19 An analysis of empirical requirements engineering survey data

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Abstract:.

The gap between research and practice in requirements engineering is immense. To understand practice and the reasons for this gap, empirical evidence about requirements engineering practice is needed. In the last ten years a number of empirical studies have been conducted to gather such data. This chapter gives an overview focusing on broad surveys. The aim of this overview is to understand the following three issues: (1) what kind of questions can and should we ask to understand practice, (2) what evidence do we have about practice, (3) what further evidence do we need about practice. To further illustrate the issues, we provide findings of new studies conducted by the authors in Germany and Australia. Altogether this chapter aims at establishing a basis for further empirical research on requirements engineering.

Keywords: empirical software engineering, requirements engineering practice, survey

19.1 Introduction

The gap between research and practice in requirements engineering (RE) is immense. Even base practices such as numbering requirements are not yet well established in industry. Many techniques popular in the research community such as formal modeling [23] or QFD [20], are almost unknown in industry. This gap has been investigated by leading researchers in [26]. They recommend in particular a two way transfer between industry and university emphasizing the knowledge transfer from industry to research. In the last 10 years more than 20 broad studies of RE practice have been conducted already. Furthermore, the basics of empirical approaches to software engineering have been collected in books such as [57]. However, so far the results of the empirical RE studies have not been collected.

It is the purpose of this chapter to provide such a collection of broad studies on RE. The collection aims at giving an overview, i.e. it aims at describing the "landscape" of studies, the questions asked and the major results. This overview is used to understand: (1) what kind of questions can and should we ask to understand practice, (2) what evidence do we have about practice, (3) what further evidence do we need about practice. In addition, we sketch findings of new studies conducted by the authors in Germany and Australia. The main purpose of this presentation is to illustrate typical findings and issues in the interpretations of such findings. The results will be discussed in the light of previous studies. Altogether this chapter aims at establishing a basis for further broad studies on RE.

The chapter is structured as follows: In section 19.2 we provide some basic terminology on empirical software engineering and motivate the need for empirical evidence in RE. Section 19.3 introduces the broad studies collected and analyses issue (1), namely what we can ask to understand practice. Thereby it provides a framework for questionnaires on RE. The outcomes of the studies are summarized in section 19.4. This answers issue (2), namely what evidence we have so far about practices. Thus, it establishes the current state of large-scale empirical evidence on RE practice. Section 19.5 provides data from new RE practice studies conducted by the authors and thus illustrates typical findings of such studies. In section 19.6 we briefly discuss the role of other types of empirical studies on RE, such as experiments. We conclude in section 19.7. with an outlook on future empirical evidence needed in RE.

19.2 Empirical Research

This chapter provides some basic terminology on empirical research and motivates the need for empirical evidence on RE. We follow the terminology of [7]. Although some researchers (e.g. [1]) may consider the following description relatively simplistic, Creswell [7] is highly regarded and frequently cited in SE engineering books.

Creswell identifies three elements for empirical research design: the knowledge claim, the strategy of inquiry and the specific method for data collection and analysis.

The *knowledge claim* comprises the assumptions on how and what one will learn during the research. Creswell distinguishes the postpositive claims starting with a theory and continuously refining this theory through the research, the socially constructed knowledge claim looking for the complexity of views and developing a theory or pattern of meaning through the research, the advocacy/participatory claim extending the socially constructed approach by an action agenda for reform, and the pragmatic knowledge claim focusing on the problem and pluralistic approaches to derive knowledge.

There are seven basic *strategies for inquiry*: A *survey* gathers data (typically in retrospect) from a representative sample through interviews or questionnaires and tries to generalize this data to the whole population. An *experiment* is done in a laboratory environment where specific subjects are assigned to different treatments and their performance is measured. The objective is to manipulate specific variables and control all the other ones. A *case study* gathers data (typically monitoring projects) over a sustained period of time and tries to understand in more detail a specific factor and its relationship to other factors. In *grounded theory* multiple stages of data collection from different groups are employed in order to maximize the similarities and the differences and to compare the data with emergent categories. *Ethnography* focuses on observational data collected in a natural setting about an intact cultural group. *Narrative research* studies the lives of individuals and re-stories the information into a narrative chronology. *Phenomenological* research studies the lived experiences of a small number of subjects to identify the essence of these experiences concerning a phenomenon.

There are also different strategies for *data collection and analysis*, varying in "their degree of predetermined nature, their use of closed-ended vs. open-ended questioning and their focus for numeric vs. non-numeric data analysis" [7].

One can distinguish three kinds of combination of these elements:

- *Quantitative studies* are typically based on post-positivist claims, use surveys and experiments and employ predetermined, close-ended questioning and numeric data analysis. However, they can involve open-ended and non-numeric analysis as well.
- *Qualitative studies* typically involve the constructivist and advocacy/participatory perspective, use the other five basic strategies of inquiry, and employ emergent, open-ended questioning and non-numeric analysis, but again can involve close-ended and numeric-analysis.
- *Mixed methods* are based on pragmatic knowledge claims and employ multiple strategies of inquiries and data collection and analysis methods. ,

In contrast to e.g. social science, so far, most research in software engineering does not involve empirical methods, but toy examples instead. Clearly, this does not demonstrate anything about applicability in practice. Endres and Rombach (2003) argue that we need observations of the practice, which help to surface laws explained by theories [16]. Only empirical research can produce valid observations, laws and theories. Unfortunately, the complexity of software engineering (SE) is often used as an excuse for omitting empirical research, as it is very difficult to identify general observations in SE. Nevertheless, there is successful empirical SE research. Endres and Rombach (2003) have collected the available SE laws and theories based on case studies and experiments. In particular, this gives evidence on the usefulness of specific techniques like e.g. patterns or prototypes. Juristo et al. (2004) give a recent comprehensive overview on testing technique experiments [25].

In this paper we focus on empirical research in RE and on the current state of the practice, not on the usefulness of specific techniques. The studies collected are presented in the next section.

19.3 Classification of existing broad RE studies

In this subsection we first present the studies we have collected and then classify the kind of questions asked in these studies.

Table 19.1 to Table 19.3 list the studies we found in the literature on RE such as the international RE conferences, the RE journal, IEEE software or related conferences such as ECBS. We are aware that there are related studies in information and management sciences which are not covered. It is a topic of further research to include these studies too.

Table 19.1: Broad studies on the RE process in general

	year	mechanism	sample	topic
[8]	1986	interviews	9 companies, 97 staff	Software design process for large systems
[30]	1992	interviews	10 companies, 87 staff	State of the practice
[13]	1994	interviews questionnaire	52 staff	Success criteria for RE
[12]	1994	interviews documentation	17 staff	Problems and best practices
[15]	1996	questionnaire	39 projects	User participation and RE success
[37]	1997	workshop	26 staff	Industrial uptake of RE R&D
[14]	1998	measurement questionnaire	70 assessments, 691 process instance	Relationships assessment score, project performance
[27]	1998	workshop	10 companies	RE in SME
[19]	2000	focus groups	12 companies, 200 staff	Problems
[21]	2000	interviews questionnaires	15 companies, 76 staff	Impact of RE on project success
[40][41] [42]	2000	interviews	12 companies, 15 staff	RE in SME
[24] [51][53]	2000	questionnaire	11 companies, 150 staff	Progress in RE practice
[36][35]	2001	interviews questionnaire	25 staff	RE for time to market projects
[39][	2002	questionnaire	194 staff	State of the practice

From this literature we collected surveys and grounded theory studies with a sample of at least around 10 individuals, but not experiments or the other quantitative studies focusing on specific individuals, cultures or phenomena. We call these studies *broad RE studies* in the following. They employ interviews, questionnaires or group discussions and different methods for data collection and analysis. We have divided the studies into three groups (as can be seen from the tables) depending on the focus of RE in general, SE in general or RE specifics. These distinctions will be explained in detail when we present the results in section 19.4.

Table 19.2: Broad studies on SE in general

	year	mechanism	sample	topic
[22]	1995	questionnaire	3805 persons	Problems and training needs
[11]	1995-1997	questionnaire	397 staff	Adoption of best practices for SW management
[54]	Since 1994	questionnaire	13522 IT projects	Status of IT project management
[9]	2001/2002	questionnaire	104 projects	Worldwide SW development

Table 19.3: Broad studies of specific RE phenomena

	year	mechanism	sample	topic
[28]	1991	Meeting minutes, videotape	3 companies, 41 meetings	Content of requirements document
[18]	1993	Focus groups, 2-stage questionnaire	100 staff	Requirements traceability
[46]	1994-1997	Interviews, focus groups, case study	26 companies, 138 staff	Requirements traceability
[20]	1994	interviews	37 companies	Software quality function deployment
[60][61][62]	1995-2001	3 studies, interviews, questionnaires	9 / 71 / 52 staff	Requirements volatility
[3][4]	1995	3 questionnaires	74 companies, 72/34/35 staff	Requirements capture and analysis
[56]	1997	interviews	Roughly 20	Scenario usage
[29]	2002	2 pre-studies questionnaire	45 staff	Software documentation
[5]	2002	questionnaire	226 staff	Software reviews

As can be seen from the tables, in the last ten years more than twenty broad studies have been conducted on RE practice. In the following we characterize the kind of information sought by them. We are not aware of any other such characterization besides [51]. In that report surveys are characterized according to purpose, mechanism of data capture and analysis method. We keep these categories, but go into much more detail on what kind of information is captured in these studies.

We distinguish the following categories:

1. Set up of the study
   - Purpose
   - Sample population
   - Mechanism
   - Analysis
2. Information on the context and background of the sample
   - Personal context
   - Company context
   - Project context
3. General information on RE process
   - General facts
   - Problems with RE process
   - Success factors for RE
4. Information on specific parts of the process, e.g. tool, practice, activity X
   - Performance of X
   - Experience with X

These categories are explained in the following. Thereby we answer issue (1): what questions can and should we ask to understand practice. It is intended as a framework for questionnaires or interviews on RE.

Set up of the study

The first category defines how the broad study is to be conducted. Of course, first the **purpose** of the study has to be determined. We adapt the distinction of [24]:

Descriptive study: tries to understand what is done in general or a specific practice e.g. whether a RE tool is used, how requirements capture is carried out or what impact requirements volatility has on the overall project success.

Prescriptive study: tries to make a judgement. Thus it aims at identifying successful practices, or success factors and obstacles for a specific practice. In [57] this is called an explanatory study, as it tries to identify reasons for actions.

Prospective study: tries to identify future needs in industry.

[57] distinguishes in addition, *explorative* studies which are used as pre-studies to a more thorough investigation. We do not explicitly deal with such pre-studies here.

The different RE *topics* investigated in the studies are mentioned in detail below in terms of the information sought from the participants. One can distinguish two general directions: on the one hand studies explore the state-of-the-practice (i.e. what practice is doing) on the other hand they explore more specifically the relationship between the state-of-the-art and the state-of-the-practice (i.e. what practice knows about research).

Depending on the purpose the **sample population** of the study has to be determined: The main facets are:

N*umber*: The typical number of participants ranges from 10 to 500 or more.

Heterogeneity: For large studies participants are typically sought just by advertisement in the community (e.g. through the web). Sometimes specific address databases (e.g. university graduates) are used. For small studies participants are filtered according to specific criteria, often they are known to the study authors.

Clearly, a small sample is not suited for prescriptive studies in general, as only few data points cannot demonstrate the necessary generality. The same holds for low heterogeneity of participant backgrounds and contexts. On the other hand, it is very difficult, particularly in RE, to identify principles which apply to all kinds of environments. A possible mixture is to do a small study with the aim to be prescriptive (to give advise) for the involved population (e.g. [27]). Several studies also use a multi-stage approach, starting with small descriptive study to understand the issue and later involving a large number of participants to establish general principles in a prescriptive study.

In parallel with the sample population the **mechanism** for capturing data is determined. There are three typical choices:

Questionnaires: a pre-determined list of open or closed questions. An example for the former is: what kind of RE tool do you use? Examples for the latter are yes/no-answers (e.g. do you use MS Word for requirement specification) or multiple-choice-answers (e.g. which of the following tools do you use) or prioritization-answers (e.g. prioritize the importance of budget, time and quality in your project). These questionnaires are typically distributed online or by mail to be filled in by the participants. Furthermore they can be filled in jointly by an interviewer and the interviewee.

Direct interaction: The list of questions is not fully pre-determined, instead the participants can influence the kind of information gathered. Examples are semi-structured interview or work observation. To involve more participants a workshop can be conducted.

Measurement data: Data is not captured specifically for the study, but is available through a measurement program or an assessment.

Obviously, the choice depends on the sample and the amount of time available for data capture and analysis. Capturing measurement data needs the most effort and thus, this data is very often not available. For a large sample, questionnaires are much easier to handle, but direct interaction gives more detail and more reliable information (as misunderstandings can be avoided). So the latter is often more suited for descriptive and prospective studies.

In parallel with the mechanism the data **analysis** approach has to be determined. As mentioned in section 19.2 the main alternatives are a numeric or non-numeric analysis. Clearly, a small sample does not allow valid numeric analysis and a large sample cannot be handled by non-numeric analysis.

Information on the context and the background of the sample

To be able to analyze RE data it is important to understand the context and the background of the participants. Typically, RE practices depend very much on this context [4]. Unfortunately, there are no standards on how to capture which context factor. This makes the comparison between different studies very difficult. Here we distinguish three kinds of contexts: personal, company and project.

The **personal context** determines the viewpoint of the participant. The following facets are typical:

Region: This determines the cultural context. Several studies are only within one country. There is no RE study so far which explicitly analyzes cultural differences. [9] discusses differences in the adoption of CMM practices between Europe, US/Canada, Japan and India.

Current role: This determines the viewpoint and the involvement in the RE process. Typical roles are user, developer, quality expert, project manager, senior management, consultant and academic.

Past professional experience: This determines whether the participant can only report preliminary insights or sustained experiences. Experience has so far only rarely been captured. It can be measured by the number of years of professional experience or the number of projects involved.

Clearly, there are much more facets influencing the participants viewpoints, e.g. the education. It is however very difficult to define meaningful categories.

The **company context** determines the setting for the SE processes. The typical facets are:

Size: The number of employees involved in SE makes a big difference for the processes. The main distinction is between small and medium enterprises (SME) and large enterprises, where the boundary size of an SME typically is assumed to be 500, sometimes also 100 or 300. Sometimes also other indicators for size are used such as age of the company or annual budget.

Business: Similarly, the business the software is aimed at makes a big difference. On the one hand one distinguishes primary industry which has software as its main business and secondary industry where software is part of a product. On the other hand the product supports different business sectors such as finance, public, telecommunication, manufacturing, transportation, logistics and health. This also implies software types such as information systems or embedded systems. Unfortunately there are no standard categories for business and software types. Thus, data of different existing studies cannot be compared.

To be able to ask specifics of the RE process also information on the typical **project context** is important. Often the interviewees are asked to choose one typical project to report on. The main facets are:

Customer/user: The customer/supplier relationship has a big influence on RE practices. Therefore, it is important to distinguish whether the project produces bespoke software or commercial off the shell software. Orthogonal is the distinction whether the customer is internal or external. Furthermore the number of users is important and the sources of the requirements.

Size: The size of the company does not fully determine the size of the project. The latter is measured by the number of staff involved, the number of person months and the duration of the project. Another important characteristic is the main project constraint in terms of budget, time or quality.

Software: The size of the software not always agrees with the size of the project. Thus, it is important to get information on the size of the code and the number of requirements. Rarely also the price of the software is captured. Of course, there are numerous other software characteristics of interest. So far studies have asked for specific properties such as the platform used, the number of variants involved or the reliability level required.

Clearly, many other facets of a project could be relevant such as more detail on the project management or the standards in the companies. The process facts of the project are discussed in the following paragraph.

General information on the RE process

Many studies are concerned with the **process as the whole**: general facts, problems experienced with this process and benefits for success. Sometimes these general questions are only used as background information for more specific questions. Terminology specific to RE is an issue here (e.g. for documents and activities) as developers often use their own terminology.

The **general facts** capture whether there is a defined RE process at all, how it was adopted, and how it is performed.

Defined RE process: Besides asking for the existence of a process standard studies ask for the adherence to certain development paradigms or lifecycles and for the existence of a role which is responsible for the RE activities in a project. Furthermore the size of the process definition is important and the extent to which the defined process is adhered to.

The *extent of the requirements documentation* is an important indicator for the level of detail of the RE process.

Performance is concerned with effort, tools, team characteristics and knowledge or use of established practices such as REAIMS or VOLERE. The effort can be measured for RE as a whole or for the individual activities. Besides asking for percentages one can also ask whether the activities are performed implicitly or explicitly.

Concerning the **problems** typically the studies ask for problems, categorize them and then compute the most common problems. The first example of such a study was [8] which was not confined to RE. [19] is the only detailed study focusing solely on RE problems.

Analyzing **success** is much more difficult. The first issue is how success can be measured at all. The next issue is how specific factors for success can be found.

Measuring success: Here we distinguish the over all project performance and the quality of the RE products and services. As discussed in [14] successful *project performance* can be measured through 6 variables: customer satisfaction, fulfillment of requirements, cost within budget, duration within schedule, staff productivity and staff morale. The first variable can be measured through fitness for use and ease of use and the numbers of defects reported by the customer [8]. Because of the diversity of activities during RE it is even more difficult to measure the quality of the RE products and services. [13] presents an empirical validated list of 34 criteria for the quality of RE products and services. These criteria can be used for two purposes: on the one hand they are an instrument for measuring success, on the other hand they can be used as a checklist of important characteristics of good RE processes.

Information on specific parts of the RE process

Many studies are interested in a specific activity X performed or specific technique X used during RE. This comprises two issues: facts on the performance and experiences on performing X.

Facts on the performance: As for the whole process, facts capture effort and performance, e.g. the number of iterations during capture and analysis.

Experiences during performance: As for the whole RE process, problems and success factors for X are identified. This also includes the impact of X on the whole RE process or on the whole project. Furthermore, the impact of other factors on X is studied.

Summary

Not all studies ask for all information mentioned in categories 2-4. The detailed choice of course depends on the purpose and to some extent on the mechanism.

However, in general we recommend cover all three categories. Information on the context is often difficult to evaluate, it is however, important to understand the plausibility of the answers. Sometimes it can be used to find patterns in the information on RE, e.g. a difference between RE processes of large or small companies. Similarly, information on the general RE process is helpful to understand the plausibility of the answers. It is interesting to try to exhibit patterns in the information on the RE specifics, e.g. differences between technique usage between companies with a defined process or without a defined process.

To allow the combination of data from different studies it is necessary to have standard questions. Such standard questions have not yet been established. They seem feasible for the context and the general RE process information, however, as illustrated in section 19.5. it is very difficult to identify all context factors relevant to RE practice. Thus, this is an issue for further research.

19.4 Broad studies outcomes

The collected studies are very heterogeneous wrt the study set up and the information captured on the sample. So it is not possible to aggregate their data. We summarize the important findings according to the above categories and indicate when studies have similar results. This answers issue (2): what evidence do we have about practice.
So, what do we know about the RE process in general and about the specific activities?

Set up and context of the studies

The set up and context of the studies is quite diverse. The Tables 19.1-19.3 list the year when they were conducted, the sample size, the mechanism and the main topic. Due to the lacking standard of context description, it is not possible to summarize the context in the tables. Most studies are confined to US, Canada and UK, but some also span several countries in Europe. Most samples also cover several roles of the participants, several kinds of business and system types, as well as different project types, sizes of the companies and their software.

General information on the RE process

Here we summarize the findings of the studies of Table 19.1 and Table 19.2.

General facts
Defined RE process standard: The percentage of companies with a defined standard evolved from only few [30], through 50% [21] and roughly 30% for SMEs [40] to 60% in general [39]. Interestingly, 70% of companies without process are happy with RE product quality [39]. More information on the process as e.g. the size of the documentation has only been captured in the studies discussed in section 19.5.

Explicit requirements document: The existence of documents is an issue. It varied widely between the SMEs in [27]. Recently, 85.6% worldwide reported about explicit RE documents [9]. However, the sample of the last study consists mainly of large companies with explicit contact to academia. The studies discussed in section 19.5. capture detailed data on the kind of RE documents.

Performance: The *effort spent on RE* was only noted twice: 14% of overall project effort was the mean in [15] and 15.7% in [21]. 38.6% of project duration was found in [21]. They also found that the ideal effort for RE in their context is estimated at 15-30%. 25% is the estimate for the ideal effort in [36]. Furthermore, one can distinguish the effort spent on individual activities: Successful teams allocate 11 % of project effort on elicitation, 10% of project effort on modeling and 7% on validation and verification [21]. This distribution of the RE effort has been roughly confirmed in [32] which is discussed in section 19.5. In these studies activities are also characterized as being performed explicitly or implicitly.

The information on overall cost and time adherence indicates more heavy time overrun: little cost but significant time overrun [21], 35% cost and 44% time overrun [39]. The well known CHAOS report indicated for 2003 43% projects with cost overruns and 82% with time overrun [54].

Average RE team size is 6.2 [21] and 7[15]. Team skill is an issue: [8] found thin spread of application domain knowledge, [30] confirmed this particularly for market-driven projects. In contrast, [21] found that team knowledge is rated good.

RE-Tool usage is not widespread: Typically general purpose tools prevail [30]. For SMEs even only 30% use standard word processor and commercial RE-tools are not used at all [40]. Another study found 30% using only word processor, but for large projects mostly RE tools (inhouse, commercial) [24]. Most recently, 29% tracing tool usage was found in [11].

Little is known about the *Adoption of new RE process:* For SMEs reasons for process improvements are schedule overruns due to high effort for testing/rework and ISO 9001 certification [27]. [24] found that more than half of the participants had recently improved RE. Very early it was noted that organizational RE problem solution is preferred over technology [30].

Still the *importance of RE for project success* is recognized: The CHAOS studies give a good overview on IT project success in general [54]. According to the 2003 summary, IT project success evolved from 16% successful projects in 1994 over 26% in 1998 to 34% in 2003. RE is very often identified as major contributor to problems: requirements specification and managing customer requirements exhibit the most problems in SW development in [21]. Similarly, RE problems had the highest share (48%) of development problems mentioned in [19]. This fact is confirmed in [54], however with downward trend. In 1994 requirements problems scored high in the top ten. In 1998 user involvement got again the highest mark, but firm basic requirements only scored in the lower half after being third in 1994. Still, 80% of the SMEs found RE of strategic importance in [40]. 70% indicated that not enough time is spent on RE in [36] and this number was reconfirmed in [39].

Expectations on academia are training and technology transfer, particularly templates [40].

Problems with the RE process:

The three problems identified in the very first study [8] have been confirmed over and over:

- *Thin spread of application domain knowledge*: has been confirmed in [30], particularly for market-driven projects. Inappropriate skills are a problem in [19].
- *Fluctuating and conflicting requirements:* Managing uncertainty was raised in [12], vague initial requirements, requirements growth and complexity of application was mentioned in [19], completeness, change management, and traceability were the main problems in [40].

- *Communication and coordination breakdown:* user participation and project management capabilities were raised in [12]. Organizational process problems are two third of the RE related problems [19]. Particularly, developer communication, inadequate resources, staff retention and user communication was mentioned, as well as the undefinedness of the RE process [19]. Identification of requirements sources was a problem in [24] and the main problem in [36] was communication.

The two other typical problems are tools and documentation:

- Tools are a problem because benefits are not clear [12], and because of tool integration, tool selection [24] and tool adaptation [40].
- Documentation often does not exist [24] [27]. If it exists, management is a problem [30], the detail of the functional process model [12] and prioritization [21], or missing template [40].

Other important problems noted are the increasing importance of market-driven segment [30], COTS usage [12], the detail of the examination of the current system [12], own RE adaptations [40] and quantitatively establishing dependability [24].

Problems for. industrial uptake of RE R&D are training, inherent complexity, integration into internal business, business culture [37].

Success factors for RE:

El Emam and Madhavji (1995) have exhibited the most refined list of success criteria [13]. It can be structured into the following 5 areas. Some of them have been confirmed several times:

- *Fitness of recommended solution* (change culture, strategic adequacy, management support for change, fitness to business and technology).
- *User satisfaction and commitment* (user buy in, user consensus, fitness to user work, adequacy of first release). User involvement and team relationships were confirmed [20].
- *Quality of requirements architecture* (clear business process, correct requirements, link from objectives to models, valid business case). Related factors were identified in [21]: coverage of requirements sources, usage of templates, prioritization, combination of prototypes and models, traceability matrix, user peer reviews, scenarios, walk-throughs. Similarly, unambiguous specification, prioritization for projects with short time to market (TTM), change management of non-TTM were identified in [36].
- *Quality of cost/benefit analysis* (management support, high business priority, accurate benefits and cost estimates also for intangible benefits) .
- *Cost-effectiveness of RE process* (compared to similar projects and to overall project effort, little change, usefulness of deliverables).

This list shows that as for the problems many factors are organizational. Adequate team skills were identified as a further success factor in [21]. El Emam et al (1996) also investigated the relationship between user participation, uncertainty and RE success. They found that in presence of uncertainty user participation enhances the first two categories (called RE service success) and vice versa that user participation has less impact on RE service success, if uncertainty is low. The relationship to the other three categories (dealing with RE product quality) could not be established.

It is also several times established that *RE makes a difference for project success*: Adoption of SPICE RE practices has positive impact on project productivity for large companies (impact on team morale, budget and schedule, customer satisfaction and fitness to requirements could not be shown) [14]. RE problems are reduced for higher CMM maturity level [19]. Main impact of RE are common goals and scope according to [36]. A more complete functional specification increases productivity (in terms of code produced per day) [9]. However, the latter also found that the incompleteness of the specification can be compensated through techniques to generate early feedback on product performance such as prototypes or testing.

Specific parts of the RE process

Some broad studies of Table 19.1 and Table 19.2 have also captured data on the usage of established best practices:

For SMEs: only 33% have standard document structure, even less use a modeling language as standard, formal methods are never used, scenarios are rarely used, requirements are numbered only in 15% of the companies, only a quarter had more than marginal use of the top 10 REAIMS practices [40].

In general, the following has been found: tool and method is not distinguished and elicitation techniques are not known [24]. Scenarios/use case are the best known practice in [36]. Also according to [39], 50% apply scenarios or use cases, but better known techniques are prototyping (60%) and inspections (59%). Less well known techniques are OOA (30%), focus groups (30%), informal modeling (30%) and even in large companies only 7% use formal models [39]. This might often still be related to missing knowledge as known techniques are more likely to be perceived as useful [36]. The adherence to very traditional processes is also confirmed by the fact that 35% of the companies still use waterfall [39].

However, it is important to note that large studies found that best practice adoption in general varies greatly: In [21] the estimated use of practices varied by 30% depending on the role of the interviewee. In [11] a variation of management practices from 65% to 32% between countries and similarly from 60% to 36% between business sectors was found. This phenomenon was observed in three consecutive studies from 1995 to 1997. The variation in [9] for a specific development practice was up to 70% between the countries. In that study the relative importance of the different practices did not vary much. So for example, the creation of a functional specification was one of the most adopted practices in all countries.

[36] asked for the main features a new RE technique should have: easy to use, facilitates good communication, complete requirements and traceability.

Other broad studies have investigated specific activities. They are listed in Table 19.3. In addition the broad study on general RE [30] gives some insight on specific phenomena.

Each specific phenomenon besides traceability has only been studied once in depth. Here we just list the main results:

Requirements documents should focus on what and how as this is what designers want to know. Typically they want to know how a user will realize this task with the system functionality. This importance remained stable in very different company settings [28].

Traceability is a problem because of lack of common definition and inadequate pre-traceability. The latter is due to problems for the providers (e.g. extra amount of work) and users of traceability information (e.g. reliance on personal communication) [18]. 60% are high-end traceability users with more than 10000 requirements and elaborate traceability schemes in [46].

Quality Function Deployment is a front-end requirements elicitation technique. It improves user involvement, management support and involvement, team involvement and shortens the development lifecycle [20].

Requirements volatility consists of instability, missing analyzability and diversity. It is related to the size of the requirements, project cost and most significantly project delay. Furthermore, developer capability has negative impact on volatility, volatility has no relationship with code quality and project management quality. High volatility is related to missing customer satisfaction. A defined methodology, frequent user communication and inspections induce volatility, while user representatives reduce volatility. Traceability could not be shown to account for the latter [60] [61][62].

Requirements capture and analysis is an iterative process, where more than half of the projects have 3 or more iterations. The number of iterations depends on the project characteristics, the methodology and the tools. In half of the projects original plans had to be changed due to lack of information, need for validation and verification, changes in requirements and inexperienced project managers. Some recommendations can be given based on the project characteristics [3][4].

Scenarios / use cases can be used in many different ways. They are particularly useful in combination with prototyping and glossaries. They help to complement abstract dynamic models and static models, to reduce complexity and to reach partial agreement and consistency. Issues are partial views, managing distributed scenario development, reviews, test case derivation, traceability and evolution [56].

Software documentation is mainly needed to learn about software (61%), to test software (58%), work with a new software (54%), to answer questions in case of problems (50%). Maintenance was only important for 35%. High-level documentation is also useful when out-of-date. Requirements are updated less frequently than all other documentation, testing documentation is updated most frequently [29].

Requirements reviews are slightly more common (42%) than design reviews (49%) for those companies who have documentation. Often (60%) reviewers do not have time for review preparation. When there is time, checklists (50%) are more common than ad-hoc (35%). Only 25% collect data during review and use this for improvement [5].

Summary

The studies collected show a quite interesting picture of RE practice. They confirm the evidence from CMM measurements of general SE [55] that process performance and practice adoption vary extremely between different companies. This is also obvious from chapter 18 which shows differences between companies and some agreement and some disagreement of their findings with the findings of the general studies collected here. Thus, in particular, it seems not valid to generalize quantitative results (percentages) found in one study to all companies. This can only be done based on a careful analysis of all context factors. Taking into account the context factors the data of large studies can be used to find patterns of practice usage as in [11] and [21].

The qualitative results, however, indicate some trends:

An explicit RE process standard was more often found today than in earlier studies. Many broad studies establish the importance of RE. On the one hand RE scores high in the general SE problems and on the other hand positive impact of RE on project productivity has been established. It would be very beneficial to study more such relationships between RE in general or specific RE practices and overall project success or problems.

The identified problems within RE seem to be quite stable, namely thin spread of application domain knowledge, fluctuating and conflicting requirements and communication and coordination breakdown. As discussed in chapter 18 the first is less of an issue as companies specialize in certain domains. The other two problems were confirmed in the studies of chapter 18. Similarly, some success factors for RE have been established several times, namely user satisfaction and commitment (in particular in the presence of uncertainty) and quality of the requirements process. Thus, there is sustained evidence on the general RE needs of companies. It seems worthwhile to focus future studies on the details of these needs. The studies on requirements volatility exemplify such detailed investigations into the problem of requirements fluctuation.

19.5 Requirements Engineering Practice: A new study

In this subsection we present new data on RE practice collected in Germany and Australia. This serves to further illustrate findings and issues in the interpretation of such studies and their aggregation. In addition, it shows some type of questions not found in the other studies. It is, however, not a complete presentation of the studies. Full presentations are referenced.

The work started 1999 with a pre-study in Germany. A small group in the RE special interest group of German computer science society (GI) collected nine two hour interviews on general RE process characteristics and experiences. The main purpose was to test whether the RE process questions are meaningful and to collect best practices. The latter did not work as the interview time was already consumed through the RE process questions. The former however was confirmed, as the questions were found very useful to characterize the RE process.

Based on this pre-study, the work commenced into two directions: In 2002 at the Fraunhofer Institut Experimental Software Engineering (Fh IESE) a questionnaire was created where participants get feedback on their RE process (in terms of recommendation of specific practices) based on the data submitted on the RE process. For that purpose the questionnaire has been extended with questions on perceived problems. The main difference to prior investigation of problems is that the problems are related to different roles, e.g. problems of the tester or the project manager with the requirements documents, or problems of the person responsible for RE with the RE process. This questionnaire has been answered till end of 2003 by 33 German companies, it is still available under http://www.iese.fhg.de/re-checkup/. Participants were mainly project managers and people responsible for RE as these people actively sought advice in the area of RE. The main outcome has so far only by published in Germany [43].

In Australia, at the University of New South Wales, the original questionnaire was used for four in-depth-studies [32][44][34][58]. The data is collected from 11 multi-national companies including banking industry, pharmaceutical and health-care industry, telecommunication industry and food industry which included 23 projects. People who participated in the interviews were project managers, business and systems analysts. The objectives of these studies were (a) to investigate the state of the art RE practice in these industries which included identifying the state of RE process in project life cycle, the degree of awareness about this process and whether there is a structured approach towards RE in each project, and identifying responsible role for RE as well as roles assigned to different RE activities, (b) to examine the RE activities, (c) to explore the amount of effort used in each RE activity and identify implicit and explicit activities in each project, (d) to construct high-level process models that describe RE process models on the projects. Some of the results are published in [33] and [45].

In the following we report on the general RE process data of all three studies (combined and individually) and on the problems found in the Fh IESE study. As will be seen there is some difference between the data. This can be attributed to the small sample sizes and to cultural differences. In addition, it is important to note that by chance the study participants had very different company context: In the pre-study two third of the participants came from companies with more than 10.000 employees. At UNSW mainly companies with more than 100 employees have been interviewed, with more than 50% over 1000. At Fh IESE two third had less than 100 employees and 18% between 100 and 1000. Furthermore, the sample of Fh IESE consists of participants actively looking for feedback to their RE process. All the three together provide a very good variety with 20% each for less than 20, less than 100, less than 1000, less than 10.000 and more than 10.000 employees.

General Facts:

The three studies confirm the trend (noted in the summary of 19.4.) to an *RE process standard*: Of the combined data 72% had a standard. These standards have quite considerable length: In the UNSW study all were over 6 pages, two third over 25 pages. In the IESE study, one third was below 6 pages and half between 6 and 25 pages. Altogether, more than two third were over 6 pages. Almost all companies confirm that the real processes adhere to this standard.

The studies did not investigate the effort for different RE activities, but instead investigated, whether RE activities are performed explicitly, implicitly or not at all. This is easier to estimate for the participants than the effort. Figure 19.1 shows that elicitation, documentation and V&V are almost equally important. However, looking at the explicit activities in each study separately, one can see a high variation (Figure 19.2). The SMEs in the IESE study do not perform so many activities explicitly, while in the GI pre-study many perform all activities explicitly. In all studies all company have at least one explicit activity.

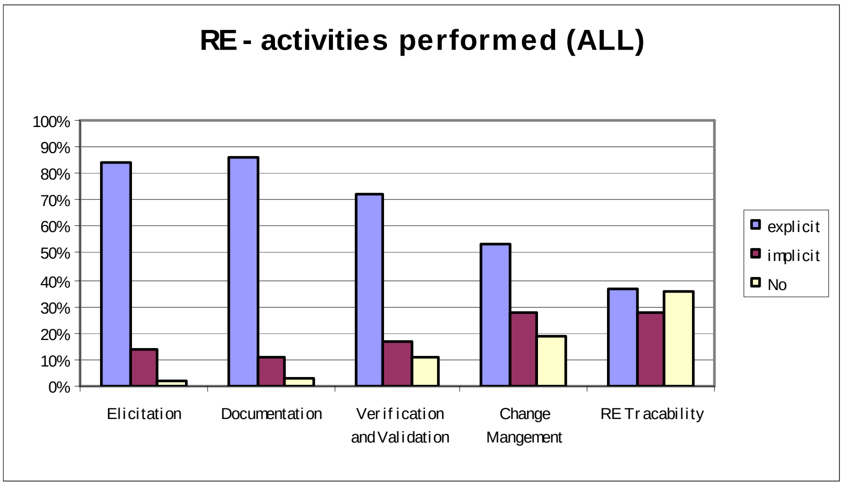

Figure 19.1: RE activities

More than half of the combined data have an explicit *RE responsible role*. Interestingly, for Fh IESE data this is even more than 70%, although these are mainly small companies. This does not seem to be due to cultural reasons, as both in the UNSW study and in the German pre-study only 30% have such a role.

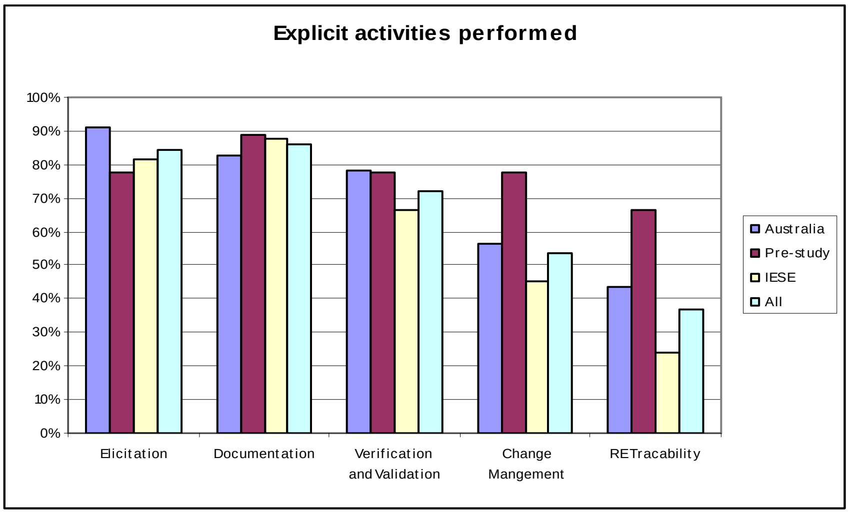

Figure 19.2: Explicit activities performed

As shown in Figure 19.3 the companies use different kinds of *RE documents*:

Customer and developer requirements are most popular, and, if one is created, then also the other is created. However, as for general practice adoption (see summary of 19.4.), the level of adoption varies with more than 30% between the samples.

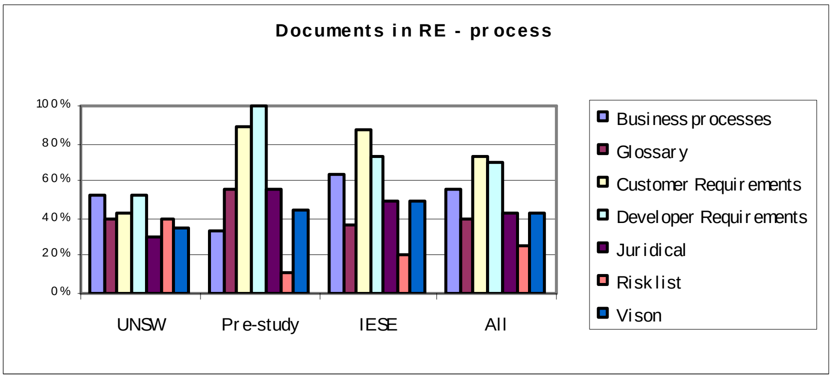

Figure 19.3: Documents created

To get a better understanding of this variety, we also investigated the relationship between the context factors (like company size, business sector) and the RE process characteristics (such as the existence of a process standard or the kind of RE documents created). The only significant relationship we found is between project size and the number of RE activities pursued explicitly and the number of different roles involved in RE. This relationship is quite obvious. So the context factors listed in section 19.3. are not sufficient to explain the variety of processes.

In the Fh IESE study we also investigated the main RE problems. In particular we asked whether the different roles (customer, RE responsible person, developer, tester, project manager) have problems with the RE process or its outcomes. The results confirm the findings on problems discussed in the last section. Problems are mainly related to project management and change management. It is stated that cost estimation is a problem (48%), that requirements are not stable (45%) and need for change is detected too late (42%). The communication between RE and design is a problem only for 33%.

We tried to establish relationships between context, general RE process and problems. Only a few relationships could be established: Creation of business processes reduces the number of problems with the finished system. It also improves communication to tester and designer. Also the existence of customer requirements reduces problems for tester, and the existence of developer requirements reduces the problems of the designers and the RE engineers. These relationships are not really surprising, but they support the plausibility of the data and give more detail to the fact also observed in [9] that creation of requirements documents is of benefit for the overall project.

Altogether the studies confirm the general findings on problems and success factors. Again, they show the great variation between different projects. They also give examples for more detailed questions on the RE process such as the different documents or the problems for the different roles. Unfortunately, they also show that it is difficult to find patterns relating project context and general process or problems. At least the context data captured in these studies is not sufficient to explain the differences.

19.6. Remarks on empirical RE research

During our literature survey we have made some observations on the broad studies which might be helpful for further studies:

- Several studies indicate that facts about RE practice depend heavily on the context. So we recommend to capture the context factors carefully and to investigate thoroughly the relationship between the context, the general RE process and the observed RE phenomenon (see summary of 19.4. and last section). This investigation would be alleviated through a more careful selection of the study sample. An example of a very careful quantitative analysis of the relationship between different process factors is [31].
- It is difficult to assess practice progress over time as the different studies have used quite different questions. It would be helpful when – at least partly – a framework such as the one proposed here is used in all studies. Recently also benchmarks for SE have been proposed [52]. It is however, an open questions whether the benchmarking paradigm can be applied to RE because of the high involvement of humans [1].

- There is a high risk of misunderstandings in standardized questionnaires. At least a glossary of terms should be provided in questionnaires.

The broad studies discussed so far, can inform research on general constraints and urgent problems in practice. A thorough understanding of specific phenomena or situations can be better achieved through in-depth studies.

It is out of the scope of the paper and a topic of further research to provide an overview of these in-depth studies on RE, such as case studies in one company or experiments. Chapter 16 is an example of an in-depth study of one company. Chapter 18 provides further examples based on what is called inductive process assessment. In the following we just give some examples of existing literature with no claim of completeness whatsoever.

Experiments have so far mainly studied requirements inspection and – much less – modeling techniques. Cox et al (2000) replicate an experiment on use case guidelines, Regnell et al (2000) and Sandahl et al. (1998) replicate experiments on different reading techniques for requirements inspection. Moynihan (1996) has compared object-oriented and functional decomposition as paradigms for communicating system functionality to users [37]. Similar comparisons can be found at the EMMSAD workshops during the annual CAISE conferences.

The most established results of SE in-depth studies have been collected in [16]. They are mainly based on case studies. One example for a recent case study has investigated RE in multi-site development projects. This case study has confirmed the problems reported in section 19.4. [59]. Another recent case study has investigated the benefits of RE process improvement [10].

These in-depth studies give very valuable insights in the RE process. So far, replications of these studies typically have not completely confirmed previous results. This indicates that still not all variables (very often related to the individuals) are completely understood. Thus, we are far from a standard process for empirical RE research.

19.7 Conclusion

Neither the state of the practice nor the state of the knowledge about the practice is satisfying. Sections 19.4. and 19.5. have collected the results of different studies. As summarized in 19.4. it is so far not possible to come up with numbers characterizing RE practice adoption uniformly. But there are repeated findings on problems and success factors. So what does this tell about future empirical research questions, what should we find out about practice?

Given the broad consensus about the problems encountered in practice, it seems time to study these particular problems in more detail.

As there is less evidence of success factors, studies should be conducted to confirm the success factor list provided in [13]. In particular, it seems important to find out, why a specific technique such as e.g. scenarios has been quite widely adopted, while another such as e.g. QFD is not adopted in spite of positive evidence. Another important point is to integrate studies from the information systems community which focus on strategic requirements and success in terms of strategic change in contrast to SE studies which focus on more operational requirements (for a detailed discussion of these levels see also chapter 1). An example for such a study is [50].

As argued before, understanding of the context and the general RE setting is important, but hindered by the diversity of terminology and the great variety of factors. Thus, we should do interdisciplinary research to get a better understanding of context factors relevant for SE projects and also to provide standard terminology for capturing this context. Standard RE terminology could be achieved through certification schemes, such as e.g. the certified tester programs offered by ISTQB. This would greatly alleviate more standardized RE education which seems essential to widespread adoption of RE practices.

The standardization would also help replication of studies. Replication is important for insights on practice progress over time.

We also believe that it is important to combine the practice analysis with improvement actions. Reifer (2003) has collected critical success factors for industrial uptake of a specific technique: It must have been proven feasible in a number of projects, the related body of knowledge must have been codified and the related rules must have been documented, tools and training must be available, hard data has been collected. Furthermore, people other than the inventors are promoting its use and the organization is prepared for the change. From this it follows that clearly there is a hen and egg problem, if industry is only willing to use a practice which is already proven. However, a set of several studies would come close to this model. First a broad study is conducted. Thereby, some companies and improvement actions are identified which are likely to be successfully adopted according to the scheme above. The execution of these actions would be the subject of empirical studies on their progress problems and success factors. The evidence of these studies can be used to find participants for in-depths studies of specific factors, such as experiments, or to find further participants for empirical studies. In-depth studies of RE improvement in specific companies can be found in the ESSI trials [17]. However, they have not been accompanied by broad studies and the findings have not been carried over to other companies.

Altogether, it is good to see the increasing number of empirical studies in RE. However, we see the need for a more sustained approach for empirical research in RE.

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