In Proceedings of the Requirements Engineering: Foundation for Software Quality, REFSQ 2009,
15th International Working Conference, Amsterdam, The Netherlands, June 8-9, 2009.
Lecture Notes in Computer Science, LNCS 5512, pp. 190-196, Springer.

Assurance Case Driven Case Study Design for Requirements Engineering Research

Robin A. Gandhi[1] and Seok-Won Lee[2]

[1]University of Nebraska at Omaha, College of Information Science and Technology,
6001 Dodge Street, Omaha, NE 68182, rgandhi@unomaha.edu
[2]University of North Carolina at Charlotte, College of Computing and Informatics,
9201 University City Blvd., Charlotte, NC 28223, seoklee@uncc.edu

Abstract. [Context and motivation] Case studies have the potential to be an essential bridge between the constructive (build new theories, algorithms, or methods to address practical problems) and the empirical (develop evidence through observation of or experience with existing methods or artifacts in practice) approaches to requirements engineering research. **[Question/problem]** To realize this potential, our aim is to provide representational guidance for designing a case study as a part of the invention process of a novel requirements engineering methodology (REM). **[Principal ideas/results]** In this paper, we present the innovative use of assurance cases to emphasize argumentation and rigorous evidence planning during case study research design. **[Contribution]** The steps involved in case study research design using the assurance case notation are outlined as a systematic way to plan a validation effort for a REM.

Keywords: Case study, Assurance Case, Requirements, Research methods

1 Introduction

A Requirements Engineering Methodology (REM) provides analytical capabilities to Subject Matter Experts (SMEs) who execute its steps for eliciting, modeling, analyzing, negotiating or validating requirements. Well-defined usage, representation and measurement of these capabilities and related artifacts are essential to demonstrate the achievement of the desired outcomes from the REM as well as their continuous improvement. An outcome is defined as a statement that describes what a SME is expected to know and to be able to perform by using the REM or the expected quality of resulting artifacts. From the definition, it is clear that any REM validation effort is heavily dependent on the skills of SMEs who participate in the validation exercise, and the problem domain.

For a newly invented REM, the outcomes are difficult to evaluate as no materializations may exist yet in the real-world context and the SMEs may have no prior experience or training for the techniques required to be applied. Comparison with other existing REMs and benchmarking is not meaningful as the unique nature (philosophy, models, steps, and techniques) of each REM influences human analytical reasoning and resulting artifacts differently. Under these circumstances, a defined strategy for data collection and analysis is necessary to make valid inferences about the fitness/quality of the desired REM outcomes from the observed phenomena or artifacts in the real world context. To carry out this effort, case study research designs allow an investigator to clearly identify the followings [12] [8] [10]: 1) The research questions; 2) The REM outcomes being studied; 3) What are the resources to be

In Proceedings of the Requirements Engineering: Foundation for Software Quality, REFSQ 2009,
15th International Working Conference, Amsterdam, The Netherlands, June 8-9, 2009.
Lecture Notes in Computer Science, LNCS 5512, pp. 190-196, Springer.

examined and what data to collect; 4) What are the logics linking the data to the REM outcomes; and 5) What are the criteria for interpreting the findings.

If used correctly, case study as a validation strategy reveals: why and how a newly invented REM works; the effectiveness of the stated outcomes; and opportunities for further improvement. However, planning a case study is a significant undertaking. Yin [12] points out that a good case study is difficult to perform, and we hardly understand the required skills on the part of the investigators or reviewers dealing with case studies. Vague or implicit research designs will only add to the many misunderstandings and skepticism [5] already widespread about case studies. Additionally, if the case study design is an afterthought the newly invented REM may not provide optimal opportunities for data collection necessary to address the original research questions. The REM steps may also lack traceability and rationale to support the expected outcomes if such contribution is not clearly identified in advance.

It is clear that systematic guidance while building case study research designs is essential. Particularly, we emphasize the need for representational mechanisms that guide and assure the development of a rigorous case study research design during the REM invention itself. This approach can effectively combine the constructive component of REM development with an empirical component to validate REM outcomes in the real world context. To facilitate this goal, in the following sections we describe the steps in combining *assurance cases* [7] and case study research designs in requirements engineering research. These steps have been developed in the context of planning a case study while inventing a novel REM. While the complexity of planning data collection and analysis in context with SMEs makes our approach particularly suited for requirements engineering research, the steps are generally applicable and can be extended for planning case studies in different domains.

2 Representing Assurance Case and Case Study Design

Often compared to a structured legal argument, an assurance case [7] is a self-contained information unit that includes a top-level goal/claim, an argument in the form of continuous claim refinement until the sub-claims can be specified in operational terms, and evidence that the claims have been satisfied. Its purpose is to provide a clear, comprehensive and defensible argument that the claimed objectives are achieved in a certain context. On the other hand, the case study evaluation strategy is mostly appropriate for “how” and “why” types of study questions [12]. These question types also correspond to top-down and bottom-up traversals in a goal refinement hierarchy, respectively. As a result, the goal structuring notation [7] of assurance cases provides a natural fit for representing case study research designs.

With an early start to case study design using assurance cases, our rationale is to identify more intuitive sources of evidence by exploring the possibilities of instrumentation (i.e. opportunities for evidence generation and gathering) as each step of the REM is being developed. Early planning of evidence generation and collection alongside the explication of the theoretical propositions that underlie the REM will assure that the identified outcomes are in fact being addressed by the methodological steps and measured properly in the case study research design. To facilitate this process, the five case study design components can be systematically captured in the form of a graphical assurance case notation as Fig. 1. The assurance case notation [7],

In Proceedings of the Requirements Engineering: Foundation for Software Quality, REFSQ 2009,
15th International Working Conference, Amsterdam, The Netherlands, June 8-9, 2009.
Lecture Notes in Computer Science, LNCS 5512, pp. 190-196, Springer.

as shown in Fig. 1, consists of the following elements: goal/claim nodes, strategy nodes, context nodes, solution/evidence nodes, and most importantly the interconnections among these nodes to construct a valid and convincing argument. Strategy elements clarify the nature of an argument, while context elements specify the conditions under which a goal/claim is stated.

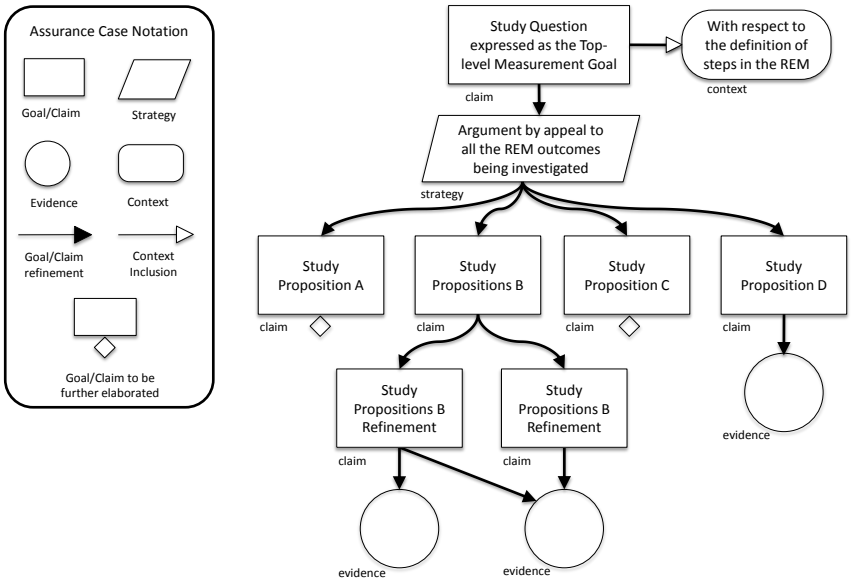

Fig. 1. An Assurance Case Skeleton and its relevance to Case Study Design Components

For developing case study research designs using assurance cases alongside the design of a new REM, a step by step method is outlined as follows:

Step 1: Study Question and the Top-level Measurement Goal/Claim. To identify opportunities for REM instrumentation as early as possible, the primary study question ("why" and "how" a newly invented REM works) needs to be re-written as the top-level measurement claim/goal in the assurance case notation. This conversion in some sense starts the linking process between constructive and empirical research approaches. For the assurance case to follow a logical argument, a claim is always worded as a predicate (i.e. it can only be true or false).

Step 2: Propositions and Goal/Claim Refinement. Case studies benefit from the prior development of theoretical propositions to guide data collection and data analysis [12]. These propositions are assertions that determine what should be examined within the scope of the study. Typically these assertions emerge from all the desired REM outcomes that reflect the theoretical propositions that guide the REM development. To capture this general rationale in an assurance case, the Strategy modeling element suggests the form that an argument is going to take for satisfying the top-level claim. Specific theoretical propositions then form the sub-claims that refine the top-level claim as shown in Fig. 1. The REM progression may correspond to the levels of intellectual behavior [3] of the SMEs or related artifacts.

In Proceedings of the Requirements Engineering: Foundation for Software Quality, REFSQ 2009,
15th International Working Conference, Amsterdam, The Netherlands, June 8-9, 2009.
Lecture Notes in Computer Science, LNCS 5512, pp. 190-196, Springer.

Step 3: Units of Analysis and Case boundary. With the REM itself being the "case", the units of analysis include the steps in the methodology, the models and methods used in each step, and the characteristics of the methodology itself. To this end, the assurance case claims and steps in the REM clearly establish the case boundary and identify the relevant phenomena/artifacts.

Step 4: Linking Logic and Goal/Claim Operationalization. The theoretical propositions may exist at a level of abstraction such that they cannot be measured directly. Through a goal refinement process, assurance cases can effectively explicate the rigor adopted by the investigator in linking the high level theoretical propositions to concrete measurement claims/goals that can be specified in operational terms of the REM steps. A particularly effective and disciplined way to gather and organize case study evidence is to construct an ordered set of questions with respect to the steps in the REM as a Summary Sheet [8]. For a newly invented REM, the summary sheet combined with the given instructions (e.g. a tutorial or workshop to teach or educate the REM) prior to a case study helps SMEs to identify the units of analysis and the corresponding evidence (qualitative or quantitative) that needs to be captured towards the case study propositions. The summary sheet columns in a table format, as shown in Fig. 2, allows SMEs to effectively conduct the steps in the REM and capture evidence with no interventions required from the investigator. In the fourth column, the identification of assurance leaf-node claims for each row of the summary sheet clearly explicates what evidence from the unit of analysis supports/rejects the claims.

Unit of Analysis	Evidence to be captured by SMEs based on specific propositions	Step/Model/Method in the REM	Related Claims in the Assurance Case

Fig. 2. Elements of a Summary Sheet

Step 5: Data Analysis through Stratification. Unorganized collections of data do not produce meaningful insights. For initial guidance in selecting data analysis techniques, we have developed a general tabular structure wherein the gathered evidence is placed in the cells at the intersection of the relevant leaf-node claims (columns) of the assurance case and units of analysis (rows). The resulting presentation, as shown in Fig. 3 (a), provides a multi-dimensional categorization of the gathered evidence in the summary sheet. This representation can also be combined with more specific data analysis techniques such as structural analysis [11] or comparative gap analysis [4].

Case study inquiry relies on multiple sources of evidence, with data needing to converge in a triangulating fashion [12]. The stratification of evidence, as shown in Fig. 3 (b), can capture multiple sources of evidence along with their relationships (converging or non-converging sources of evidence) towards making stronger analytical conclusions about a claim. An assurance case allows relatively weak evidence to be combined in argumentation with other evidence to make a stronger conclusion [6]. The evidence stratification effectively utilizes this flexibility to include varying degrees of rigor in evidence as well as different types of evidence in a case study to make appropriate analytical generalizations. This presentation exercise with summary sheet questions may also identify instrumentation defects.

In Proceedings of the Requirements Engineering: Foundation for Software Quality, REFSQ 2009,
15th International Working Conference, Amsterdam, The Netherlands, June 8-9, 2009.
Lecture Notes in Computer Science, LNCS 5512, pp. 190-196, Springer.

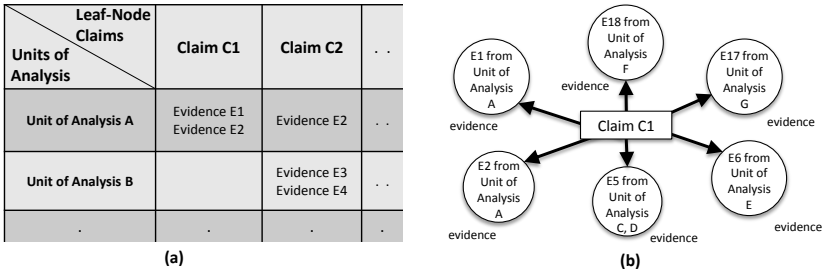

Fig. 3. (a) Stratification of Evidence gathered in the Summary Sheet; (b) Convergence of Multiple Sources of Evidence to support/reject a Claim

Step 6: Criteria for Interpreting the Findings. As with any empirical evaluation, usually there is no precise way of setting the criteria for interpreting the case study findings. The assurance case representation adds much needed rigor to this design step. In particular, the criteria are clearly based on metrics that evaluate the importance/significance of the evidence to support the argument. These metrics can be supported by quantitative or qualitative measures depending on the types of the evidence available from the case study.

The assurance case as a whole helps to maximize the utilization of limited resources and available evidence in a given research setting. Their analytical structure allows a careful and fair review of the level of trust that can be put into the case study results. In other words, an explicit body of knowledge exists for a reader to determine the level of trust to be expressed in results that may have different values depending on the research settings [9].

Step 7: Testing for Threats to Validity and Assurance Case Representation. *Construct Validity.* The assurance case argument maintains an explicit chain of evidence from the original study question to any conclusions that are made. Such traceability enables a reviewer or participating SMEs to assess that correct operational measures have been chosen for the characteristics of the REM being studied.
External validity. This test for a case study is often addressed through replication logic in multiple case study design, which is outside our current scope.
Internal Validity. For explanatory type case study, an assurance case facilitates systematic review of the inferences being made about causality between the REM execution and the desired outcomes. During review, an assurance case improves the chance to detect if any factor contributing to the observed outcomes is missing.
Reliability. The assurance case outlines a repeatable protocol for case study execution and data analysis. When multiple investigators are involved, the assurance case can help to promote a common understanding regarding the research design.

3 Discussion and Future Work

The work presented here builds upon the goal-oriented case study research design for a newly invented software engineering methodology by Lee et al. [8]. Identifying the representational strengths of assurance cases for the early planning of case studies during REM invention, and evidence stratification to support logical argumentation

In Proceedings of the Requirements Engineering: Foundation for Software Quality, REFSQ 2009,
15th International Working Conference, Amsterdam, The Netherlands, June 8-9, 2009.
Lecture Notes in Computer Science, LNCS 5512, pp. 190-196, Springer.

are the novel ideas contributed through this work. In the footsteps of other goal-driven approaches such as GQM [2], our selection of the assurance case notation puts equal emphasis on structured logical argumentation and planned evidence collection, which are both important elements of a case study to draw analytical generalizations. In contrast to the goal/claim, argument, and evidence structure of assurance cases, theory diagrams [1] use action-oriented structure of precondition, actions, results, and effects to model theories. In both cases, the objective is to increase reviewability through a defined logic, linking the theoretical propositions to the observed phenomena.

Our exploration of the case study design possibilities here is by no means complete. Many subtleties will emerge as the approach outlined in this paper is employed across cases and their results are reported. Our approach is intended to provide a structured capability for tracing the usages, acceptance, and feasibility of a newly invented REM based on defined data collection and analysis strategy over a period of time across multiple cases and in different domains. We hope that early adoption of this strategy, while a new REM is being developed, will reduce the gap between constructive and empirical research approaches.

An important aspect of our future work includes the codification of case study design approaches. Unlike other research strategies, a comprehensive catalog of research designs for case studies does not exist [12]. Assurance case patterns [6] provide a promising direction for codifying different case study designs to be used in requirements and software engineering methodology validation. Well-codified research designs will guide the selection of cases and units of analysis that are similar to previous works in the literature and provide points of comparison. This form of case study design is highly encouraged in social sciences.

References

1. Axelsson, K., Goldkuhl, G.: Theory Modelling - Action Focus when Building a Multi-Grounded Theory. In: 3rd Euro. Conf. on Research Methods in Buss. & Mgmt. (2004)
2. Basili, V.R., Caldiera, G., Rombach, H.D.: The Goal Question Metric Approach. (1994)
3. Bloom, B.S., Krathwohl, D.R.: Taxonomy of educational objectives: The classification of educational goals. Handbook 1: Cognitive domain, New York, Longmans (1956)
4. Breaux, T., Anton, A., Dorfman, B.: Legal Requirements, Compliance and Practice: An Industry Case Study in Accessibility. In: 16th IEEE Req. Engg. Conf., Spain (2006)
5. Flyvbjerg, B.; Five Misunderstandings about Case Study Research. Qualitative Research Practice, Thousand Oaks, Sage Publications, pp. 420--434 (2004)
6. Goodenough, J., Lipson, H., Weinstock, C.: Arguing Security - Creating Security Assurance Cases. Technical Report, Software Engineering Institute (2007)
7. Kelly, T.P., Weaver, R.A.: The Goal Structuring Notation: A Safety Argument Notation. In: DSN Workshop on Assurance Cases. Florence, Italy (2004)
8. Lee, S.W., Rine, D.C.: Case Study Methodology Designed Research in Software Engineering Methodology Validation," In: 16th SEKE Conf., Canada, pp. 117--122 (2004)
9. Shaw, M.: The coming-of-age of software architecture research. In: 23rd International Conference on Software Engineering, Toronto, Canada, pp. 657--664 (2001)
10. Sim, S.E, Perry, D.E., Easterbrook, S., Aranda, J.: Case Studies for Software Engineers. In: the 28th International Conf. on Software Engineering, Tutorial, China (2006)
11. Wasson, K.S.: A Case Study in Systematic Improvement of Language for Requirements. In: 14th IEEE International Requirements Engineering Conference, pp. 6--15 (2006)
12. Yin, R. K.: Case Study Research: Design and Methods. 2nd Edition, Thousand Oaks: Sage Publications, Applied Social Research Methods Series, vol. 5 (1994)