of a requirements documentation technique, capability means the *expressiveness* of the notations used for the requirements documentation. Therefore, the capability is judged by the effectiveness and flexibility of the technique adopted.
   - *Maturity assessment results*. This element represents the maturity level of the given RE process model. It is one of the evaluation criteria for the RE process.
   - *Major COREs addressed*. The major COncerns of RE (COREs) model is a RE process assessment model developed in our research [18, 22]. This element represents the number of the concerns that are addressed by an activity and/or a RE process model. By defining this element, the connection between RE process development and the major COREs is established.

These five elements provide a mechanism for the evaluation of the activities, techniques and the development of an RE process model as a whole.

3.4 RE Process Building Blocks

An RE process building bock is a structured unit of RE process knowledge. Each building block is composed of a set of guidelines of a certain part of RE knowledge. The following factors have been considered in the construction of the RE process building blocks in order to facilitate RE process development:

- The building blocks and the knowledge structure whereas it is based, should reflect the current RE process research and practice.
- The organization of the building blocks should have a connection with the attributes of the project.
- The building blocks should contain a cohesive set of RE process knowledge.

Based on these considerations, we developed the RE process building blocks illustrated in Fig. 3.

A brief explanation of these building blocks is given as follows. The interested reader can refer to [20] for more details.

- Each of the main activities in our RE process template is defined as a building block to facilitate RE process development. These building blocks are Elicitation, Analysis & Negotiation, Documentation and Validation & Verification. Additionally, sub-activities and associated knowledge are also organized into building blocks.

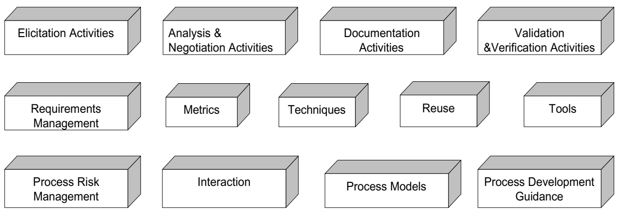

Fig. 3. RE process building blocks

- The building block of RE Process Risk Management contains a checklist of RE process risk indicators, some of which are derived from the taxonomy-based risk identification framework [14].
- The building block "Process Development Guidance" contains a collection of process development guidelines at two different levels of abstraction. Section 3.5 contains more details on this building block.
- The blocks "Process Models" and "Techniques" contain a collection of currently identified RE process models and techniques. These models and techniques are organized according to the four main activities of the RE process template (Fig. 2).
- The "Interaction" building block includes various issues related to the management of requirements interaction, requirements inconsistency and requirements conflict.
- The "Metrics" building block is related to the knowledge of methods, techniques for measuring requirements and the overall requirements process in a qualitative and quantitative way.
- The "Tools" building block includes information about the selection of RE tools.
- The "Requirements Management" building block contains information on techniques and activities related to requirements management.
- The "Reuse" building block includes details on techniques and activities related to requirements reuse as well as product families and product lines.

3.5 Development Guidance

There are many different RE models and techniques which make it difficult for requirements engineers to select the most appropriate RE model and the most suitable techniques. For this reason, we developed guidelines at two levels (Figure 4):

- General guidelines. These guidelines provide general or high-level guidance for process definition, process tailoring, model and techniques selection. The heuristic guidelines are examples of this type of guidelines (Table 2).
- Specific guidelines. These guidelines can be divided into the following types:
    - i. RE process building block guidelines: These guidelines recommend the appropriate building blocks for the construction of the RE process (Table 2).
    - ii. Process model guidelines: These guidelines are for the selection of the RE process model.

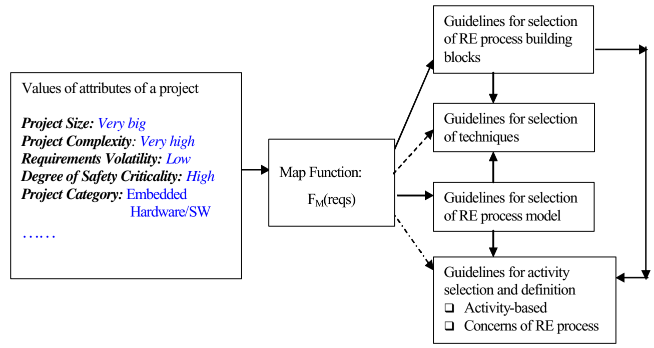

Fig. 4. Relationship of the guidelines and project attributes

- iii. Technique guidelines: Technique guidelines provide information about the suitability of techniques for certain projects.
- iv. Activity guidelines: These guidelines provide information about the activities that are to be used in the selected RE process model. There are two kinds of guidelines in this category: the first category contains activity-based guidelines while the second category contains the major concerns of a RE process. An in-depth description of the concept of major COREs is given in [18, 22].

There are relationships between these guidelines and the values of the project and product attributes. Fig. 4 illustrates these relationships: solid lines indicate that the attributes of project and product are directly mapped to the specific guidelines for the selection of RE process model and building blocks. The selection of an RE model as a reference model will further influence the selection of techniques and activities. The dashed lines indicate an indirect relationship between higher level RE technique selection and activity definition guidelines. A more detailed discussion about the rationale of the relationships can be found in [20].

3.6 Process Development Operations

Several operations are defined to help RE process development. These operations are addition, deletion, splitting, merging and modifying.

- *Addition* inserts additional activities into the RE process model under development.

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- *Deletion* removes activities from the process model as they might be too expensive or not necessary for the given project.
- *Splitting* divides an activity into sub-activities if the tasks of the activity are too complex to be accomplished as one activity.
- *Merging* combines several activities to form a higher level activity if these activities accomplish the same or similar tasks.
- *Modifying* changes the name or definition of an activity to makes it more useful.

Table 4. The definition of project

Project Description	This project is a "Port Scheduling System". The objective of the system is to schedule a container terminal with a throughput of over 1 million TEU (twenty foot equivalent unit) each year. Smaller cargos must also be possible to be handled. The project requires a highly interactive interface.	
Project Attributes	***Project Size***: middle (>1000 and <3000 Requirements)	
	Project Complexity: middle	
	Requirements Volatility: low	
	Organization and Customer relationship: SCR (SCR stands for responding to a Specific Customer Request)	
	Project Category: Semi-detached mode	
	Team Size *(Number of people in the Project):* 30	
	Degree of knowledge of Requirements: middle	
Product Attributes	***Degree of safety criticality***: high	
	Quality Standard: high	
	Product type: New	

Table 5. Recommendations and final selection

		Recommendation	Final selection
RE process model		VORD (Viewpoints-based Model), Goal-based Model, RUP	VORD (Viewpoints-Oriented Requirements Definition)
RE process building block		Elicitation, Analysis & Negotiation, Documentation, Verification &Validation, Tool support:, Metrics, Technique set, Model set, Change management	Elicitation, Analysis & Negotiation, Documentation, Verification & Validation, Tool support, Technique set, Change management,
RE techniques	**E:**	Interview, Focus Group, JAD,	Focus group, Interview
	A/N:	Viewpoint OO, Scenario-Based Analysis (use case), OO Analysis, Structure Analysis, AHP, Goal Based Analysis,	Viewpoint OO
	D:	Viewpoint definition, Structure Formal specification, UML,	Viewpoint definition
	V:	Viewpoint Validation, Formal Inspection	Formal Inspection
	T:	DOORS, RequisitePro	DOORS
Keys: E: stands for Elicitation. A&N: stands for analysis and negotiation. D: documentation. V&V: stands for verification and validation			

4 Case Study

Several case studies have been conducted throughout the course of this research based on the methodology introduced above. Currently, we are in the process of building a prototype of the tool. The following case study shows the feasibility of the methodology discussed above. A software organization starts working on a medium-sized project to develop a Port Scheduling System. Realizing that none of the existing RE process models in the organization is suitable for the new project, the requirements engineers decide to use the methodology to develop a suitable RE process model to guide the RE process for the given project. A simple description of the case study using this methodology is shown below:

1. Project definition (see Table 4)

After the initial analysis of the project, the requirements engineers proceed to provide a basic definition of the project. This procedure involves two steps:

(a). Identification of the characteristics of the project based on its description.

(b). Assign the appropriate values to the project attributes identified in (a).

2. Decision support:

Based on the values given in Table 4, the following activities are performed:

(a). Case-based reasoning using the REPKB: The results of the reasoning are (Table 5):

  i. Recommendations of RE process building blocks for process development.
  ii. Recommendations of RE process models. These process models serve as reference models for the definition of the new RE process model for the given project.
  iii. Recommendations of RE techniques.

(b). High-level guidelines can be retrieved from the database that help with the selection of the RE process model. Two typical examples of these guidelines are *"Choose rigorous RE model"*, *"techniques with highly expressive notation are preferred"*.

(c). More detailed information about recommended RE process models, techniques and activities can be retrieved from the database. Table 6 gives three simplified examples of such information.

Table 6. Examples of the Retrieved Information

Model	Technique	Activity
Process Model Name: VORD **Activities:** **E:** Prune the abstract viewpoint class hierarchy… **A&N:** Prioritize requirements… **D:** Document viewpoint with defined language… **V&V:** Check for conflicts of viewpoints… **Technique used:** Document mining, Modeling… **Tools Supports**: *viewpoint based tool available* **Introduction Cost:** medium **Application costs:** medium **…** **Maturity Assessment Results**: *level 1* **Recommended system**: Interaction intensive system **Complexity of the model:** medium ….	**Technique Name**: AHP **Match value:** High ***Techniques Category:*** *A & N* **Introduction Cost:** medium **Application Cost**: low **Capability**: High **Recommended system**: Any, **Tool Support:** Available in the market. **Complexity of the techniques**: Low ***Strengths***: *give priority for the requirements* ***Weaknesses:*** *Time consuming when number of requirements is large* **Recommended project:** number of requirements is not very large ….	**Activity Name:** Identify system stakeholders **Actors:** requirements engineers **Category**: E **Major COREs addressed:** identification of the stakeholders **Pre-Activities**: Prune the abstract viewpoints **Post-Activities**: *Hold focus group meeting to identify viewpoints requirements* **RE CMM Level:** level 1 **Introduction Cost:** low **Application Cost:** low **Artifacts:** List of stakeholders, ideally, the prioritized list of the stakeholders. **Candidate Techniques**: interview **Detail_description:** … ….

3. Decision making

Based on the recommendation and guidelines given above, requirements engineers make the final decisions about the RE process model and the techniques that are to be used during the next steps. The results of the decision making are shown in Table 5. The reasons behind the decisions are briefly explained:

(a). According to the project description, the project is a highly interactive system. Based on the guidance and the information of the recommended RE models, the VORD model is selected as the reference model for the definition of the new RE process model for the project. The main reasons for this choice are:

- VORD is a process model designed for highly interactive system.
- VORD is more suitable for systems with multiple stakeholders.
- The requirements engineers are familiar with viewpoint-based analysis methods.
- VORD provides a fairly complete structure for the requirements specification document.

(b). According to the project characteristics, i.e., low requirements volatility, more than 1,000 requirements, etc., the requirements engineer decides to choose the building blocks illustrated in Table 5.

4. Process development

(a). Process definition is carried out using the VORD process model as the reference model. Realizing that VORD has to be customized for the project at hand, the requirements engineer decides to use the operations of *Addition*, *Deletion, Merging, Modifying* to develop a new process model for the project. As shown in Table 7, several elements are added to the newly defined RE process model. This newly developed RE process model addresses more major COREs and is more suitable for the given project.

(b). The definition of activities in the new RE process model is based on both the activity definition template and guidelines:

- Defining the activities of the new process model by using the template and guidelines generated from the VORD process model.
- Defining the activities of the new process model by using the template and guidelines generated from the major COREs model.

An example of an activity definition using the activity template is shown in column 3 of Table 6. More new activities developed for the new RE process model for the given project are given in Table 7. These new activities shown in *italics* are based on the consideration of the major COREs and the attributes of the project; other activities are either directly used or modified versions of the activities of the VORD process model. Reasons for some of the newly defined activities are summarized in the following:

- o Since the project involves a lot of stakeholders the activity *"record the rationale of the viewpoints requirements"* becomes a very important issue in order to manage the requirements. This activity also addresses one of the major COREs.
- o Since the project requires a high degree of safety and criticality, the requirements engineer decides to *analyze safety related requirements in the system using Fault Tree Analysis techniques,* which is a technique s/he is familiar with. This activity also addresses one of the major COREs.
- o Based on guidance from the major concern "Understanding non-functional requirements and system constraints", the requirements engineer realizes that non-functional requirements are of great importance in this project, so an activity *Document non-functional requirements with a structured language* is defined.

Table 7. Comparison between the original VORD and the modified process model

Phases	Original activities in VORD	Activities defined for the Project
E: Identify viewpoints	• Prune the abstract viewpoint class hierarchy • Consider the system stakeholders • Use a model of the system architecture, identify system viewpoint. • Identify system operators • Consider the roles of the principal individual who might be associated with that class.	• Prune the abstract viewpoint class hierarchy • Identify the system stakeholders • Identify system operators and consider the roles of the principal individual who might be associated with that class. • *Hold focus group meeting to elicit requirements from various viewpoints (both functional and non-functional)* • *Record the rationale of the viewpoints requirements*
A/N: Analysis and negotiation of viewpoints requirements	• Prioritize requirements • Consider/analyze non-functional requirements and constraints • Model viewpoint service behaviour (functional requirements modelling) • Represent user interface requirements as constraints on viewpoint services	• Prioritize requirements • Analyze and understand non-functional requirements and constraints • Model viewpoint service behaviour • Represent and model user interface requirements as constraints on viewpoint services • *Identify and analyze the safety related requirements in the system using Fault Tree Analysis techniques.* • *Develop the test cases for key functional requirements.* • *Identify the conflict and resolve the conflict by negotiation with stakeholder* • *Analyze and identify the relationship of requirements.*
D: Document viewpoints	• Document viewpoint with defined language • Document viewpoint requirements with the template of viewpoint	• Document viewpoint requirements with the template of viewpoints • *Define terminology in the system level* • *Document functional requirements of all viewpoints with UML* • *Document non-functional viewpoints requirements with structured language.* • *Document the test case for key function requirements.* • Document the relationship of requirements.
V: Verification and validation	• Check viewpoint documentation • Analysis conflicts • Resolve conflicts	• Check requirements documentation by using defined checklist. • *Check document to ensure requirements completeness, unambiguous and implementable* • Identify and resolve interactions • *Verify and validate the safety requirements of the system*
Requirements Management	• Manage requirements (viewpoints) evolutions (change).	• Identify and document requirements with high volatility • *Use requirements baseline techniques to management requirements.*
Tools Support	• Use appropriate tool	❑ Buy requirements management tool to management requirements.

5. Process evaluation

After the definition of the activities of the new RE process model and the selection of the techniques, the newly developed RE process model is assessed based on the evaluation models.

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The new process model is applied to the project once the requirements engineer is satisfied with it, otherwise, more modifications are necessary.

This case study has shown the feasibility of the methodology proposed in this paper. We are currently working on several industrial case studies that will provide further improvement of the methodology.

5. Conclusions and Future Research

Developing the most suitable RE process and using the most effective RE techniques have been considered as key factors for the success of RE [16, 17]. However, process development is time-consuming and expensive, and only few project teams can afford to develop their own models from scratch [15]. For this reason, support for process development is necessary to enact effective software processes. This is also true for RE process development. The framework proposed in this paper provides a possible solution for RE process development by combining decision support mechanisms with evaluation mechanisms. Our case study has illustrated the support provided by the framework during RE process development and techniques selection. The benefits gained from this framework and the methodology as a whole are not only that they can help requirements engineers to develop suitable RE process models, but they can also provide educational opportunities for requirements engineers to enrich their RE knowledge through REPKB.

Our further research will provide more evaluation functions for RE models, further refinement of the framework, as well as an implementation of the approach.

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