Design for Excellence in the Context of Very Large-scale Requirements Engineering

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Abstract: The increasing complexity of software-intensive systems (SIS) has led to a completely new concept: Very Large-Scale Requirements Engineering (VLSRE), where the sheer number of requirements typically exceeds 10,000. Design for eXcellence (DfX) principles and their execution have been studied in different contexts for decades. However, DfX has not been in the focus of the Requirements Engineering (RE) process, and especially not in the VLSRE context. This paper addresses the DfX topic through an empirical study of the DfX RE-process and practices in a large global ICT organisation operating in the VLSRE mode. The result of this study is a conceptual framework that helps to overcome the challenges identified, leading towards changes in the operational procedures of the DfX RE-process, accommodating the requirements of very large-scale development. The piloting of the framework has been started in the case company, and initial feedback has been positive. The findings of this study offer new insights for scholars and practitioners.

1 INTRODUCTION

Competition is severe in the information and communications technology (ICT) industry. In order to beat its competitors, a company should be the first to bring products to the market, which causes time pressure for the product life cycle. On the other hand, the provided systems should meet the desired quality or "-ilities" in general.

Due to the increasing complexity of software-intensive systems (SIS), the number of incoming requests or requirements is increasing (Gorschek and Wohlin, 2006). Naturally, all requirements cannot be implemented at once. Requirements need to be prioritised and the release chosen in which the selected requirements are finally implemented (Wohlin and Aurum, 2005). The number of internal and external stakeholders, resources and technical constraints needs to be taken into account when decisions are made on the order of implementing the requirements (Geer and Ruhe, 2004). Decision-making is not a trivial task, especially early in the process, since information available for the decisions is often abstract and uncertain (Ngo-The and Ruhe, 2005).

The concept of Very Large-Scale Requirements Engineering (VLSRE) was introduced by (Regnell, et al., 2008), and the measure used to define the scale of RE has been set, based on the number of requirements in a database. In the case of VLSRE, the number of requirements typically exceeds 10,000. In addition, the very large number of requirements also implies more involved stakeholders and connections between requirements (Regnell et al., 2008).

The requirements inevitably change during the project, and the requirements are sometimes hard to predict (Abran, et al., 2004). Managing the changes and bringing all the necessary views of the internal and external stakeholders into the final system is a demanding task for RE and the design process. Design for eXcellence (DfX) is a means to cope with this challenge. It is a knowledge-based approach that drives design to optimise the desired characteristics of the product and to minimise overall lifetime costs, including, for example, manufacturing costs (Bralla, 1996). Examples of DfX viewpoints and published research are assembly (DfA) (Dalgleish, et al., 2000), environment (DfE) (Cooper, 2004) and reliability (DfR) (Xuan, et al., 2006).

DfX has been studied from different viewpoints, such as quality (Booker, 2003), manufacturing (Mottonen, et al., 2009) and sustainability (Mottonen, et al., 2010). It has been applied in various industrial domains, like automotive

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(Krumenauer, et al., 2008) and new product development (Shih-Wen, 2002). Tools have been developed for DfX (Xie, et al., 2004), and organisational aspects have been published (Hyysalo, et al., 2009). However, DfX is not widely studied from an RE perspective, and especially not in the VLSRE context.

There are a few articles discussing DfX in RE, which suggest that DfX is also a tangible way to manage, coordinate and communicate requirements in a product development lifecycle, through the whole development chain. It is very useful, for example, in requirements prioritisation, as it takes into account different stakeholders' views in a commensurable way. Therefore, DfX can be used to structure RE activities and practices (Mottonen, et al., 2009) (Hyysalo, et al., 2009) (Lehto, et al., 2011).

The aim of this research is threefold. First, the study provides a rich description of the DfX RE-process in the context of VLSRE in a large ICT company. Second, it identifies and analyses the challenges in the DfX RE-process. Third, as a conclusion based on empirical data and literature, this paper proposes a conceptual framework that has been constructed to overcome the challenges. Thus, the following research questions have been formulated:

RQ1: How can a DfX RE-process be organised effectively in industry?

RQ2: What are the challenges relating to the DfX RE-process?

By answering these questions, a rich picture of the DfX RE-process and its challenges can be obtained in the context of VLSRE. The next step is to study how to tackle these challenges, which is done by answering the third research question of a constructive research nature:

RQ3: How does one construct a framework to overcome the challenges of the DfX RE-process?

2 RELATED WORK AND KEY CONCEPTS

In the early 1990s, it was proposed that software engineering and systems engineering should be combined into a new discipline: software systems engineering. The rationale behind the proposal was that both of the mentioned disciplines address the creation of a complex SIS (Stephen, et al., 1993). RE is a branch of systems engineering containing requirements development and management (Wiegers, 2003) (Aurum and Wohlin, 2003), where requirements are formed through a requirements development process that includes activities related to eliciting, analysing, documenting and validating requirements (Wiegers, 2003) (Potts, 1995).

The requirements management process focuses on maintaining the requirements (Aurum and Wohlin, 2003). Many authors (Wiegers, 2003) (Maciaszek, 2005) (Lauesen, 2002) emphasise the nature of change in RE; thus, the requirements management process is defined as a process of managing changes to the requirements (Kotonya and Sommerville, 2003). However, it has also been claimed that requirements management includes all RE phases from elicitation to maintenance (Leffingwell and Widrig, 2003).

It has been pointed out that existing research efforts that attempt to validate tools or methods used in RE are based on small- or medium-scale RE. Consequently, most existing tools or methods are not applicable in VLSRE (Regnell, et al., 2008). Since the introduction of VLSRE, research has been conducted, for example, on aligning the RE and verification (Sabaliauskaite, et al., 2010), on organising traceability between requirements, on test specifications (Leuser and Ott, 2010), on linking customer wishes to product requirements through linguistic engineering (Natt och Dag, et al., 2005) and on requirements scoping (Wnuk, et al., 2009). Tools and methods have been proposed to tackle the issues with the large sets of requirements (McZara, et al., 2014)

DfX is an approach to designing products to meet desired "-ilities", taking into account the product life-cycle and means of ensuring the cost-effectiveness of the development, delivery and disposal of the product (Pun, 2006). The roots of DfX originate in an idea of serving internal customers regarding manufacturability and value analysis (Huang, 1996). However, the term "design for" was first used with assembly (DfA) by (Boothroyd and Dewhurst, 1983). Design for final assembly (DfFA) and board assembly (DfBA) (Mottonen, et al., 2010) are recently introduced terms, and different "design for" domains have emerged through the decades. Examples of these are design for packaging (DfP) (Hemmings, 1974) and design for supply chain management (DfSM) (Lee and Billington, 1992). A discipline design for security (DfSec) regarding the physical security of facilities was discussed as early as the 1960's (Healy, 1968), while design for software security DfsSec was introduced a few years ago (Ramachandran, 2011). One of the emerging topics

of the century is design for e-commerce (DfeC), while design for serviceability (DfS) is an example of early considerations. Design for delivery competence (DfD) as a discipline has not been discussed, but the aspects of it are related to those considered for logistics (De Hayes and Robert, 1972) and supply chain management (Lee and Billington, 1992). One common aspect for the majority of the mentioned DfX disciplines is that they are tightly connected with the engineering (HW) domain. In the case company, comparable to literature DfX disciplines exist; however, in the case company, the DfX disciplines have a stake in SW development too, not just in HW.

Applying DfX principles reduces the time-to-market, lowers life-cycle costs and increases the quality of the developed products (Maltzman, et al., 2005). On the other hand, the purpose of RE is to provide business value for the company, focusing on an expected value for different stakeholders (Aurum and Wohlin, 2007). Further, the quality of the developed system has been argued to be dependent on the quality of the development process as a whole (Strigini, 1996), and on the quality of the requirements (Ruhe and Saliu, 2005). The needs of internal customers were first considered in manufacturing and assembly (Huang, 1996).

A few papers address DfX in the context of Software Engineering and RE. According to (Lehto, et al., 2011), DfX is a way to address the needs of internal customers and manage requirements during a product development process. Through DfX, requirements can be treated in equal terms. A study by (Mottonen, et al., 2009) highlighted the importance of a dedicated function to manage requirements from internal customers.

Problem domain, solution domain (Hall, et al., 2002) and *stakeholders* (Maciaszek, 2005) are fundamental concepts in RE. The problem domain is the bounded part of reality where the problem is defined. Usually, the realised problem should be solved by a system or a product (Jacobson, et al., 1999). The proposed settlement of the challenges of the problem domain is defined in the solution domain, where the solution domain is the developers' and designers' sandbox. In both domains, the language and semantics originate from the stakeholders, so concepts and entities in domains are usually unique. The terminology used may be contradictory within and between the domains.

The stakeholders are people who have a stake in the system, and they are usually divided into external and internal stakeholders. The two main groups of stakeholders are customers and developers (Maciaszek, 2005). Examples of external stakeholders are legislators, system users or system owners on the customer site. Internal stakeholders are, for example, system designers, engineers and different specialists. A wider perspective defines a stakeholder as a group or an individual who is affected by the achievement of the organisation's objectives, or a group or an individual who can affect them (Freeman, 1984). DfX is a means to present stakeholder views using company terms which, in commensurable form, are meaningful to the systems provider (Hyysalo, et al., 2009) (Lehto, et al., 2011). Having stakeholder views represented by various DfX disciplines, representing different views to product development, could be a means to form a bridge between the solution and problem domains.

Operations is usually defined as an organisational unit responsible for managing and running the processes, which in turn input into physical products or systems. Operations includes production (manufacturing, assembly and testing of systems and components). It also takes care of logistics and distribution, and is involved in decision-making to transform designs into systems and services. Operations aims to reduce defects and costs by paring unwanted variability and uncertainty in product delivery, and still maintaining constant output and high quality (Dodgson, et al., 2008). The benefit of coordinating DfX within operations has already been demonstrated in (Hyysalo, et al., 2009) and (Lehto, et al., 2011); however, in this paper, the intention is to go further and describe the DfX RE-process as part of VLSRE and a framework to overcome identified challenges.

3 RESEARCH PROCESS

The research process is shown in Figure 1, and the research was conducted following the case study process steps defined in (Runeson and Höst, 2009). The case is a holistic case study, and the case company is a large business-to-business operating enterprise. This company is a typical enterprise in its market sector, which provides software intensive systems and services for a global market. The case company operates in the ICT sector, and has successfully followed DfX principles for over a decade. An overall RE-process in the case company consists of several processes, in which the number of requirements related to systems and services clearly exceeds the definition of VLSRE (Regnell, et al., 2008). The case concerns the DfX RE-process,

which is one of those processes. The purpose of the DfX RE-process is to define requirements concerning a large group of internal and external stakeholders.

Figure 1: Research process (Runeson and Höst, 2009).

In the design phase, the objectives of the case and research questions were determined; and the theoretical background, research methods and sources were chosen. The preparation phase included questionnaire development, decisions on who should be interviewed and agreement on procedures and schedules. During the collection phase, the data was gathered via 20 qualitative interviews (first-degree data), archived materials and literature (third-degree data). The interviews were transcribed and analysed first by the DfX discipline, and then cross-analysed based on themes like organisational aspects and processes.

3.1 Case Design and Data Collection

The data gathered and analysed in this case study originates from three main sources: 1) archived material provided by the case company in advance and by the interviewees, 2) interview recordings and transcriptions and 3) scientific literature. The case company delivered background material in advance for the researchers to familiarise themselves with the company's DfX organisation and practices before the interview questionnaire was prepared. The interviewees also provided some clarifying examples on the topics discussed during the interview. The examples of the provided company material are process descriptions, organisational charts and design principles. The duration of the case study was five months from the first workshop until the final report was delivered to the case company. During that time, weekly meetings were held and at least one representative from the case company participated in each meeting. This provided a good opportunity for the researchers to discuss in quick cycles any unclear issues encountered during the case. Weekly meetings were also recorded and transcribed, and this material was used on need bases to support the analysis and writing of the report.

The richest information about the DfX RE-process was gained through 20 qualitative, semi-structured and thematic interviews (Gubrium and Holstein, 2002) in the case company (Table 1). The themes discussed were RE concepts used in the company, types of requirements, stakeholder aspects and utilised tools. The interviewees where located in two countries and in five different sites, and were confident in the researchers, since the researchers worked under a non-disclosure agreement and ensured that the gathered data was always handled anonymously. The first version of the questionnaire was updated based on the first four interviews. The changes were minor; few words were changed, and examples and two small questions were added. The questionnaire was sent in advance to the interviewees so they could prepare themselves for the interview and finish the interview within the given time limits. The interviews were face to face, except for two interviews (one over the phone and one in a video meeting). They were completed in one month and the average duration of each interview was a bit over one hour. The interviews were conducted on the case company's premises to save the interviewees' time and make participation as easy as possible for the interviewees. All interviews were recorded and transcribed. Two or three interviewers were assigned for each interview, and one of them did the first summary. The purpose of the summaries was to condense the main points of each answer, to be checked by the interviewees. The summaries did not contain any conclusions or interpretations by the researchers.

Table 1: Interview summary.

Int.	Role	Durat./ Exec.
1	DfS manager	70 min/ F2F
2	DfS team member	79 min/ F2F
3	DfP manager	88 min/ F2F
4	DfFA manager	51 min/ F2F
5	DfE manager	72 min/ F2F
6	Testing technology expert	70 min/ F2F
7	Product line expert	96 min/ F2F
8	DfeC manager	61 min/ F2F
9	DfSM manager	55 min/ F2F
10	DfR manager	88 min/ F2F
11	DfBA manager	59 min/ F2F
12	DfD manager	66 min/ F2F
13	DfsSec manager	55 min/ Phone
14	DfsSec team member	60 min/ F2F
15	DfD RE-process	35 min/ F2F
16	DfX RE-process expert	65 min/ Video
17	DfD SW expert	61 min/ F2F
18	DfD SW member	34 min/ F2F
19	Product development process expert	79 min/ F2F
20	Head of DfX managers	120 min/ F2F

3.2 Analysis and Validity Procedures

The interviews were grouped by the DfX discipline,

and the data was used to describe each discipline. For each discipline, the flow of requirements, that is, the input and output data, was determined, its stakeholders were identified and the SW-related issues were recorded. The challenges in each discipline were identified and solutions were proposed. The interview data was cross analysed by re-grouping the interviews based on for example processes, research, platforms and product life-cycle phases.

The analysis involved comparing the empirical evidence with the existing literature and archival data provided by the case company and by the interviewees. Finally, the common denominators across all disciplines were identified, for example, on requirements, communication, organisation, DfX concept and tools. The major and minor challenges were listed for each topic, and solution ideas were proposed.

The recorded and transcribed interviews provided rich authentic data. The interview transcriptions and first summaries were emailed to the interviewees within two weeks, and the interviewees were asked to validate the data within one week. Four interviewees made minor comments, such as explaining the abbreviations. Otherwise, the interviewees replied that the gathered information was correct.

After that, the data was analysed based on the DfX disciplines, and then, the analyses were sent to the interviewees. They were given one week to validate, comment and correct the analyses. None of the interviewees commented on the content.

The case report for the company was written based on the analysis of the interview data, material provided by interviewees, company materials and literature. The results were presented in a seminar organised in the case company. This seminar was recorded and transcribed to capture the feedback that was analysed to validate the results.

4 RESULTS AND ANALYSIS

4.1 DfX RE-process

In the case company, the DfX concept is divided into disciplines according to knowledge and technology *platforms*. Examples of the disciplines are design for assembly and design for serviceability. The platforms include a product or a system, and process expertise. Operations' platforms are Manufacturing, Sourcing and Delivery. The disciplines are led by the DfX managers, and the head of the DfX managers has the responsibility for the overall concept. Close co-operation between different DfX disciplines is required to manage common issues, and the co-operation is organised thorough efficient networking. In the case company, the DfX concept runs the DfX RE-process to produce requirements concerning their views on the products and their development process, in order to cover the views of external stakeholders the disciplines represent.

Operations aims to maintain platforms, for example, by keeping a list of recommended components and ensuring standardised manufacturing, delivery and sourcing processes. DfX stresses the optimised use of products and platforms, as well as the implementation of best practices, for example, in sourcing, services and environmental management. In order to achieve the efficiency goals, both the Operations and product creation processes must be managed effectively. In principle, DfX has the same goals, but has a wider scope, taking into account the whole product life-cycle and the customers' costs.

Traditionally, DfX has been considered to be an R&D-driven design approach. In contrast, our industrial case differs significantly; the DfX principles are applied by Operations' DfX capability management to the DfX RE-process. During the DfX RE-process, the SIS are not *designed*, but *requirements are set* for the design, development, delivery, maintenance, service and disposal of SIS.

Another difference is that the problem domain and solution domain must be looked at in a new light, since DfX management operates and influences in both domains. In the case company, the DfX capability management organisation has a global responsibility for running the DfX RE-process. The DfX management organisation elicits, for example, the raw requirements and constraints, and identifies challenges, for instance, in the SIS (through testing), development and delivery processes. However, the DfX teams within each discipline analyse the elicited data to look for solutions to the identified problems. This is clearly a solution domain issue.

In the analysis phase, the feasibility of the requirements is analysed, taking into account, for example, the available resources, risks and costs from an Operations' point of view. The business evaluation is done to convince product managers in a requirements negotiation phase and to affect the requirements prioritisation. The analysed data is written down as guidelines or well-formed requirements that ought to be followed or

implemented in the product design, feature specification and product creation processes. Many of the DfX requirements are *constraints* from the product creation, maintenance and delivery process viewpoints. The well-formed requirements and guidelines are globally reviewed to validate that the needs of the relevant stakeholders are formulated as requirements, or that their viewpoints have been taken into account in the guidelines. During the global review, the goals of the DfX disciplines are agreed-upon, and they are explained in the DfX feasibility study. DfX management operates in the solution domain, as well as via dedicated DfX advocates, who ensure that the minor modifications are taken into account when the program plan is created, and that plan, in general, is in line with Operations' goals. The DfX advocates are also responsible for seeing that DfX requirements are implemented and maintained based upon agreed-on platform specifications. The number of requirements is immense, and to choose the set of requirements that will be implemented by program releases, the requirements need to be prioritised. In this task, the internal stakeholders' requirements are often overlooked in comparison to the (paying) customers' requirements. The guidelines are used to influence the decisions made in the product creation process. Those well-formed requirements that need to be further analysed, taking into account SIS content on the large scope, are fed into feature specification. The results of the feature specification are stored in a database as feature proposals that are used in the product creation process. Figure 2 illustrates the studied DfX RE-process.

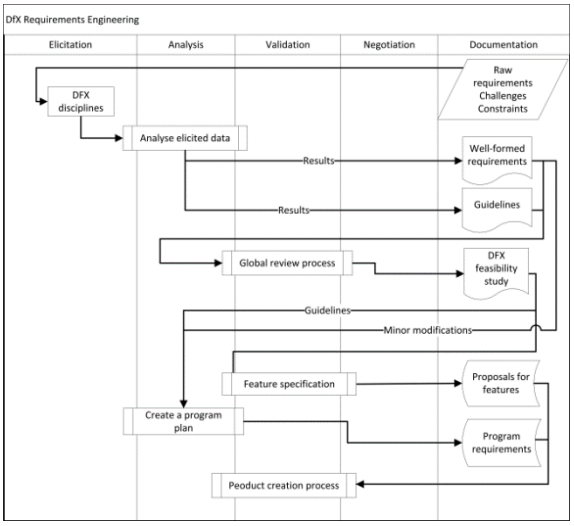

Figure 2: The simplified illustration of the common parts of the DfX RE-process.

4.2 Identified Challenges

Based on the interviews, the common challenges for all disciplines were divided under the DfX RE-process phases and some other general themes. It is possible that some of the themes overlap, and common issues are presented. The fundamental reasons behind the challenges are traced and discussed in relation to the literature, and recommendations are provided to address the identified challenges.

Requirements elicitation and analysis. One of the widely acknowledged challenges in RE is that requirements tend to be unclear and incomplete at the beginning of the process. This issue is also denoted as ambiguity in the literature (Paasivaara and Lassenius, 2004). One way to address the challenge is to establish a practice to systematically gather stakeholder requests in a commensurable form. The DfX RE-process is a way to gather requirements from platforms, and communicate those to the SW development process. However, it was noted that the rationale behind the requirements is often missing, which leaves room for improvement in the requirement analysis and documentation. Argumentation regarding risk management has been discussed in (Heindl and Biffl, 2006). **It is suggested that the rationale is a mandatory part of a requirement description**.

Requirements prioritisation. The DfX RE-process provides input program requirements, which are included in a program plan. Development in programs is done in releases, implementing a subset of requirements in each release. Requirements are prioritised by program teams; however, in a VLSRE context, DfX managers do not have visibility of the prioritisation criteria and process. Practical challenges in requirements prioritisation are discussed in (Lehtola, et al., 2004). The QUPER model has been suggested in (Svensson, et al., 2008) to support release planning with regard to quality requirements. Prioritisation criteria should be created to support the aspired added values of both internal and external stakeholders. The interviews revealed the fact that DfX disciplines face challenges in creating a winning argumentation from a business view to achieve high priorities for DfX requirements. Literature acknowledges this dilemma (DeLain and O'Meara, 2004). There are different types of requirements, like business and product requirements (Lauesen, 2002); therefore, stakeholder views, and consequently their requirements, often conflict (van Lamsweerde, et al., 1998), for example, in usability and security. **It is suggested**

that practical support for business argumentation is created, including requirement categorisation, to enhance analysis and prioritisation tasks.

Requirements validation. The DfX RE-process produces companywide guidelines to be utilised in product design and development. The case company has established a global review process for guidelines; however, reviews are not always conducted. **The company should decide on which levels reviews are really needed, and then practices should be harmonised. Literature on design reviews should provide scientific suggestions for the situation**.

Requirements negotiation and communication. During the interviews, it was observed that DfX requirements should be taken into account early in the product development process. This is due to the nature of the DfX requirements, which are often constraints in nature, and based on standards or regulations. However, the DfX concept in the case company's VLSRE context does not have the means or authority to get its requirements accepted at the right levels. This means, if the guidelines are not taken into account when making strategic decisions, their influence in the programs cannot be ensured. **Therefore, the DfX requirements are often overlooked by the product management (PM) due to short term business impact goals. Heavy lobbying is done to affect requirement priorities; however, such an activity cannot be seen as a successful strategy in the long run**. It is also noted that missing requirements early in the process is one of the costliest changes to fix later on in the process (Nurmuliani, et al., 2006).

Requirements documentation and tools. Requirement management and communication in the case company is largely document based, even though tools are available. By document based, it is meant that (for example) guidelines are Word documents, which are then stored in the company databases. During the programs, the requirements are recorded in excel sheets, which are updated according to changing priorities. Some issues were identified regarding the documentation and the tools. Employees often consider a document based process to be laborious; thus, important updates and revisions of documents are easily neglected. This leads to the challenges related to poor and inadequate documentation (Herbsleb and Moitra, 2001). A shared understanding about requirements and proper documentation may be achieved through training, adequate templates and improving visibility. It was learned that there are several tools that are utilised for requirements management. The DfX RE-process has its own tools and databases, while the PM has its own and product programs utilising yet another set of tools. One example is that some product teams use legacy tools, while others use the one chosen as a global company tool. The utilised tools, their implementation or usage cause challenges. If the tools do not match the needs of their users, many manual actions are needed between process steps, or when communicating between the processes. For example, in one tool, the export functionality does not provide output, which could be uploaded to the next process as such. There are several studies pointing out tool related issues, for example, (Herbsleb and Moitra, 2001), (Ebert and De Neve, 2001), (Braun, 2003), (Maznevski and Chudoba, 2000) and (Herbsleb, et al., 2001). **It is suggested that a unified database for diverse requirements be established. To reduce the number of documents in the process, an electronic idea feeder (unifying information channel), which supports the variety of requirements and large attachments provided by customers, should be developed**. The documentation created during the DfX RE-process is a common documentation style, since it covers a large group of internal stakeholders and platform expertise.

Processes and practices in general. Different teams have customised the defined global processes, practices and tools fitting their specific needs. However, in the VLSRE context, the processes have synchronisation points, or they may be seen as the consecutive phases of product development. In these situations, tailored ways cause challenges. Similar issues have been reported in, for example, (Paasivaara and Lassenius, 2004) and (Battin, et al., 2001). **The common practices and ways of working should be agreed upon and maintained**. The DfX process is systematically managed throughout the disciplines; however, the synchronisation with other processes is diversified.

Organisation and roles. The company has experienced several significant organisational changes over the past few years. Due to these constant changes, the roles and responsibilities are not clearly defined, and some of the positions have not been filled. Aspects of organisational issues have been discussed in, for example, (Herbsleb, et al., 2001), (Gray, 1989) and (Tiikkaja, 2002). **It is suggested that the roles and responsibilities be defined**. This is a time consuming task, which requires various kinds of expertise from the company, but should pay back the effort through well organised VLSRE.

4.3 Framework for the VLSRE

In the context of VLSRE, the requirements are not developed and managed through one RE-process, but several connected processes. The DfX RE-process presented in this paper is one of those processes. It provides requirements, for example, for the feature specification process. The experience gained from industry co-operation indicates that other internal and external stakeholders run their own RE-processes. The outputs of the stakeholder specific RE-processes vary from full requirement specifications to the high level description of a market need. **The developed VLSRE framework includes identified internal and external stakeholders, defines their (RE) processes and establishes a unified information channel for requests. In addition, it identifies the "receiver" processes and their needs regarding the information provided by stakeholder specific (RE) processes. The framework suggests that the requirement data structure should have two major parts: a) basic data common for all types of requests and stakeholders and b) categorised data depending on the receivers' information needs**. The unified information channel enables the gathering of data systematically from all sources. It also provides a commensurable form for documenting request data, and thus, enhances decision-making and prioritisation. See Figure 3.

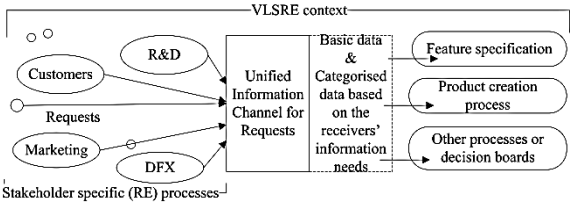

Figure 3: The simplified illustration of the VLSRE framework.

The developed framework addresses some of the identified challenges in the VLSRE context. The framework acknowledges different stakeholders and their needs for products and their development process. The interviewees mentioned that getting the product programs to "buy" the DfX requirements is currently the most time-consuming activity. To create a "winning" reasoning for DfX requirements, which usually aim for internal savings, is a hard task when compared with customer requirements, in which case the rationale is shown via sales figures. The framework suggests a structured data content for different types of requests based on their receivers' information needs. The structured data content is intended to support, for example, creating a cost-value argumentation and reasoning behind requests. The framework identifies receivers at several organisational levels, providing an opportunity to choose a proper receiver for each different type of request. This addresses the identified challenge to get guidelines accepted by the proper authority. Related to the challenge of different incompatible tools, it suggests establishing a unified interface for all types of requirements from all data sources. The idea of the framework is to align stakeholder specific (RE) process outputs so that they correspond to the needs of the receiver organisation. Thus, the framework addresses the challenge of request/requirement documentation as well. Currently, the picture of VLSRE practices based on empirical evidence is scarce, and the framework gives a high level view about the case in a large ICT organisation. To form a richer view, further in depth studies on VLSRE practices must be conducted.

5 CONCLUSIONS AND FUTURE WORK

Answer to *RQ1: How can a DfX RE-process be organised effectively in industry?* The general RE-process phases (Sommerville and Sawyer, 2004) were identified in the DfX RE-process; however, the case company is a large organisation and its processes are not as simple as those presented in the literature. Thus, requirements development and management are actually a series of parallel and continuous processes that are managed by several different organisational units. Another difference is that in the case company, the global responsibility of the DfX RE-process resides in Operations' DfX management organisation, instead of R&D.

Answer to *RQ2: What are the challenges relating to the DfX RE-process?* The challenges related to the DfX RE-process in a VLSRE context were identified as discussed in the previous chapter. The identified issues and challenges do not differ significantly from earlier published research, but the magnitude of the issues grows exponentially when the challenges are considered in small-scale RE versus VLSRE. For example, time from customer negotiations and request initiation to actual implementation often take years. During that time information regards customer agreement and initial request is used and processed by various experts, and several decisions are made on system

development and releases. In addition employees change for number of reasons. Thus, it is, for example, impossible to manually update the dependencies between requirements, and trace the requirements back to their original stakeholders, etc. (Leuser and Ott, 2010). Furthermore, the documentation should contain all relevant information for the later phases, from the very beginning, and it must be well organised, since there are many handovers along the development process, and contacting people in other time zones causes delays in processing requests.

Answer to *RQ3: How to construct a framework to overcome the challenges of DfX RE-process?* The DfX requirements can be divided into two main types: guidelines that ought to be followed during product creation process, and well-formed requirements that should be either implemented in the product creation process or further analysed during the feature specification. The DfX disciplines are not the only stakeholders that feed requests, for example, into the feature specification. The data from all sources should be systematically gathered and fed into later phases in a commensurable form, to enable efficient decision-making and prioritisation. The developed VLSRE framework addresses several identified challenges.

5.1 Evaluation of the Validity

There are four aspects of validity that need to be considered (Runeson and Höst, 2009): *construct validity*, *internal validity*, *external validity* and *reliability*. The threat to the construct validity in this case study relates to the questionnaire. The construct validity was mainly addressed by careful review to ensure a good and common understanding of the questionnaire. Four researchers created the questionnaire, taking into account the objectives of the case. The questionnaire was reviewed by four other researchers, and four pilot interviews were done to test the questionnaire. The internal validity is not relevant to this case, since it relates to conclusions made of causal relationships, and the threats to the external validity relate to the generalisation of the results. The objective of this case study was to describe the DfX RE-process in a large ICT company, reveal the challenges in it, and propose a conceptual framework to tackle the identified challenges. In general, case studies provide low possibilities to generalise results (Runeson and Höst, 2009); however, the results could possibly be analytically generalised to another large ICT company applying DfX principles. The generalisability of results is promoted by the typical characteristics of the case company; representative DfX disciplines, ordinary RE-process phases and utilised tools for instance. More studies are needed to generalise the results to other domains.

The reliability issues related to the data and analysis depend on the researchers. The question is: If other researchers conduct a similar study, would the results be the same? The threats to the reliability have been addressed in this case, so that the results have been derived at least by two researchers, usually by three, and the results have been reviewed by six other researchers. In this case, the data collection and analysis procedures have been clearly defined and maintained. The interviews were carried out by at least two researchers, and the interviews were recorded and transcribed by professionals. One of the interviewers wrote a summary of the interviews based on notes, which were taken during the interview, and transcription data. The summaries and the initial analyses were reviewed by the interviewees, but the corrections were minor, like the explanations of the abbreviations. Another threat to the reliability is that the interviewees described their subjective viewpoints about the discussed issues. This issue was addressed by interviewing 20 employees, who represented different organisational units, different DfX disciplines and all product life-cycle phases. It was also noted that saturation was achieved, meaning that the more interviews we conducted, the fewer new findings came up. The validity of the results was also addressed using data triangulation, and taking into account the feedback received from the company. To conclude, during this case study, the validity issues were properly addressed.

5.2 Implications for Practice and Research

The created framework has been further developed in the co-operation between the researchers and the case company representatives. Piloting the framework and new practices relating to it have just begun. The framework has been well accepted by the managers in the company; in other words, it has passed a weak market test (Kasanen, et al., 1993). In addition, the received feedback from the experts has been positive. The results of the study have already led to changes in the case company's DfX RE-process, and further studies have been initiated.

The competition in the ICT domain is severe, and organisations must continuously aim for internal efficiency and seek innovative practices to gain

business advantages (Helo, 2004). The results of the study also bring value to other large organisations in the ICT sector, but the applicability of the results to other industrial domains needs to be further studied. The results here should encourage other organisations in all industrial domains to study their RE practices and design processes to determine how they can apply DfX principles.

Even though DfX has been successfully utilised in industry for decades, especially in manufacturing, the DfX principles have not been addressed from the RE-process viewpoint, and definitely not in a VLSRE context. Therefore, the academic world benefits from the new insights that the results provide. The conducted case study also opens up new directions for future work, since all relevant stakeholders who process requests need to be identified, as well as their information needs. Tools and methods applicable in VLSRE to assist requirements engineers need to be developed.

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