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Scaling Up Requirements Engineering –Exploring the Challenges of Increasing Size and Complexity in Market-Driven Software Development

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Abstract. [Context & motivation] Growing software companies with increasing product complexity face the issue of how to scale up their Requirements Engineering (RE) practices. In market-driven requirements engineering, release planning and scoping decisions are increasingly challenging as the size and complexity increases. [Problem] This paper presents initial results of an on-going exploratory, qualitative investigation of three market-driven, industrial cases with the objective of increasing our understanding of challenges in scaling up requirements engineering and how these challenges are addressed by the studied companies. [Results] Through 13 interviews in three companies, requirements engineering scalability issues are explored related to scoping and the structure of RE artifacts. [Contribution] The main contribution are findings related to increasing RE scale based on interpretations of the experienced interviewees' views.

Keywords: scalability, case study, requirements challenges, market-driven requirements engineering, very large-scale requirements engineering.

1 Introduction

When large organizations develop systems for large markets, the size and complexity of the work products of requirements engineering impose critical challenges [1],[2],[8]. Several studies report on experiences applying RE methods in industrial practice [2],[6] while other report on facing challenges in engineering and managing requirements in industrial practice [3],[4],[5]. On the other hand, the scalability of requirements engineering techniques and processes is neither exhaustively reported when proposing these techniques, nor empirically evaluated [6]. In this paper, we focus on the scalability of RE by analyzing challenges that are reported by advisers in three organizations that differ in size and domain but all acknowledge the need to address the scaling up of their RE practices.

2 Case Company Descriptions

Three companies have been involved in this study. All companies produce software intense products in a market-driven context [5]. The characteristics of the involved companies are depicted in Table 1.

Table 1. Characteristics of the companies involved in the study

	Company A	**Company B**	**Company C**
Domain	Embedded devices	Embedded devices	Medical care and infrastructure
Size (number of employees)	~5000	~110	~400000
Size of the typical project	Hundreds of market features linked to thousands of system requirements	5-15 persons, 15 man years effort , around 30 features per project	Hundreds of features, several thousands of contract requirements
Length of a typical project	2 years	6 months to 1 year	2-6 years

Company A is a large company in the embedded systems domain that is using a product line approach. Company B provides solutions which enable fast and reliable transmission of handwritten text into a digital format. Company C is a large provider of embedded devices in several different domains, including the energy, transportation and medical sectors.

3 Methodology

The research was conducted using a two-phase qualitative research approach [7]. We used semi-structured interviews with a high degree of discussion between the interviewer and the interviewee [9]. Two interview instruments have been used and can be accessed at [10],[11]. Previous research in large-scale requirements engineering [8][13], related surveys [5][6] and our previous efforts in understanding and supporting scoping [12] have helped to shape the interview instruments. Several aspects were discussed, such as: background and context, tasks related to requirements management, requirements types and representations, issues and challenges. The data from the transcripts was analyzed by using the content analysis technique [7] with respect to the interview instruments. Each chunk of text that was categorized and marked by a corresponding code. Categorized chunks of the text were then grouped into current situation, challenges and improvements.

4 Results

Two challenges among findings have exhibited a potential relation to scaling up of RE practices, namely: *scoping and structure of RE artifacts* (the latter is related to the term *requirements artifact structure* as defined in [13]). These challenges are

summarized in Table 2. For each challenge or issue the ID of the advisor who mentioned it is provided, often augmented by a direct quote.

Table 2. The summary of two selected challenges related to scale.

Challenge	Company A	Company B	Company C
Scoping	- Satisfy all project stakeholders vs. producing a balanced scope. - Scope reductions are difficult. - Wasting effort on de-scoped features. - Hard to get an overview or see the "big picture". - Requires deep knowledge of people and system.	- Hard to get an overview or see the "big picture". - Acquire enough knowledge to be able to make the decision.	- Difficult to avoid late scoping decisions. - Hard to satisfy all needs.
Req. artifact structure	- Unclear req. - Too complicated to understand. - Uncontrolled changes. - Information cannot be trusted.	- Too complicated to understand. - Unable to reuse the req.	- Unclear req. - Difficult to make relevant grouping.

4.1 Scoping

Responders from both Company A and B experience challenges related to scoping. In the case of Company C, the scoping was reported as partly non-challenging due to the nature of some of the projects discussed (in one case the project was regulated by a contract while in the other case the scope of the project was limited to the core set of features required to launch the product). Five out of seven responders from Company A have mentioned that it was challenging to solve the trade-off between having a balanced scope of the project and satisfying all project's stakeholders. Similarly, responder C2 mentioned that "*sometimes marketing wants it all*". This situation is frustrating for some of the interviewees, as described by responder A2: "*Yes, and that is a problem because I love the technology, that is why it took this [job], so I love all the features that are proposed and I would love to see them in our products but on the same time I need to take on the bad guy"*. Responder A4 mentioned that sometimes hard decisions have to be made due to the fact that it is not possible to please everyone with given limited implementation resources "*we had to do a very drastic scope reduction cutting down hundreds of features*". On the other hand, analyzed but removed feature is an extra cost for the company (responder A2).

Surprisingly, responders at Company C did not experience much of scoping reductions stating that "*it was actually less than you can expect from the project of this size*", responder C2. As explained by responder C1, avoiding scoping decisions was an effect of spending a lot of time on understanding the core set of features and customer needs. Moreover, leaving some "*space for late negotiations*" and "*effort reserved for maintenance*" was also mentioned by responder C1 as a workaround for over-scoping (including more features to the scope of the project than the available resources [12]). Finally, as the date of the product release was critical, the management limited the functionality to the minimum required for the product to be

working, avoiding the "*over-engineering*" issue which was mentioned in case of Company A.

In the case of Company A investigations took much more time comparing to small projects and decisions required more advanced negotiations, as pointed out by responder A1: "*there is a lot of work goes into actually coordinating and understanding different perspectives and getting that into one picture ... so it takes a lot of time to reach that consensus"*. These negotiations are often impeded by previously made commitments that may influence the decision (responder A4). As responder A2 describes it in a suggestive way: "*there are many stakeholders and everybody is screaming that they want their stuff to be done and we are sitting kind of in the middle of this..."*. On the other hand, although responders B2 and B3 mentioned that scope changes require extensive technical knowledge and sometimes time-consuming negotiations with customers, the scoping decisions were made by one person (utilizing a "*dictatorship model*"), which was reported to work well at their scale of the project. However, the challenge mentioned here is the knowledge needed to make the decision; the bigger and the more diverse the project is the more knowledge is required and one person may simply not be capable of storing all this knowledge. Responders C2 and C3 reported that the change process for scoping is rather sophisticated and often standardized. As a result the impact analysis and negotiations with the customer have to be thoroughly performed. Finally, the limited number of scope changes in case of responder C3 was caused by the fact that the project was initiated from a contract written by the customer.

4.2 Structure of RE Artifacts

With the structure of RE artifacts we include the following general aspects in the analysis of responses: (1) requirements entities such as features, system requirements, detailed requirements, quality requirements, etc. and their relationships; (2) the information structure (meta-model) of requirements entities including (a) attribute types of entities, and (b) the relationship types including different types of dependencies to other entities; (2) the evolution of the information structure and its scalability as the number of entities increase and the inter-related set of entities gets more complex.

The structure of requirements is considered to be *"too complicated to extract the information because it passed the limit where it is understandable for the user"* and "*we have little too complicated structure, naturally there is a balance, sure but I think we have driven little bit too far on the complication side*" (responder A4). On the other hand, we noticed problems due to the fact that each new project is coming up with new attributes and change proposals to the ordinary structure of requirements (responders A4 and A5). This problem is partly caused by the differences in requirements management tool policies between the various sites of the company (responder A4) and lack of change control board for handling changes into the requirements management tool structure. This makes searching for information and quality assessment more difficult. Moreover, the result of the mentioned issues may be for example, a problem while doing impact analysis of how many customers a certain de-scoping decision will affect, as pointed out by responder A4. Moreover, Responder A4 expressed the previous fact as a constant problem since "*there are too*

many trees to see the forest". Due to the overload of attributes in the requirements database, there is a lot of redundant information and information whose reliability can be questioned. Moreover, a challenging trade-off between the complexity and the cohesion of the requirements structure was expressed. According to our responders, the more effort is put on documenting a detailed level the less coherent and understandable the structure becomes on the high level. As a result it can be hard to see the full holistic view of a large project (responder A4). Finally responder C3 mentioned that the real problem with the requirements information is a human problem of keeping the information up to date: *"Once you force people to insert and update correct data the information will be maintained automatically"*, says (responder C3).

Responder B3 mentioned that producing a detailed specification with low coupling turned out to be counterproductive for its reuse, understandability and comprehension aspects. As a result, the specification had to be written from the beginning each time a new project starts. All responders from Company B and one from Company C graded understandability (B1, B2, B3 and C3) and extensibility (B3) as important quality aspects of requirements structure. Responder B2 mentioned that grouping and tagging are efficient ways of reducing the complexity and improving the impact analysis. Grouping and creating abstraction layers was also mentioned by responder C1 as an effective workaround of the complexity problem. Responder C3 stressed that finding the best grouping solution depends on the project specifics and can be challenging. For example, grouping by technical areas, or subcomponents of the system does neither refer to marketing requirements, nor to quality attributes. Moreover, it is questionable if quality requirements should be grouped in a separated module or attached to adjacent functional aspect of the system. Adding non-functional requirements on a low level creates a risk of rapidly growing number of duplicates, when the system grows, which is partly cause by the cross-cutting nature of non-functional requirements (Responder C3). Responder B2 mentioned that having a standardized requirements structure is a scalable solution, which is required starting from medium size projects (not necessary for smaller projects). Regarding the abstraction level of requirements and the number of requirements, responder C3 mentioned that the number of requirements is dependent on the process used (naturally the more rigorous process will produce a more detailed specification, in the case of Company B may be counterproductive.

5 Conclusion

In this paper, we report two challenge areas related to the scalability issues of requirements engineering, namely: *scoping and structure of RE artifacts.* The results of this study are aimed at informing further research into the nature of scalability in industrial, market-driven RE. Discovered challenges in scoping call for more research effort in providing a better overview of the size and dynamics of scope changes [12]. Moreover, our results imply a need for revisiting current methods of prioritizing requirements [1] for the purpose of assessment of their scalability and usefulness in multiple-customer environments where decisions have to be re-evaluated and adjusted. More research is required to assess the scalability breakpoints of various

scoping models, such as the centralized "*dictatorship model*" reported in case of Company B. Finally, our study reveals a need to provide a scalable method of knowledge management and exchange that can speed up complex investigations. We further explore research opportunities defined in [8] and stress the importance of designing a scalable requirements architecture that can be easy to understand, extend and modify in a controlled way. Our study has confirmed that in large and very-large projects addressing the issues related to the structure of requirements artifacts is important for efficient management of requirements.

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