Combining Requirements Engineering Techniques –Theory and Case Study

[1]Li Jiang [2]Armin Eberlein [1]Behrouz H. Far

[1] *Dept. of Electrical & Computer Engineering, University of Calgary, Canada*

[2] *Computer Engineering Department, American University of Sharjah, UAE*

Email: {ljiang, eberlein, far} @ucalgary.ca

Abstract

The selection of requirements engineering (RE) techniques during software project development is a challenge for most developers. One of the reasons is that there is a great lack of requirements engineering education in most academic programs, so software developers have to learn requirements engineering practices on the job. This can easily result in the selection of techniques that are ill-suited for a particular project, as the selection is based on personal preference rather than on the characteristics of the project. Very little research has been done in the area of technique selection based on project attributes. This paper describes research into the selection and combination of RE techniques as well as a case study that applied the selection process to an industrial software project.

Keywords: Requirements engineering techniques, requirements engineering process, project characteristics.

1. Introduction

Even though we have made significant progress in software development, we still face some challenges that we experienced already 20 years ago: software tends to be over budget and late. And when it is delivered, its quality is below customer expectation. Although reports of the Standish Group indicate that we are slowly getting better (the percentage of canceled projects is decreasing and the number of successful projects is increasing), still about half of all software projects are experiencing major challenges [1]. When one investigates the reasons why projects run into difficulties, a large percentage can be attributed to bad requirements engineering practice. Using appropriate requirements engineering (RE) techniques during the development of a software project has the potential of making a project successful.

The significance of choosing proper techniques and models during software development has already been emphasized by numerous researchers and practitioners. Already in 1993, Alan stated that applying the right technique to a given problem is necessary for effective requirements analysis [2]. This was confirmed by Glass *et al* who stated in a more general way the need for a methodology that helps developers choose the most appropriate software development methodology for the task at hand [3]. Until today, various other papers from the RE domain (e.g., [4, 5, 6, 7,8]) talk about the importance of adopting the right techniques in order to effectively elicit, model, document, verify and validate requirements.

A significant amount of research has been devoted to the development of new methods, techniques, and tools for RE. But very little work has been done into the combination of techniques and the mutual benefit that they can provide. This paper describes research into the combination of RE techniques by describing a selection methodology and its application in an industrial case study. Even though there are many factors that influence the success of a project, we argue that the case study provides compelling evidence of the positive influence that a pragmatic, project-oriented combination of RE techniques has on the success of software systems.

This paper uses the RE process model proposed by Kotonya and Sommerville [9] which consists of four stages: requirements elicitation, requirements analysis and negotiation, requirements documentation, requirements verification and validation. Requirements management is part of each one of these stages. The RE techniques mentioned in this paper are therefore categorized into the following five groups: requirements elicitation techniques, requirements analysis and negotiation techniques, requirements documentation techniques, requirements verification and validation techniques, and requirements management techniques.

The rest of the paper is organized as follows: Section 2 describes the motivation, foundation and the reasons behind the combination of RE techniques in a RE process. Section 3 presents an industrial case study in which a

Table 1 Project attributes that influence RE techniques selection

Project attribues	Reasons for the definition of the attributes	Definition and description of project attribute (Refer to [15] for more information about the definitions of the attributes)
Project Size	The size of project is important to the RE techniques selection. For example, large projects require systematic techniques to elicit, analyze, document, verify and validate requirements.	This attribute is defined as the size X of a project in terms of number of requirements. The requirements refer to atomic requirements which are defined as indivisible "well-formed" requirements [23]. Possible values for this attribute are: very small (X<100 requirements), small (100<=X<500), medium (500<=X<1000), big (1000<=X<4000), very big (X>=4000).
Project Complexity	The complexity of a project matters to the selection of RE techniques. For example, a project with high complexity requires systematic techniques to be used in the RE process.	The complexity of a project is estimated using factors such as the number of project requirements, the overall system architecture, the relationships between requirements and the heterogeneity of stakeholders. The value of the complexity of a project is defined as very low, low, medium, high, and very high.
Requirements Volatility	Requirements volatility is an important attribute that has to be considered in the selection of RE techniques. For example, projects with higher requirements volatility require more flexible techniques to be used in a RE process.	This attribute is defined as the percentage Y of requirements that change throughout the development of the project. The attribute can have the following values: very low (Y<1%), low (10%>Y>=1%), average (30%>Y>=10%), high (50%>Y>=30%), and very high (Y>=50%).
Project Category	Projects in different categories require different techniques to be used in the RE process. For example, the techniques used in a safety-critical system will not be the same as the ones used in a non-safety critical system.	This attribute defines the type of project. Possible values are: Communication, Embedded, Semi-detached and Organic. Some of these values are borrowed from the COCOMO model [21].
Degree of Safety Criticality	Degree of safety criticality is considered as an important attribute for the selection of RE techniques. Projects with a high degree of safety criticality require more rigorous and disciplined techniques.	This attribute is defined as the degree of safety required by the system measured by the potential loss of human life or property. The values are defined as follows: very low, low, medium, high, and very high.
Quality Standard	Different domains have different quality standards. This influences the RE technique selection. For example, if quality standards have to be met, more rigorous RE techniques are required.	This attribute indicates the required quality of the system. The following quality requirements are used in this research: reliability, usability and functionality. The values can be: very low, low, medium, high, and very high.
Time Constraints	Time constraints have to be considered when it comes to the selection of RE techniques. Projects with high time constraints require lightweight techniques to be used because heavy-weight techniques will significantly delay the overall project.	Time constraints are defined as the degree of the time-to-market pressure for the software project. The attribute values are defined as: very low, low, medium, high, and very high.
Cost Constraints	Projects with high cost constraints require lightweight techniques to be used in the RE process because heavy-weight techniques will increase the cost, especially when training for the use of the technique is required.	Cost constraints are defined as the ratio of the overall budget of the project with respect to its actual cost. The attribute values are defined as: very low, low, medium, high, and very high.
Team Size	Team size has an impact on the selection of RE techniques. For example, if the team size is big, communication can become challenging, i.e., rigorous and systematic RE techniques are required. Requirements have to be documented and management in an effective way.	Team size is defined as the number of people in a team. The values of the attribute are defined based on the work of Yourdon [22]: very small team, small team, medium team, big team, very big team
Acquaintance with Domain	The level of acquaintance with a domain influences the selection of RE techniques. For example, if the team is not well acquainted with the domain, requirements modeling techniques are required in order to understand requirements better.	This attribute is defined as the level or degree of the overall knowledge of the problem domain to which the given software project belongs. The values of the attribute are defined as: very low, low, medium, high, and very high.
Reusability	If the project is likely to be part of a product family, reusability is an important issue that has to be considered. Techniques that support requirements reuse have to be used.	This attribute is defined as the degree of reusability of requirements and the potential of the project being part of a product family. The values of the attribute are: very low, low, medium, high, and very high.

combination of RE techniques has been used. An overall discussion is presented in Section 4. Conclusions and future work are described in Section 5.

2. Foundation of RE Technique Combination

2.1. The need for RE techniques combination

Even though many different RE techniques and methodologies have been developed over the last decades, their application is not yet wide-spread in industry. There are several challenges:

- The different problem domains require different techniques. For example, requirements of a real-time software system must be rigorously analyzed and verified. Therefore, more rigorous formal methods are necessary for this type of project.
- Different software projects require different techniques. Some projects require a very short time-to-market. In this case, light-weight techniques are required that do not significantly compromise the quality of the product. Other projects might have requirements that are very difficult to identify as there is a large amount of implicit knowledge required. In this case, Ethnographic techniques are useful.
- The diversity of stakeholders requires different techniques. Some projects have a large number and heterogeneous stakeholders. Maximizing the satisfaction of stakeholders is important for the success of a project. Group session techniques are helpful for the success of such projects [10].
- Numerous techniques have not yet been widely used. This does not necessarily reflect on their capability, as publicity and tool support have a major impact on the acceptance of techniques.
- So far, there is no single technique that provides a solution for all RE problems. This means that developers have to carefully select and combine suitable techniques for a project.

The significance of combining RE techniques in a software project has already been addressed by several researchers. Macaulay argues that no single method or technique is sufficient for all projects [11]. Similarly, in order to examine the merit of combining several techniques, some researchers report their experience with combining prototyping, scenario-based analysis and several design methods in a software project [5, 6]. Additionally, the US Department of Defense published software design guidelines in which a combination of top-down and bottom-up techniques are used to develop and document requirements. Top-down functional analysis is used to identify gaps, analyze alternative approaches, measure outcome effectiveness, and produce an initial capabilities document (ICD). Bottom up is essentially a combination of analysis, verification and inspection

Proceedings of the 12th IEEE International Conference and Workshops on the Engineering of Computer-Based Systems (ECBS'05)
0-7695-2308-0/05 $20.00 © 2005 IEEE

techniques with the intent to develop the capabilities development document (CDD) [12] [13]. Frank Anger, program director and senior scientist of the U.S. National Science Foundation, stated that “a science of software construction should be able to help us choose between viable alternatives” [14]. This claim calls for research that can help software engineers select different alternatives throughout the whole software development process.

The merit of using a combination of RE techniques is that a specialized technique that is highly effective in addressing a particular problem can be complemented with other techniques that deal with issues that the former technique does not address. This will help develop high-quality requirements for software projects.

However, very little research effort has been invested into the combination of RE techniques in the various stages of the RE process in a software project. Currently, there is no effective methodology to categorize, select and combine RE techniques for a particular software project as numerous factors influence this process. Table 1 shows a summary of some project attributes used in our research and considered important for the selection of RE techniques [10, 15, 16]. The justification of the importance of these factors is also given in Table 1. The selection of RE techniques for a given project is a knowledge intensive task that requires a systematic methodology. We therefore developed a methodology called Methodology for Requirements Engineering Techniques Selection (MRETS). MRETS is a systematic process for the selection of a combination of RE techniques supported by a requirements technique library and has been described in detail in [17]. The focus of this paper is on the application of MRETS to an industrial software project.

2.2. Research approach

In order to examine the merits of combining RE techniques, several industrial case studies were conducted during which various combinations of RE techniques were selected and used to carry out different projects. The authors were directly involved in these projects to provide methodological guidance and training for the project team members. The term *requirements engineer* refers to both requirements engineers and the authors where it is appropriate thereafter.

This paper tries to answer the following research questions: Is it at all feasible to use a combination of RE techniques in a software project? If this is the case, what are the major benefits of using a combination of RE techniques? Can a combination of RE techniques provide a cost-effective solution for the overall quality of the specification for a software project in terms of the quality specification it affects? Will RE tools provide effective support for the RE process, and how many tools are needed?

The following four steps describe the overall research approach at a high level of abstraction:

Step 1. Project definition
A set of software project attributes were defined to describe the characteristics of the given project. The project attributes play an important role when it comes to project characterization and selection of RE techniques. Each of these attributes has been defined in detail in [15]. A brief description of some of these attributes can be found in Table 1. The purpose of this step is to understand the basic characteristics of the project and score the attributes.

Step 2. Select a combination of RE techniques by considering characteristics of RE techniques as well as the project using MRETS.
A library of RE techniques was developed and currently contains more than 46 techniques. A combination of RE techniques includes: requirements elicitation techniques, requirements analysis and negotiation techniques, requirements documentation techniques, requirements verification and validation techniques, and requirements management tools.

Step 3. Plan and apply the selected techniques to the project.
In order to apply the combination of RE techniques to the given project, appropriate planning is needed to ensure success. It is also essential that a requirements engineer “owns” the requirements engineering process and is available for any questions by the development team.
Additionally, training is provided in this step, i.e., before the actual application of the RE techniques begins. The training includes RE techniques, process management, and team work.

Table 2 Attributes selected to be measured in software process

Attributes of the project (see Table 1)
RE Techniques used
Number of requirements (atomic requirements):
Number of analysts involved (play also the role of requirements engineers)
Number of developers involved
Number of original requirements
Number of requirements elicited using the selected RE techniques
Number of requirements modified during requirements verification and validation
Number of requirements added during requirements verification and validation
Number of requirements discovered during the design stage
Number of requirements discovered during the testing stage
Number of requirements changed after start of design
Planned time for the project
Time actually used for the project

Step 4. Collect data from the RE process.
The data related to the research has to be collected to determine the pros and cons of applying the combination of RE techniques. The metrics to be measured in our particular case study are shown in Table 2. The major

reasons for using these attributes are: first, data values of these attributes provide information regarding the quality of the requirements; second, data related to these attributes are available from previous projects in the company. This will allow us to compare the new project with previous projects to see what impact the RE techniques have on project success.

Table 3 Project definition (partial)

Project Description	**Name of Project:** Power Optimization System (IPOS). The major objective of IPOS is to provide advanced, real-time supply chain management solutions targeted at the end-to-end optimization of power networks within a large geographical area. This area covers 685,000 square kilometres with the population of over 2 million people. The allocation of electrical power can be done both automatically and manually. The tariff structure consists of three layers: peak price, partial peak price and normal price which reflect the overall objectives of minimizing power production costs and to meet stringent emission regulations of electrical power. Companies in which sudden power outages can lead to very high cost and disastrous accidents have to be protected from power outages if at all possible.
Project Attributes	**Project Size**: Big (between 1000 and 4000 requirements)
	Project Complexity: Very High
	Requirements Volatility: Very Low
	Project Category: Embedded System
	Degree of Safety Criticality: High
	Quality Standard: High
	Time Constraints: Low
	Cost Constraints: Low
	Team Size (Number of people in the project): 62
	Acquaintance with Domain: Low
	Reusability: Medium
	……

Table 4 The RE techniques recommended for the IPOS project

Categories	Recommended Techniques
Elicitation	Focus Group, Interview, Ethnography
Analysis and Negotiation	State Machine, Fault-Tree, Analysis, Scenario-Based Approach
Documentation	UML, State Machine Notation.
Verification and Validation	Formal Inspection
Requirements Management	Requirements Change Management, Requirements Traceability Management.
Tools	RequisitePro, Rational Rose

3. A Case Study

Several case studies have been conducted throughout the course of this research. The data from one of the studies is presented in this paper in order to help analyze the usefulness of RE techniques combination in industry.

3.1. Project description

The following case study shows the application of the combination of RE techniques to an industrial project in company Y (the name of the company is withheld for

Table 5 Justification for use of the RE techniques

Categories	Recommended techniques	Justification	
		Condition for the applicability of the techniques	**Characteristics of the IPOS project and the project team**
Elicitation	Focus Group	Focus Groups are suitable in situations where: (1) there is high stakeholder heterogeneity (2) a skilled facilitator is available (3) time and cost constraints are low (4) some specific foci are planned and need to be resolved	The project meets conditions (1), (2), (3), (4). Additionally, all requirements engineers in this team of the project knew this technique and had previous experience with it.
	Interview	Interviews are suitable in situations where: (1) there is high stakeholder heterogeneity (2) the opinions or the characteristics of people are sensitive in outspoken environment (3) the opinions of some stakeholders are particular important and the stakeholder cannot attend the group session meeting	The project meets conditions (1), (2), (3). Additionally, all requirements engineers in this project team knew this technique and had some experience with it.
	Ethnography	Ethnography is suitable in situations where: (1) there is high stakeholder heterogeneity (2) functionality and usability are crucial (3) elicitation of implicit knowledge is essential (4) customer availability is high	The project meets conditions (1), (2), (3), (4). Additionally, the authors were part of the project team and provided the necessary training to the member of the project team.
Analysis & Negotiation	State Machine	State Machines are suitable in situations where: (1) the project demands rigorous, precise, consistent and unambiguous descriptions of system behaviour and states. (2) the project is a safety critical system (3) degree of reuse or maintenance requirement is very high	The project meets conditions (1), (2), (3). Additionally, the project team has a lot of experience with this technique as it was used in previous projects.
	Fault Tree Analysis	Fault Tree Analysis is suitable in situations where: (1) the project is a safety critical system (2) the project complexity is very high	The project meets conditions (1), (2). Additionally, the project team has a lot of experience with this technique as it was used in previous projects.
	Scenario-Based Approach	Scenario-Based Approaches are suitable in situations where: (1) the team is familiar with both Structured Analysis techniques and OO techniques (2) usability and functionality are the most important issues for the project	The project meets conditions (1), (2). Additionally, the project team has a lot of experience with this technique as it was used in previous projects.
Documentation	UML	UML is suitable in situations where: (1) modeling and documenting the static structure and dynamic behavior of a system are both important issues for the project (2) project complexity is very high (3) the project does not have safety-critical requirements	The project meets conditions (1), (2), (3). Additionally, the authors were part of the project team and provided the necessary training to the member in the project team.
Verification & Validation	Formal Inspection	Formal inspections are suitable in situations where: (1) the project is a safety critical system (2) the complexity is high (3) stakeholders are available and willing to participate in the process (4) requirements preciseness and consistency are of major concern	The project meets conditions (1), (2), (3), (4). Additionally, two requirements engineers in the project team knew already the technique. Training was given to the other team members who were involved in the inspection process.
Requirements Managements	Requirements Management	Requirements management has to be used in all types of projects. More rigorous requirements management and associated tool support is necessary if: (1) the project is a safety critical system (2) the complexity of the project is high (3) the size of the project is medium or big (4) the quality of the requirements specification such as preciseness and consistency are of major concern	The project meets conditions (1), (2), (3), (4). Additionally, the company used their existing licenses for RequisitePro and Rational Rose to support the RE process.

reasons of confidentiality). Company Y is a medium-sized software organization that started work on a large project to develop an Intelligent Power Optimization System (IPOS). The project manager and requirements engineers of the project were very cooperative with the authors. A combination of RE techniques was selected by requirements engineers through applying MRETS. The selected techniques were considered the most suitable for the project IPOS. The following subsections give a brief description of the case study and the major findings.

Table 6. Application of the techniques used in the IPOS project

Sequence of RE techniques used in the project	Techniques used	Major objectives
1	Unstructured Interview	Identify various stakeholders and additional information related to the scope, social and political issues of the project.
2	Formal (Structured) Interview	Identify stakeholders and key stakeholders; fundamental objective of using this technique is to elicit requirements from key stakeholders, especially those stakeholders that cannot participate in planned focus group meetings due to unavailability.
3	Focus Group	Elicit requirements from the different stakeholders.
4	Scenario-Based Approach	Model and understand the main functional requirements, and clarify ambiguous requirements.
5	Interview	Elicit requirements from those stakeholders who were unable to participate in the scheduled Focus Group meeting. The intent of this interview was to make sure no major stakeholders are missed.
6	Scenario-Based Approach	Model newly identified requirements to understand them better and to clarify ambiguous requirements.
7	Ethnography	Elicit implicit requirements which are essential to the system but were not identified using the previous techniques.
8	State Machine	Model requirements which were related to safety issues of the system so that they can be better understood.
9	Scenario-Based Approach	Model new requirements that were identified using the Ethnography Approach or that emerged during the previous modelling process. Requirements that were still ambiguous were verified.
10	UML	Define and document the requirements in UML.
11	Formal (Structured) Interview	Negotiate, verify and validate requirements
12	Inspection	Verify and validate requirements systematically
…	…	…
Notes: The tools Rational Rose and RequisitePro were used throughout the RE process.		

3.2. Techniques selection and their usage in the project

Step 1. Project definition

After the initial analysis of the project, the requirements engineers provided a basic definition of the project. Part of the definition of the project is illustrated in Table 3.

Step 2. Select a combination of RE techniques by considering characteristics of RE techniques as well as the project using MRETS

The selected combination of RE techniques for the project is shown in Table 4. The justification of the final combination is shown in Table 5. Moreover, two existing earlier licensed software tools Rational Rose and RequisitePro were strong recommended and used to support the RE process. Although the versions of the tools are 2000, they are considered good enough for the project. Rational Rose is used for the requirements analysis and verification; RequisitePro is used for requirements documentation, management and analysis. Even though the company had these tools, these tools were not used any more in the past two years since two senior system analysts had left who were the only persons trained in using the tools in the company.

Step 3. Plan and apply the selected techniques to the project

Four kinds of internal training events were provided for all the members involved in the project before the RE techniques were applied: (1) training in the Ethnography techniques; (2) training in UML, (3) training in Rational Rose and RequisitPro, (4) training in process management and team work. The training took place during 2 days. The overall training cost was about 4.8 person-months.

Table 6 gives an example of how the different techniques were used in the project. As can be seen, some elicitation and analysis techniques were used several times. Elicitation, analysis and negotiation, documentation, and verification and validation techniques were used iteratively. This confirms the complex nature of the RE process.

Step 4. Collect data from the RE process

The data collection process covers all phases of software development; it requires considerable support from the management of the organization. The collected data is documented and shown in the second column of Table 7.

3.3. Findings

The recommended techniques were used in the RE process of the IPOS project. The overall feedback from the project team was very positive. The company was able to develop a much better requirements specification with more precise requirements, a clear structure and traceability. But most importantly, requirements ambiguity and conflict were greatly reduced. The requirements engineers and project manager appreciated the overall quality of the requirements gained from using the selected combination of RE techniques. Currently, the system is in full service.

The requirements metrics show that requirements change has been lower compared to similar projects previously carried out by the company. Especially, no major requirement (see Table 7 for the definition of “major requirements”) was added or deleted that would have had a significant impact on the overall system structure or on major functionalities.

Table 7 Comparison between IPOS and 3F system

Measured Data \ Project Name		Intelligent Power Optimization System (IPOS)	3F System
RE Techniques used		See the recommended techniques shown in the fourth column of Table 4	Informal Focus Group, OO Modeling, State Machine, Informal Review
Total number of (atomic) requirements in the final requirements specification		1232	1776
Number of the analysts involved (playing the role of requirements engineers as well)		6	6
Number of developers involved		62	59
Number of original requirements		725	1042
Number of requirements elicited using RE techniques	Absolute	412	496
	% of the total number of requirements	33.4%	27.9%
Number of requirements added during verification and validation	Absolute	41	65
	% of the total number of requirements	3.3%	3.6%
Number of requirements modified during verification and validation	Absolute	164	116
	% of the total number of requirements	13.3%	6.5%
Number of requirements discovered during the design stage	Absolute	32	102
	% of the total number of requirements	2.6%	5.7%
Number of requirements discovered during the testing stage	Absolute	22	71
	% of the total number of requirements	1.8%	4%
Number of requirements changed after start of design	Absolute	54	173
	% of the total number of requirements	4.4%	9.7%
Number of *major* requirements changed after start of design	Absolute	0	12
	% of the total number of requirements	0	0.7%
Percentage of overall requirements change after start of design		4.38%	9.74%
Planned time for the project		22 months	32 months
Time actually used for the project		Less than 24 months	More than 38 months
Effort in the person-months	Planned	1364	1888
	Actually spent	1448	2242
Cost overrun in terms of effort in the person-months	Number	124	354
	% increased over planned	9.0%	18.8%

Notes:
1. 3F is an abbreviation for a confidential project of Y company.
2. A major requirement is defined as a requirement which has a major impact on the overall system structure and overall system functionality

3.3.1. Comparative Evaluation. A comparative evaluation was conducted between the project IPOS where the recommended RE techniques were used in all stages of the RE process and a previous project, called 3F System that did not use RE techniques in every stage of its RE process.

The data related to IPOS and 3F System is shown in Tables 7 and 8. As can be seen from Table 8, both projects have very similar project attributes. Furthermore, the two projects were carried out by the same team except that three junior developers were added to the team of the IPOS project. Table 7 shows that the two projects have a similar number of people involved. When comparing the data, the IPOS project, which used the RE techniques recommended by MRETS, had the following improvements over the 3F project, which did not use MRETS. Project IPOS had

- 5% more requirements elicited during the requirements elicitation stage,
- 6.8% more requirements modified during the requirements verification stage
- 3.1% less requirements changed during the design stage
- 5.3% less requirements changed after the start if the design phase.
- 7 % less time overrun
- 9.8% less cost overrun (measured in person-months)

Table 8 Project attributes of the two projects

IPOS System	3F System
Project Size: Very big **Project Complexity:** High **Requirements Volatility:** low **Project Category:** Embedded system **Degree of Safety Criticality:** high **Quality Standard**: **High** **Time Constraints:** Low **Cost Constraints:** Medium **Team Size:** Medium (62) **Acquaintance with Domain:** Medium **Knowledge of Requirements:** Medium	**Project Size:** Big **Project Complexity:** Very high **Requirements Volatility:** Very low **Project Category:** Embedded system **Degree of Safety Criticality:** high **Quality Standard**: High **Time Constraints:** Low **Cost Constraints:** Medium **Team Size:** Medium (59) **Acquaintance with Domain:** High **Knowledge of Requirements:** Medium

Our assumption is that the recommended RE techniques helped discover and correct more requirements earlier in the development cycle than was the case in the 3F project, which experienced very late requirements changes due to spending insufficient time in requirements engineering. A comparison of the two projects convinced the project manager and developers in company Y that the advantages of using the recommended RE techniques clearly outweigh the cost associated with the training and the time spent on applying RE techniques. Furthermore, the skills gained from the training can be used in future projects.

3.3.2. Observation of the techniques used in the project. This section outlines some of the major observations and experiences gained in the project with regard to the usage of RE techniques:

- Even though Focus Groups, Interviews and Ethnography are considered complementary techniques during requirements elicitation, they have different strengths. For example, Focus Groups and Interviews were both used to elicit a considerable amount of functional and non-functional requirements. This is especially important in situations when there is high stakeholder heterogeneity. Implicit requirements were elicited using Ethnography.
- The recommended techniques were not used in a particular sequence (see Table 6). They were used iteratively and in parallel depending on the situation. When a recommended technique is to be used depends on the situation of the project and judgment of requirements engineers.
- The combination of scenarios and state machines can effectively foster system comprehension when analyzing requirements of the system. Scenarios can be used to model requirements at a high level of abstraction; while state machines model behavior and interaction of the requirements in more detail.
- Formal Methods can facilitate the understanding and verification of requirements. However, this project used formal models (such as state machines) only as an intermediate form of documentation, which was not part of the final specification presented to the customer.
- The techniques should only be used to the extent where the benefits outweigh the costs. As state machines are complex and time-consuming to develop, only poorly understood requirements were modeled and verified with state machines. In this project, about 12 percent of all requirements were modeled using state machines. However, Fault Tree Analysis was used to model and understand the safety critical requirements of the system. This has proven to be very effective in this project.
- Not all features of a technique have to be used. Unnecessary features can be omitted (cf. [18] [19]). For instance, the following 2 activities of the technique Ethnography were mainly used in the case study: "An in depth study of one or more situations" and "The study of action in a social and cultural context". The use of Ethnography in the project led to the discovery of essential power management and scheduling functionalities for the IPOS system which would otherwise have been overlooked.
- High-level design, such as architecture design, can already begin right after the major functionalities are clearly defined thus increasing development efficiency. Detailed design had to wait until after all the requirements were verified and validated. This works especially well in situations where requirements volatility is low as was the case in the IPOS project. Even though some requirements emerged after design, none of them had a significant impact on the software architecture or major functionality. We attribute this to the fact that the proposed requirements engineering process helped reduce requirements volatility thus making the development more efficient. The emergence of minor requirements after design suggests that RE is not solely a front-end activity but ongoing throughout the overall software development process.
- The case study confirmed the importance of tool support for requirements management. Even though the functionality of requirements management tools might vary, we require it in all process models suggested by MRETS. For small projects, a standard word processor might be sufficient to manage the requirements.
- In our case study, the additional costs for training and RE techniques application were far outweighed by the overall cost savings throughout the project.
- The time for the iterative usage of the techniques from elicitation to verification and validation has to be monitored in order to ensure the overall progress of the software project.
- Requirements engineering is not the sole duty of requirements engineers. Experience from this project has shown that the involvement of developers and management in a RE process has had a very positive impact on the project.

4. Discussion

We acknowledge that the data from the two projects might not be sufficient to claim that the application of a combination of RE techniques is the main factor why the IPOS project was more successful than the 3F system. However, the feedback from the requirements engineers and developers involved in the two projects are another indicator that well-planned RE has been very beneficial. They also agree that the savings from reduced rework outweigh the additional cost and effort made in the early development phases. Furthermore, two additional case studies (a Port Schedule System was finished and a Custom-Tariff System was still on ß-testing stage) are further indications of the benefits of using MRETS. The results of these two case studies will be published in upcoming research papers.

5. Conclusions and Further Work

It is widely accepted in social science that a good technique can lead to success and confidence; inappropriate usage of a technique will lead to negative results [20]. Experience also tells us that this also applies to the RE domain. This paper presented our experience of improving the requirements engineering process for a software project using a combination of RE techniques based on project attributes and characteristics of RE techniques. The case study in this paper shows a positive result of the application of a combination of RE techniques to a software project.

A good understanding of the suitability of RE techniques for a given project increases the quality of requirements, which, in turn, will increase the likelihood of high customer satisfaction and improve efficiency of the RE process.

Our further research will focus on answering the following questions:

- Can the application of different RE techniques be beneficial even to projects with higher requirements volatility?
- Is MRETS also beneficial for software projects of smaller size?

There are always requirements that are discovered late. This poses the question when and how these requirements changes are to be considered. Monitoring the RE process is currently largely experience based; how to identify the indicators in a project to decide the change of the focus of the process from one stage to other, i.e. to stop using a technique and change to another techniques, is still to be researched.

References

[1] The Chaos Report, the Standish Group International Inc. 1995, http://www.standishgroup.com/sampleresearch/index.php

[2] D. M., Alan, Software Requirements, Objects, Functions and States Prentice Hal, 1993.

[3] R. L. Glass and I. Vessey, Contemporary Application-Domain Taxonomies, IEEE Software Pages 63-76, 1995

[4] B. Nuseibeh and S. Easterbrook, Requirements Engineering: A Roadmap, In "The Future of Software Engineering", Anthony Finkelstein (Ed.), ACM Press 2000.

[5] A. Sutcliffe, A Technique Combination Approach to Requirements Engineering, 3rd IEEE International Symposium on Requirements Engineering (RE'97), Jan. 05 - 08, 1997, Annapolis, MD.

[6] M. Mannio and U. Nikula, Requirements Elicitation Using a Combination of Prototypes and Scenarios, Technical Report. Telecom Business Research Center, Lappeenranta University of Technology, P.O.BOX 20, FIN-53851 Lappeenranta, Finland, Lappeenranta, 2001, ISBN 951-764-528-7

[7] L. A. Macaulay, Requirements Engineering, Applied Computing, Springer, 1996.

[8] L. Jiang, A. Eberlein and B. H. Far, A Methodology for RE Process Development, ECBS 11th IEEE Int'l Conf. & Workshop on the Engineering of Computer-Based Systems, Brno, Czech Republic, May, 2004

[9] G. Kotonya and I. Sommerville, RE, Processes and Techniques, John Wiley & Sons Ltd, 1998

[10] Simon, Pfeiffer, Requirements Engineering for Dynamic Markets, MSc Thesis, Department of Electrical and Computer Engineering, University of Calgary, Calgary, Alberta. July, 2003

[11] L. A., Macaulay, Requirements for Requirements Engineering Techniques, IEEE Proceedings of ICRE 1996.

[12] Chairman of the joint Chiefs of Staff Instruction, CJCSI 3170.01D, http://www.dtic.mil/cjcs_directives/cjcs/instructions.htm #3000, Mar. 12, 04:

[13] Chairman of the joint Chiefs of Staff Manual, CJCSM, 3170.01A, http://www.dtic.mil/cjcs_directives/cjcs/manuals.htm#3000, Mar. 12, 04:

[14] A. L. Wolf and D. Notkin, Letter from the Chairs, ACM SIGSOFT Software Engineering Notes, Volume 29 Number 5, page 1, Sep. 2004.

[15] L. Jiang, A. Eberlein and B. H. Far, A RE process Template for Aiding RE process development, Technical Reports, August, 30, 2003, Dept. of Electrical and Engineering, University of Calgary, http://www.enel.ucalgary.ca/~jiangl/research/indexOfResearch.htm

[16] C. McPhee and A. Eberlein, (2002) RE for Time-to-Market Projects, Proceedings of the 9th Annual IEEE International Conference on the Engineering of Computer Based Systems (ECBS2002), Lund, Sweden, 2002.

[17] L. Jiang, A. Eberlein, B. H. Far, M. Majid, A Requirement Engineering Technique Selection Methodology, Technical Reports, August, 30, 2003, Dept. of Electrical and Engineering, University of Calgary, http://www.enel.ucalgary.ca/~jiangl/research /indexOfResearch.htm

[18] B., Fitzgerald, An investigation of the Use of System Development Methodologies in Practice. In: Fourth European Conference on Information Systems, 1996, pp 143–161

[19] Steve Easterbrook, R. Lutz, R. Covington, J. Kelly, Y. Ampo, and D. Hamilton, Experiences Using Lightweight Formal Methods for Requirements Modeling IEEE Transactions on Software Engineering, VOL. 24, No. 1, page 1-11, Jan. 1998.

[20] J. Ellul, The Technological Society, Vintage; Oct. 12, 1967

[21] B.W. Boehm, Software Engineering Economics, Pren-tice-Hall, Englewood Cliffs, NJ 1981.

[22] E. Yourdon, Death March, The Complete Software Developer's Guide to Surviving, "Mission Impossible" Projects, Prentice Hall PTR, 1997.

[23] H. Salzer ATRs (Atomic Requirements) Used Throughout Development Lifecycle, presented at the 12th International Software Quality Week 1999