Aalto University
School of Science and Technology
Faculty of Information and Natural Sciences
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Timo Lehtinen

Development and Evaluation of an Efficient Method for Software Engineering Root Cause Analysis

Master's Thesis

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Supervisor: Professor Casper Lassenius

Instructor: Jari Vanhanen, Lic. Sc. (Tech)

Aalto University
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Aalto University School of Science and Technology Faculty of Information and Natural Sciences Degree programme of Computer Science and Engineering	ABSTRACT OF THE MASTER'S THESIS

Author: Timo Lehtinen

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Supervisor: Casper Lassenius, Professor
Instructor: Jari Vanhanen, Lic. Sc.(Tech)

Abstract:
Software companies face problems in software development. This has consequences that motivate the companies to develop corrective actions to avoid the reoccurrence of the problems. It is argued that the key for effective problem prevention is to know why a problem occurred. Root cause analysis (RCA) is a structured investigation of a problem to identify which underlying causes need to be fixed.

The goal of the research was to develop, evaluate and further develop an RCA method (ARCA), which is appropriate for software companies. The research consisted of a literature review, development work of the ARCA method, and four industrial cases where the ARCA method was applied to problems of the case companies. Through the literature review different RCA applications were analyzed and commonly recommended RCA practices were recognized. These were exploited when the first version of the ARCA method was developed. The cases enabled researchers to collect feedback. Evaluating the feedback helped in developing the method further.

The ARCA method includes four steps: Problem Detection, Root Cause Detection, Corrective Action Innovation, and Documentation of the Results. Problem Detection consists of selecting a target problem and collecting its preliminary causes. Root Cause Detection consists of a workshop session where the causes of the target problem are detected, analyzed and organized into a cause-effect diagram. Corrective Action Innovation consists of a workshop session, which is focused on developing corrective actions for the most important causes. Documentation of the Results consists of documenting the detected causes and corrective actions. The ARCA method is performed by an RCA team which is lead by an RCA facilitator. The team consists of target problem experts including project managers, product managers, developers, and testers. The team members are selected for both workshop sessions separately, because they might require different expertise.

The ARCA method is an efficient RCA method for corrective action development in software companies. The method helped develop many corrective actions which were believed to be feasible with considerable impact on eliminating the target problem. Organizing the detected causes was experienced as challenging. We assume that this was caused by the high number of detected causes. On the other hand, the ARCA method was experienced as easy to learn and use in general, and as a better method for problem prevention than the current state-of-practices in the case companies. The success factors of the ARCA method were: 1. collecting and analyzing target problem causes, and 2. developing corrective actions by writing them on paper and rotating them through the RCA team members. The effort of applying the ARCA method was experienced as proper or slightly too high. This was caused by a high number of RCA team members. The greatest challenges of the method are facilitating the cause organizing task and lowering the required effort.

Keywords: Root Cause Analysis, Root Cause Analysis Method, RCA, RCA method, DCA, Defect Causal Analysis, problem prevention, corrective action development, quality assurance, software quality

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Työn ohjaaja: Jari Vanhanen, Lic. Sc.(Tech)		

Tiivistelmä:
Ohjelmistoyritykset kohtaavat ongelmia kehitystyössä. Niiden seuraukset motivoivat yrityksiä kehittämään korjaavia toimenpiteitä, joilla ongelmien toistuminen pyritään välttämään. Väitetään, että ongelman syiden selvittäminen on avaintekijä tehokkaiden korjaavien toimenpiteiden kehittämisessä. Juurisyyanalyysi (RCA) on rakenteellinen selvitystyö, joka pyrkii tunnistamaan ongelman piilevät syyt, jotka vaativat korjauksia.

Tämän tutkimuksen tavoitteena oli kehittää, evaluoida ja jatkokehittää RCA-menetelmä (ARCA), joka soveltuu ohjelmistoyrityksien tarpeisiin. Tutkimus koostui kirjallisuuskatsauksesta, ARCA-menetelmän kehitystyöstä, sekä neljästä teollisesta käyttötapauksesta, joissa menetelmää sovellettiin kohdeyrityksien kohtaamiin ongelmiin. Menetelmän ensimmäinen versio pohjautui kirjallisuuteen. Kirjallisuuskatsauksen avulla analysoitiin erilaisia RCA-sovelluksia ja tunnistettiin yleisesti suositeltuja RCA-käytäntöjä, joita ARCA-menetelmässä hyödynnetään. Käyttötapauksien avulla kerättiin palautetta, jonka evaluointi auttoi menetelmän jatkokehittämisessä.

ARCA-menetelmä koostuu neljästä vaiheesta: Ongelman tunnistaminen, Juurisyyn tunnistaminen, Korjaavan toimenpiteen innovointi ja Tuloksien dokumentointi. Ongelman tunnistaminen sisältää kohdeongelman valinnan ja sen alustavien syiden keräämisen. Juurisyyn tunnistaminen koostuu työpajasta, jossa havaitaan ja analysoidaan kohdeongelman syyt, jotka organisoidaan syy-seuraus-diagrammiin. Korjaavan toimenpiteen innovointi koostuu työpajasta, joka keskittyy vakavimpien syiden korjaavien toimenpiteiden kehittämiseen. Tuloksien dokumentointi koostuu havaittujen syiden ja korjaavien toimenpiteiden dokumentoinnista. ARCA-menetelmä suoritetaan RCA-ryhmällä, jota RCA-vastaava johtaa. Ryhmä koostuu kohdeongelman asiantuntijoista, kuten projektipäälliköistä, tuotepäälliköistä, kehittäjistä ja testaajista. Ryhmän jäsenet valitaan molempiin työpajoihin erikseen, koska ne saattavat vaatia erilaista osaamista.

ARCA-menetelmä on tehokas RCA-menetelmä korjaavien toimenpiteiden kehittämiseen ohjelmistoyrityksissä. Menetelmä auttoi kehittämään useita korjaavia toimenpiteitä, joiden uskottiin olevan toteuttamiskelpoisia ja merkittäviä kohdeongelman poistamiseksi. Syiden organisointi koettiin haastavaksi, mikä suurelta osin johtui niiden korkeasta lukumäärästä. Toisaalta ARCA-menetelmä koettiin helppokäyttöiseksi ja paremmaksi menetelmäksi ongelmanehkäisyyn kuin yrityksien nykyisin käytössä olevat menetelmät. ARCA-menetelmän avaintekijät ovat: 1. kohdeongelman syiden keruu ja analysointi ja 2. korjaavien toimenpiteiden kirjoittaminen papereille ja niiden kierrättäminen RCA-ryhmän jäsenillä. Menetelmän käytöstä aiheutuvat kulut koettiin suurehkoiksi, mikä johtui pääasiassa suuresta osallistujamäärästä. Menetelmän merkittävimmät haasteet ovat syiden organisointityön yksinkertaistaminen ja vaaditun työpanoksen pienentäminen.

Avainsanat: Root Cause Analysis, Root Cause Analysis Method, RCA, RCA method, DCA, Defect Causal Analysis, problem prevention, corrective action development, quality assurance, software quality

Acknowledgements

Dear Reader, while looking at this text you may find only characters, but by looking beyond the characters you may find The lines. Once upon a time there was a boy who talked to God. God said: "*I have always walked beside you.*" The boy smiled and answered: "*I do remember the time when I struggled alone in a snowstorm, and there I saw only my footmarks.*" God answered: "*Yes, but that was the time when I carried you.*"

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I want to acknowledge our industrial partners and their particular representatives. You made it possible for us to collect feedback and empirical evidence through real-world cases. You believed in what we were doing and you were ready to undertake an important role in the cases as well. You had a major role in this tale.

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Finally thanks to you, Dear Reader, for taking the ideas and results of this work with you.

Please accept my apologies for any omissions. You truly carried me through this journey and I want to thank you all for it.

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Terminology and abbreviations

ARCA	The RCA method, which was developed in the research. It includes four steps: Problem Detection, Root Cause Detection, Corrective Action Innovation, and Documentation of the Results. It is conducted by a team which is lead by an RCA facilitator and followed by RCA team members. The method includes two workshop sessions.
Branch	A cause in a cause-effect diagram which is explained by a chain of causes.
Cause-effect diagram	A diagram of causes and their related effects.
Cause entity	A group of branches which result in a problem or a cause. An entity that is reasonable to process together.
Detected cause	A cause of an event that is recognized.
Parent cause	A cause which is explained by a cause in a cause-effect diagram.
RCA	Root cause analysis (RCA) is a structured investigation of a problem to identify which underlying causes need to be fixed
RCA facilitator	A person who leads an RCA team
RCA team member	A participant of an RCA team
Root cause	An underlying cause of an event for which effective corrective actions for preventing recurrences of the event can be generated.
Software development	Covers all the activities, practices, and other different aspects of development work that results in software.
Sub cause	A cause which explains a cause.

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1. Introduction

This research is made as a Master Thesis for Aalto University. The research has been conducted as a part of the Evidence-Based Software Quality: Practices and Assessment (ESPA) research project of the Software Business and Engineering Institute. The ESPA research project helps organizations choose the most suitable software quality practices in different contexts, thereby optimizing quality assurance costs and benefits. The project results include a goal and evidence-based method for quality practice selection and improvement, and an adaptive reference model for software testing. A contribution of this thesis is that it can be used to collect causes of quality problems and to develop corrective actions for them.

1.1 Background

Software companies face problems in software development. This has consequences that motivate the companies to develop corrective actions to avoid the reoccurrence of the problems. A trivial method for the corrective action development is brainstorming corrective actions for a problem without analyzing its causes. However, it is argued that the key for effective problem prevention is to know why a problem occurred (Rooney, Vanden Heuvel 2004). Root cause analysis (RCA) is a structured investigation of a problem to identify which underlying causes need to be fixed (Latino, Latino 2006 p. 18).

RCA has many strengths and weaknesses that are presented by different authors. RCA is claimed to be a low-cost and effective technique (Card 1998, Card 1993, Leszak, Perry & Stoll 2000), especially in identifying deficiencies and improvement areas (Leszak, Perry & Stoll 2000). The mean effort to fix a problem is reduced and problems are detected earlier (Leszak, Perry & Stoll 2000). The Computer Science Corporation performed RCA regularly during a period of two years and they estimated a 50 percent decrease in the error rates as a result (Card 1998). Lucent Technologies applied RCA and they estimated 53 percent savings in costs and a 24 percent increase in the productivity (Leszak, Perry & Stoll 2000).

On the other hand, RCA is akin to studying the ocean floor with a microscope (Grady 1996). This can be justified by that too many problem causes are detected (Jalote, Agrawal 2005) and that the causal analysis mechanism is qualitative and labor intensive (Grady 1996). Additionally, if wrong root causes are detected then wrong corrective actions will be developed (Rooney, Vanden Heuvel 2004). It is also argued that RCA can be seen as a "witch-hunting tool" that eventually may eliminate an employees' job (Latino, Latino 2006 p. 109).

In our interviews with our research project partners and companies, it became apparent that they did not have a lot of previous experience on using RCA in problem prevention. And where RCA had previously been used, the usage had not been according to recommendations, and its advantages had not become clearly evident. The strengths and weaknesses of RCA, already mentioned above, motivate to research RCA further. It would be interesting to find out what kind of an RCA process is efficient and how the claimed weaknesses of RCA could be simultaneously avoided.

1.2 Research Problem

The existing RCA studies in the software industry (Card 1998, Leszak, Perry & Stoll 2000, Jalote, Agrawal 2005) do not present detailed results on the required effort to conduct RCA. They don't present estimations of the quality of the output of the RCA applications either. Additionally, the studies don't compare an application of RCA to the current state-of-practices in the companies. Instead, the required effort to conduct RCA is presented as a proportion of an annual budget (Card 1998, Leszak, Perry & Stoll 2000) and the quality of the output is presented as a change in defect rates (Card 1998, Leszak, Perry & Stoll 2000, Jalote, Agrawal 2005). These in turn leave blind spots in the literature. How much effort is required to conduct an individual RCA case in general? What is the quality of a corrective action developed by using an RCA based method? Is an RCA based method for problem prevention worthwhile if compared to a method where the corrective actions are developed without analyzing the causes of the problem?

1.3 Scope of Thesis

The scope of this thesis was to study the application of RCA in the context of preventing problems faced in software development. Based on our interest to understand the quality of RCA based corrective actions and required effort to perform RCA in detail, it was decided that the identification of target problem causes were to be conducted by using RCA practices.

We developed an RCA method, which includes detection of a target problem, identifying the target problem causes and developing corrective actions for them. The method was evaluated and further developed by applying it in four software companies. The evaluation and further development were based on estimations and opinions of representatives of the case companies and observations made by the researchers. Implementation and validation of the actual improvements were not included in the research, because the corrective actions were not implemented during the study. Consequently, the ARCA method doesn't include a step where the corrective actions are implemented.

1.4 Research Objectives

The goal of the research was to:

1. Develop an RCA method (ARCA), which is appropriate for software companies
2. Evaluate the method through four industrial cases
3. Further develop the method based on the evaluations

The requirements for the method were that it is easy to learn and use, and that it is a cost effective way to develop corrective actions for a target problem in software companies.

1.5 Research Questions

Based on the research objectives presented in the previous section and the research problem presented in Section 1.2, the research questions below present the perspectives from which the method was evaluated and further developed.

RQ1: Does the ARCA method generate corrective actions which are feasible and which have a significant impact on a target problem?

Because this question can't directly be measured in the scope of this thesis it is evaluated by using indirect indicators. The research question is divided into four aspects:

1. Were the detected causes correct with respect to the target problem?
2. Were the most important root causes processed?
3. Were the corrective actions experienced feasible with significant impact on the target problem?
4. What proportion of the detected problem causes did the processed root causes cover?

RQ2: How much effort is required to conduct the ARCA method?

This question is analyzed by presenting how much effort was used in different activities of the cases.

RQ3: Is the ARCA method easy to learn and use?

Generally the ARCA method should be easy to learn, and there should not be anything difficult while using it either. This question is divided into:

1. How did the RCA facilitators of the case companies experience the ARCA method in general?
2. How did the RCA team members of the cases experience the individual activities of the ARCA method?

RQ4: Is the ARCA method a feasible method for problem prevention, if compared to the current state-of-practices in the case companies?

This question is approached through the following questions:

1. How did the RCA team members experience the ARCA method in contrast to the current practices of the case companies?
2. How did the RCA facilitators of the case companies experience the ARCA method in contrast to other known methods?
3. How did the RCA facilitators of the case companies experience the value of the output of the ARCA method in contrast to the required effort?

RQ5: How could the ARCA method be improved?

The goal of this question is to challenge the latest version of the ARCA method by analyzing how it could be improved. The research question is divided into:

1. How could the ARCA method be improved with respect to corrective actions?
2. How could the required effort be lowered without lowering the quality of the corrective actions?
3. How could the ARCA method be improved to make it easier to use and learn?
4. How could the ARCA method be more useful for the companies?

The research questions support one another. RQ1 supports RQ4, because the higher the impact and the higher the feasibility of the corrective actions that the method generates, the more advantageous it is. RQ2 supports RQ4 by that the lower the required effort to conduct the method is, the more feasible it is. RQ3 supports RQ4, because the easier the method is to use and learn, the more usable it is. RQ3 supports also RQ2 by that the required effort is lower if the method is easy to learn and use. RQ5 supports all of the other research questions. Figure 1 summarizes the interdependencies between the research questions.

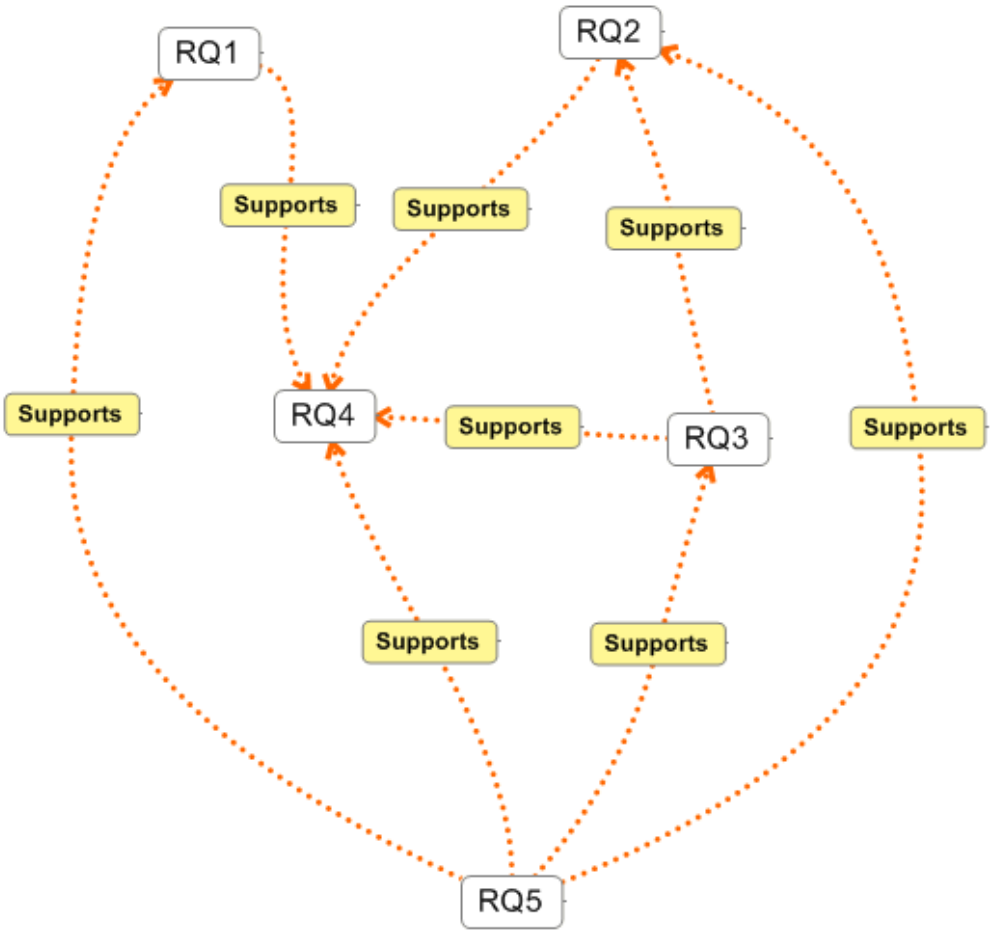

Figure 1: Interdependencies of the research questions

1.6 Structure of Thesis

This thesis is divided into nine chapters as presented below.

Chapter 1 gives an introduction to the study.

Chapter 2 is the methodological part. It presents the research framework and the practices used in the data collection and the analysis of the collected data.

Chapter 3 contains the literature review.

Chapter 4 presents the initial ARCA method and how it was developed. The development was conducted in three steps. The first step was to study how the other authors have applied RCA. The second step was to create a prototype of the ARCA method based on the literature. The third step was to conduct a pilot case with students to improve the prototype.

Chapter 5 presents the cases from three aspects:

1. Section 5.1 presents the target problems of the cases in general
2. Section 5.2 presents the RCA team members of the cases
3. Sections 5.3 to 5.6 present case overviews including:

    - A short company and case introduction
    - A description of how the case was planned to be conducted
    - A description of how the case was conducted
    - A summary of what was learned from the case

Chapter 6 evaluates the ARCA method by combining the data from the cases and analyzing the empirical evidence from them. The important data sources were interviews conducted with the RCA facilitators of the case companies (see Appendix A and Appendix B), feedback collected from the RCA team members (see Appendix C and Appendix D), and observations of the researchers from the cases.

Chapter 7 presents the improved ARCA method. The chapter also presents how the challenges in the method that were detected in the cases, are noted in the improved ARCA method.

Chapter 8 answers the research questions and evaluates the research.

Chapter 9 summarizes the study and discusses the future work related to RCA.

2. Research Methodology

This chapter presents the framework used in the research, and how the data was collected and analyzed.

2.1 Research Framework

This research was conducted by using the framework of Information System Research in Design Science, which covers development of theories and artifacts for industrial needs (Hevner et al. 2004, March, Smith 1995) (see Figure 2). The framework consists of the environment, the IS Research, and the knowledge base. The environment corresponds to sites where the theories and artifacts are needed. The knowledge base provides applicable knowledge for IS Research to apply known foundations and methodologies into action. The IS Research consists of the actual development work of the artifact (the ARCA method).

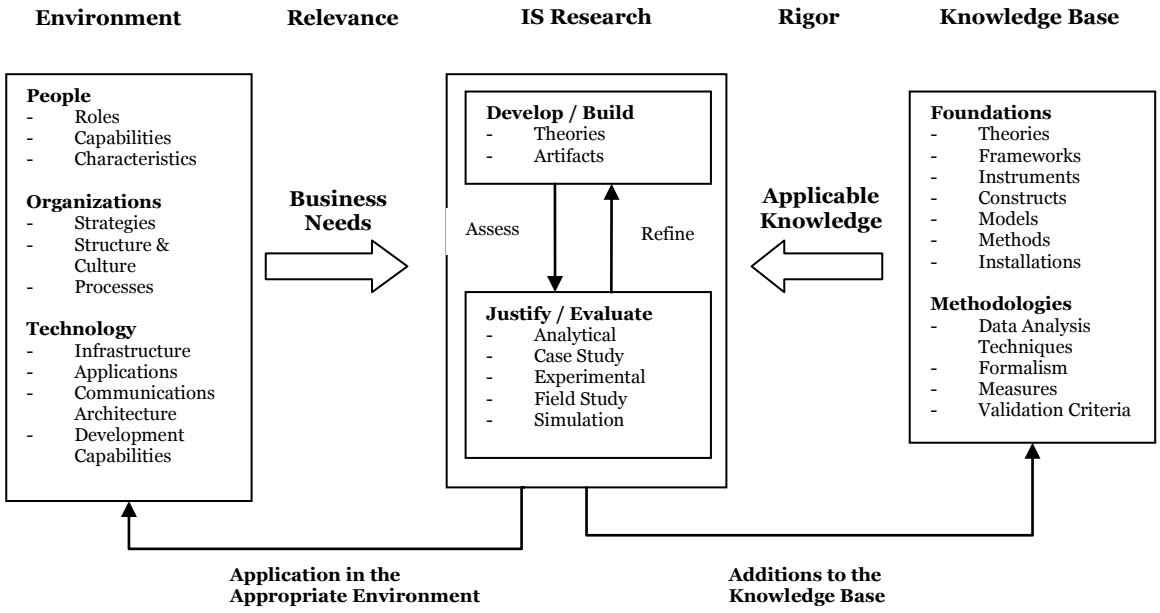

Figure 2: Framework for IS Research in Design Science (Hevner et al. 2004)

The environment was seen as a client system, consisting of people, organizations, and technology, connected together as a network of companies with a partnership in the research project ESPA. The common business needs for the companies was to find new practices to avoid a problem reoccurrence.

The knowledge Base was established by a literature review of relevant subjects, which were in general around RCA applications, RCA tools, RCA methods, and other RCA related perspectives (see Chapter 3).

The IS Research was conducted through field studies by using a research methodology similar with the experimental action research which is defined as a cyclical development of a client system infrastructure where researchers and client system's participants are both closely involved in action taking and evaluating the actions (Susman, Evered 1978). The

field studies were conducted as a series of cases by following the cyclical process of action research (Susman, Evered 1978, Järvinen 2007) with one cycle in each (see Figure 3).

The ARCA method was applied into a target problem chosen by the RCA facilitators of the case company who also selected the RCA team members. To avoid highly ambiguous cases the RCA facilitators were consulted to choose such a target problem and such RCA team members which create as similar and RCA friendly context as possible. Susman claims that the relationship between people, events, and things is a function of the situation (Susman, Evered 1978). The case context was divided into dimensions of people, events, things and company.

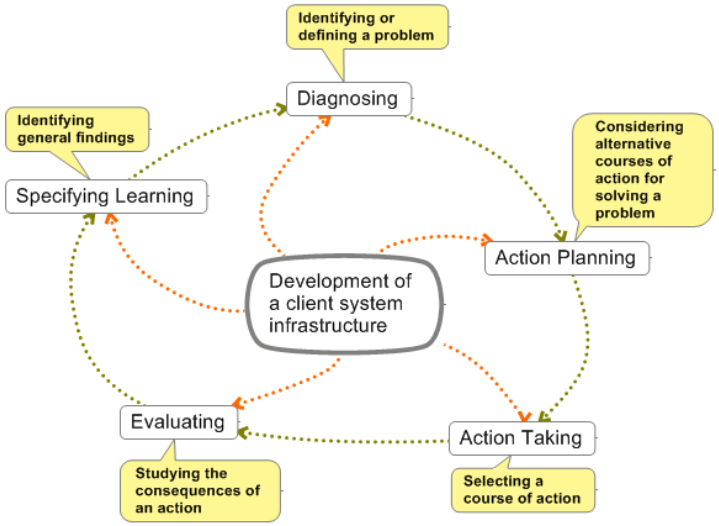

Figure 3: The cyclical process of action research

The study was conducted in the following order:

1. **Knowledge Base:** The literature review (see Chapter 3) provided a guide for generating possible courses of action (Susman, Evered 1978)
    - A prototype of the ARCA method was created based on the literature
    - The prototype was evaluated in a pilot case by the author of the Thesis and a team of six students who were chosen from Aalto University's software project course "*Software Development Project 1 & 2*" (T-76.4115 & T-76.5115)
    - Based on the evaluations, an initial ARCA method (see Chapter 4) was developed by improving the prototype

2. **Field Studies:** The cases (see Chapter 5) provided knowledge to generate a theory grounded in action (Susman, Evered 1978):
    - **Refinement:** Diagnosing and Action Planning before a case
        - The researchers made preliminary plans on how the case was to be conducted
        - The company's RCA facilitator(s) together with other representatives were interviewed before the case to finalize the case plans and to collect information about the case company

- **Action Taking:**
  - The researchers participated in the case as RCA facilitators
- **Assessment:** Evaluating and Specifying Learning after the case
  - The company's RCA facilitator(s) were interviewed to analyze their experiences
  - The collected feedback data from the RCA team members was analyzed
  - The researchers' observations were analyzed

3. **Evaluation of the ARCA method:** A general evaluation of the ARCA method (see Chapter 6) was conducted after all the cases were first performed. This was done by combining the data from the cases and analyzing the empirical evidence from them. The important data sources were interviews conducted by the RCA facilitators of the case companies (see Appendix A and Appendix B), feedback collected from the RCA team members (see Appendix C and Appendix D), and observations of the researchers from the cases.

4. **Further development of the ARCA method:** The further development of the ARCA method was conducted after the general evaluation of the method was done, as presented in Chapter 7.

2.2 Data Collection

This section presents how the data was collected.

Collecting the data was conducted by using the following principles (Yin 1994 p. 90, Runeson, Höst 2008):

1. To establish the construct validity and reliability, a triangulation of data, evaluators, perspectives, and methods should be used
2. An external database for collected data should be created to improve the organizing and documenting work of the study
3. The chains of evidence have to be maintained, so that the reader of the report can follow the derivation of any evidence from initial research questions to its ultimate conclusions

The triangulation of the data sources and methods (see Table 1) was conducted by using the following practices:

1. Performing Focused interviews (Yin 1994 p.84) with the RCA facilitator(s) and other representatives of the company
2. Collecting feedback from the RCA team members by using closed and open ended questions (Foddy 1994 p. 127)
3. Participant-Observation (Yin 1994 p. 87) by the researchers
4. Calculation of used effort
5. Calculation of intermediate results

Table 1: Data collection methods for the dimensions people, events, things, and company

Target dimension		Focused interview 1	Feedback Form 1	Participant-Observation	Feedback Form 2	Focused interview 2	Measurement
People	Satisfaction with communication climate	X	X				
	Satisfaction with superiors	X	X				
	Satisfaction with horizontal informal communication	X	X				
	Satisfaction with personal feedback	X	X				
	Openness in communication		X		X		
	RCA team member's roles in a company		X				
	RCA team member's personal contribution		X		X		
	Team size						X
Events	Challenges in the method		X	X	X	X	
	Easiness to use and learn the method		X	X	X	X	
	Feasibility of the method		X	X	X	X	
	Used effort						X
Things	Characteristics of the target problem	X	X				
	Correctness of the detected causes		X			X	
	The number of the detected causes						X
	Importance of the selected root causes				X		
	The number of the processed causes						X
	Feasibility of the corrective actions				X	X	X
	Impact of the corrective actions				X	X	X
	The number of the corrective actions						X
Company	Earlier experiences on the target problem	X	X				
	Current problem prevention practices	X					
	The number of the employees	X					

2.2.1 Focused Interviews

Focused interviews were held with the RCA facilitator(s) and other representatives of a company before and after a case by using premade questions with open ended form (see Appendix A and Appendix B). Similar protocol was used in each interview and the duration was not longer than 60 minutes, as Yin recommends (Yin 1994 p.85). Each interview was recorded.

The goal of Interview 1, which was performed before the case, was to get an overview of the case context. The questions were focused on the company in general to characterize its current problem prevention practices, its earlier experiences of RCA, its earlier effort used to prevent the target problem, its RCA team members' satisfaction in communication and skills, and the impact of the target problem for the company. Additionally, the interviewees were asked to estimate how the target problem could be best prevented.

The goal of Interview 2, which was performed after each case, was to evaluate the practices and results of the ARCA method. The interviewees were asked to evaluate the correctness of the detected root causes and overall quality of the corrective actions, to evaluate the

easiness to use and learn the ARCA method, and to evaluate the efficiency and feasibility of the ARCA method.

2.2.2 Feedback Forms

The ARCA method was conducted through two workshop sessions. The feedback was collected from the RCA team members after the first and after the second workshop session by using closed and open ended questions (Foddy 1994 p. 127). The feedback forms (see Appendix C and Appendix D) were developed iteratively through modifications and testing by using students as test persons.

The goals of Feedback Form 1, which was used after the first workshop session, were to collect information about roles of the RCA team members in the case company, their earlier experience on the target problem, the correctness of the detected causes in general, the RCA team members general opinions about the practices used to detect the causes and root causes, and the RCA team members opinions about openness in communication and level of personal contribution in the workshop session. To characterize the communicational differences of the cases, the RCA team members were also asked to answer 20 questions measuring their communication satisfaction of their company on following topics: *organization's communication climate, satisfaction on superiors, satisfaction on horizontal informal communication, and satisfaction on personal feedback*. The topics were part of a premade instrument developed to measure communication satisfaction (Downs, Hazen 1977). To spare effort only these four topics were used, since they were experienced the most relevant in RCA context.

The goals of Feedback Form 2, which was used after the second workshop session, were to collect general information about the importance and correctness of the selected root causes, to measure the openness of communication and the participants' personal contribution to the session, and to collect feedback about the practices used to develop corrective actions.

2.2.3 Participant-Observation

Two researchers participated in the cases. They acted in the role of the RCA facilitator together with the company's staff. The researchers made notes during the workshop sessions and after them they usually kept a feedback session together. Additionally, the workshop sessions were video recorded so that the researchers were able to backtrack to the details when needed.

The reasons for using the Participant-Observation technique were:

1. The researchers were able to direct the companies in using the ARCA method in a similar way which also helped in maintaining the comparability of the cases

2. The researchers were able to collect personal experience and observe the actions of the ARCA method

2.2.4 Used Effort

The used effort was recorded as man-hours. The duration of meetings and workshop sessions was timed. Additionally, the RCA facilitators and RCA team members of the companies were asked to estimate how much time they had personally used in other ARCA related activities. The time the researchers used as RCA facilitators was also recorded.

2.2.5 Intermediate Results

All of the detected, selected, and later processed causes were recorded by the researchers. A cause was recorded only once, thus if a cause was listed twice or more it wasn't recorded several times. However, this was done only in very explicit cases. All of the corrective actions were also recorded by the researchers and evaluated by the RCA team members.

2.3 Data Analysis

The goal of the data analysis was to find and generalize relationships between actions and their consequences (Susman, Evered 1978). Each case included different people and a different target problem, but the way the ARCA method was applied was mostly similar in each.

The data analysis was performed in two phases. First, after each case the collected data was analyzed to help understand the strengths and weaknesses of the ARCA method by using the cyclical process of action research (see Figure 3). Second, the general evaluation of the ARCA method was conducted by combining the empirical evidence from the cases.

It was mentioned in Section 2.1 that the case context was divided into four dimensions. The following list presents how these dimensions were taken into account in the data analysis.

- The dimension of *people* was analyzed from perspectives of communication environment, size of the ARCA team, the RCA team members' experience of the target problem, the RCA team members' personal contribution in the cases and their roles in the case companies

- The dimension of *events* was analyzed by focusing on practical challenges of the ARCA method detected by the observations and the feedback from the RCA team members

- The dimension of *things* was analyzed by focusing on the ARCA method's target problems, intermediate results, and corrective actions

- The dimension of *company* was analyzed by focusing on its earlier effort used to prevent the target problem and its current problem prevention practices

2.3.1 Case Analysis

After each case an analysis of the case was performed. The goal was to combine the collected data from the different sources and analyze it to understand what should be improved in the ARCA method. The case analysis was done in two phases. First, an assessment of the case was conducted. The assessment included evaluating the ARCA method used in the case and specifying the learning that was based on the evaluation (see Figure 3). Second, a refinement of the ARCA method was conducted before the next case. The refinement included diagnosing of the ARCA method and action planning of the next case (see Figure 3).

2.3.1.1 Assessment: Evaluating and Specifying Learning

The Participant-Observation data (see Section 2.2.3) was the major source of information for the analysis that was conducted between the cases. The researchers shared their experiences focusing on the strengths and weaknesses of the performed actions. The idea was to analyze if there was something inconvenient which had a negative impact on the required effort or on the output of the action, and vice versa.

The interview data (see Section 2.2.1) was analyzed by focusing on the strengths and weaknesses mentioned by an interviewee(s). This helped in understanding how the RCA facilitator(s) of the company experienced the ARCA method.

The feedback data (see Section 2.2.3) helped the researchers confirm the conclusions based on the Participant-Observation and on the focused interviews. The data was analyzed by studying the averages and deviations of the RCA team members' answers in a particular close ended question.

The analyses were finally connected by using an Excel sheet to make the ultimate conclusions of the case.

2.3.1.2 Refinement: Diagnosing and Action Planning

Diagnosing and Action Planning was conducted in two phases. First, the experience from previous cases was considered and practical difficulties were analyzed by the researchers to plan how to conduct the ARCA method in the next case. Second, the plan was presented to the company's RCA facilitator(s) and the other representatives of the next case to reconsider it together. Then the final plan for the case was made.

2.3.2 Evaluation of ARCA Method

Based on the research questions (see Section 1.5), the ARCA method was evaluated as cross-sections of the cases. The detected causes and developed corrective actions, the used effort to conduct, easiness to use and learn, and feasibility of the ARCA method for problem prevention were taken into account. The analysis was conducted by combining the case analyses and using the triangulation of the data sources when possible (see Section 2.2).

3. Literature Review

This section is the literature review of the thesis. The literature was collected by using search words ("*RCA, root cause analysis, DCA, defect cause analysis, defect analysis, defect prevention, and problem prevention*") in random search engines including Google and Scopus. The articles were selected if they covered an application of RCA or DCA.

The literature review was scoped by using seven research questions each focusing on the software industry. These are presented below:

LRQ1: What are the generic parts of all the RCA processes used in problem prevention? This is an important question, because it helps understand the most recommended parts in RCA processes.

LRQ2: What is required to adopt RCA? It is important to highlight the requirements of RCA, because the goal is to use RCA in the cases.

LRQ3: What sort of target problems can be analyzed by RCA? The goal of this question is to understand what sort of target problems can be analyzed so that the cases can be targeted right.

LRQ4: How has RCA been used to prevent problems? It is important to understand how RCA has been used in the software industry to develop the ARCA method as feasible for software companies as possible.

LRQ5: What sort of personnel should be included in RCA? The goal is to help the researchers and the RCA facilitators of the companies to organize fertile RCA teams in the cases.

LRQ6: What are the expected benefits of RCA? To motivate the case companies to use the ARCA method the researchers need to understand the benefits of RCA. Additionally, these can be compared to plausible benefits reached in the cases.

LRQ7: What are the expected challenges of RCA? Understanding potential flaws of RCA might help avoid them. Additionally, these can be compared to the potential challenges detected in the ARCA method.

3.1 RCA Definitions

This section presents how different authors have defined a root cause and root cause analysis.

3.1.1 Root Cause

Ammerman stresses that there are three different types of causes (Ammerman 1998 p. 64). First, *presumptive causes* may be apparent at the beginning of the investigation, and are more like hypotheses and need validation. Second, *contributing causes* are causes that alone would not have caused the problem but are important enough to be recognized as needing corrective actions to improve quality of a process or a product. And third, *root*

causes are the most basic reason for the problem, and if corrected, will prevent recurrence of that particular problem.

Rooney and Heuvel (Rooney, Vanden Heuvel 2004) define a root cause in the following way: 1. root causes are specific underlying causes, 2. root causes are those that can reasonably identified, 3. root causes are those management has control to fix, and 4. root causes are those for which effective recommendations for preventing recurrences can be generated.

Andersen and others present that for a visual problem there are always first level causes, higher level causes, and root causes. A root cause is "*the devil at the bottom*" manifesting many different symptoms through higher-level and first-level causes. Thus the visual problem is eventually a symptom of the root cause. (Andersen, Fagerhaug 2006 p. 5)

There are differences in the definitions. Ammerman and Andersen present that the root causes are causes which are in the end of the causal structure, but Rooney and Heuvel present that root causes are just underlying causes.

3.1.2 Root Cause Analysis

Rooney and Heuvel define that RCA is a technique which helps identify not only what and how an event occurred, but also why it happened (Rooney, Vanden Heuvel 2004).

Andersen and others present that: *"Root cause analysis is a structured investigation that aims to identify the true cause of a problem and the actions necessary to eliminate it."* (Andersen, Fagerhaug 2006 p. 12)

Latino and others present that: "*RCA is any structured approach to identifying the factors that influenced the consequences of one or more past events in order to identify what behaviors or conditions need to be changed to prevent recurrence of similar consequences, when adverse, and to identify the lessons to be learned to promote the achievement of better consequences.*" and "*RCA is any evidence-driven process that, at a minimum, uncovers underlying truths about past adverse events, thereby exposing opportunities for making lasting improvements.*" They stress that seeing RCA only as a use of tools like a fishbone diagram is definitely not RCA, because without hard evidence (written documents, security cameras, etc.), the people are only guessing the causes of the problem. Thus the corrective actions are based on hypotheses while they are handled as "facts". (Latino, Latino 2006 p. 20)

There seems to be no unique and commonly accepted definition for root cause analysis (Latino, Latino 2006 p.17, Andersen, Fagerhaug 2006 p.12). Several authors present RCA as a cause detection process only (Rooney, Vanden Heuvel 2004, Latino, Latino 2006 p. 10, Leszak, Perry & Stoll 2000, Ammerman 1998 p. 3), whereas some of the authors present RCA as a process including the development of corrective actions (Card 1998, Card 1993, Andersen, Fagerhaug 2006 p. 7, Björnson, Wang & Arisholm 2009, Stålhane 2004, Wikipedia 2009b). Usually the idea is to decrease the likelihood of some specific problem reoccurring (Rooney, Vanden Heuvel 2004, Card 1998, Card 1993, Leszak, Perry & Stoll 2000, Wikipedia 2009b).

3.2 RCA Targets

In practice, RCA is focused on an event or a class of events (Rooney, Vanden Heuvel 2004, Latino, Latino 2006 p. 210, Card 1998, Card 1993, Leszak, Perry & Stoll 2000, Grady 1996, Jalote, Agrawal 2005, Ammerman 1998 p. 3, Andersen, Fagerhaug 2006 p. 3, Kalinowski, Travassos & Card 2008). Usually the event is represented as "a problem", "a defect", or "an impact". However, depending on a case context, RCA targets vary. For example, RCA is used to detect causes of project experiences (Björnson, Wang & Arisholm 2009) and to distill textual raw data which is useful for requirements collection and knowledge elicitation (Jin et al. 2007).

RCA is classified into five broadly defined schools: *Safety-based, Production-based, Process-based, Failure-based, and System-based RCA* (Wikipedia 2009b). In the safety-based RCA, the focus is on accident analysis and occupational safety and health. The production-based RCA is based on quality control for industrial manufacturing, meanwhile the process-based RCA, expands the scope of the analyses to include business processes. The failure-based RCA has its roots in the practice of failure analysis. The system-based RCA is a combination of the preceding schools added with ideas from change management, risk management, and system analysis. Rooney and Heuvel (Rooney, Vanden Heuvel 2004) present RCA in the same way, whereas it is focused on safety, health, environmental, quality, reliability, or production impacts.

Latino and others present that there are two types of target events for RCA: chronic and sporadic events. Chronic events are not very dramatic when they occur, but they do happen over and over again. In the course of time they become a cost of doing business. Sporadic events are very important, massive in their nature, and rare to occur. RCA is applicable on both types of events, but chronic events are more advantageous to analyze than sporadic events. (Latino, Latino 2006 p. 45)

Andersen and others present that an RCA target problem is a state of difficulty that needs to be prevented. It can be divided into the following characteristics: 1. it represents a challenge that encourages solving to establish more desirable circumstances, and 2. it is a state of affairs plagued with some difficulty or undesirable status. (Andersen, Fagerhaug 2006 p. 2)

Ammerman defines an RCA target problem in the following way: 1. a deviation from a requirement or expectation, 2. an undesirable event, situation, or performance trend, and 3. is the primary effect which is critical for a situation to occur. (Ammerman 1998 p. 9)

As a summary, it seems to be that RCA can be targeted to any kind of a problem or other kinds of events. However, the most feasible targets are problems that create severe consequences.

3.3 RCA Requirements

Although RCA has relatively few pre-requirements, some aspects are important to be highlighted. First, to focus on a relevant and systematic event, a defined development process is required to provide a framework for less solitary and effective corrective actions (Card 1998, Kalinowski, Travassos & Card 2008). Second, if supposed to be focused on defects, there needs to be a way to detect and report them (Card 1998, Kalinowski,

Travassos & Card 2008, Burnstein 2003 p. 445), since without the defects there is no sense to analyze them either. Third, a root cause analyst must be a skilled interviewer and local expertise has to be available (Card 1998). Fourth, the atmosphere has to be one where people have a desire to avoid mistakes and negative feedback associated with the mistakes is seen from positive perspectives (Card 1998, Grady 1996). Fifth, the commitment of the managers to RCA is required (Burnstein 2003 p. 445). Other essential elements are action teams to implement and oversee the suggested process changes, a tracking system to monitor the process changes and provide feedback, and a technology transfer that will ensure that the defect prevention becomes a standard set of practices (Burnstein 2003 p. 445). These indicate the maturity of a software company, which is usually characterized by process improvement models (Burnstein 2003 p. 445). According to Burnstein, in many models (TMM, CMM, and CMMI-SE/SW) defect prevention and causal analysis belong to the most advantaged level (Burnstein 2003 p. 570). This doesn't mean that RCA couldn't be used if the level isn't reached, but an environment is more fertile for process optimization if there is an infrastructure in place consisting of policies, goals, staff, methods, tools, measurements, and organizational structures to support the program (Burnstein 2003 p. 445).

3.4 RCA Processes

This section introduces different RCA related processes used in problem prevention.

3.4.1 General RCA Processes

Andersen and others (Andersen, Fagerhaug 2006 p. 7) present a problem prevention process where RCA has taken place to detect and analyze root causes for any problem.

The process is presented in 7 steps:

1. **Problem Understanding**

   The authors emphasize that effort can be saved by giving a fertile focus for RCA. This is best done by understanding how the target problem occurred (Andersen, Fagerhaug 2006 p. 22).

2. **Problem Cause Brainstorming**

   The idea in this step is to detect the most potential cause candidates (Andersen, Fagerhaug 2006 p. 44).

3. **Problem Cause Data Collection**

   This step is about collecting real evidence on the target problem, since it is important to base the analysis around facts and insights, rather than guesses (Andersen, Fagerhaug 2006 p. 70).

4. **Problem Cause Data Analysis**

   The cause candidates are clarified by creating a clear connection between the target problem and its causes (Andersen, Fagerhaug 2006 p. 86).

5. **Root Cause Identification**

   In this step, the root causes of the target problem are detected. In terms of duration and complexity this is the most difficult or the most long-lasting step in the process. However, by doing the antecedent phases thoroughly the step can normally be proceeded quickly. (Andersen, Fagerhaug 2006 p. 118)

6. **Problem Elimination**

   This step is about developing corrective actions for the detected root causes (Andersen, Fagerhaug 2006 p. 141).

7. **Solution Implementation**

   The solution implementation step consists of organizing the implementation work, developing an implementation plan, creating acceptance of the required changes and a favorable climate for the implementation, and carrying out the implementation itself (Andersen, Fagerhaug 2006 p. 158).

Another RCA based problem prevention process model is presented by Rooney and Heuvel (Rooney, Vanden Heuvel 2004). In the process the focus is a single problem.

The process consists of four steps:

1. **Data Collection**

   The step is about gathering target problem related data.

2. **Causal Factor Charting**

   The data collected in the first step is organized and analyzed. Causal factor charting provides a way to structure the data, which helps investigators recognize "*causal factors*" which are seen as the most potential causes of the target problem. The preparation of the chart should start immediately after the investigators start to collect information of the target problem.

3. **Root Cause Identification**

   After the causal factors are recognized the identification of root causes can begin. Using a premade map of root causes is recommended to understand why particular causal factors occur. Every causal factor has a unique place in the map, which is basically a list of potential root causes in a tree structure. The map includes a class "*other*" for unclassified causal factors.

4. **Recommendation Generation and Implementation**

   The authors do not present how the recommendations should be carried out and implemented, but they emphasis that if left without attention all the effort goes down the drain.

3.4.2 Problem Identification and Correction (PIC)

Ammerman (Ammerman 1998) presents an RCA process named as PIC (Problem Identification and Correction).

The PIC process consists of 8 steps:

1. **Problem Definition and Data Collection**

   To conduct an accurate and efficient analysis the problem needs to be first defined, which is followed by collecting the problem related data. The step consists of defining a starting point by identifying what, who, when, where, and how. (Ammerman 1998 p. 9)

2. **Task Analysis** (optional)

   Task analysis is conducted to understand where the pitfalls are within the task under evaluation. This will help find out what was assumed to happen, not exactly what happened. (Ammerman 1998 p. 19)

3. **Change Analysis** (optional)

   Change analysis is about understanding what actually happened and what was expected to happen. This can be done by comparing an activity that was successfully performed to an activity that was unsuccessfully performed. (Ammerman 1998 p. 27)

4. **Control Barrier Analysis** (optional)

   Control barrier analysis is a technique in which the focus is on an activity or a process to recognize where physical or administrative barriers are needed to prevent unwanted actions. The technique helps understand where the barriers are either missing or ineffective. (Ammerman 1998 p. 31)

5. **Event and Causal Factor Charting**

   Based on causal factor categories, this step is about creating a flow chart that graphically displays an entire event. (Ammerman 1998 p. 37)

6. **Root Cause Determination**

   Root cause determination is about determining the root causes of the event. The determination should be done in a systematic way and supported by visual tools like lists, worksheets and charts. (Ammerman 1998 p. 63)

7. **Corrective Action Development**

   This step is about identification, development, and evaluation of corrective actions required in preventing the problem recurrence, or exceedingly reducing its likelihood. In the identification, causal factor categories and control barriers should be considered. In the evaluation, three aspects are important to highlight: 1. impact on resources,

2. impact on schedules, and 3. impact on regulatory commitments. The development is best done by using the following steps:

1. Formulate alternative corrective action(s) for each root cause
2. Formulate alternative corrective action(s) for selected contributing causes
3. Evaluate alternative corrective action(s)
4. Select recommended corrective action(s)

(Ammerman 1998 p. 72)

8. **Report Conclusions**

   All the intermediate results and recommended corrective actions are documented. (Ammerman 1998 p.79)

3.4.3 PROACT RCA

Latino and others (Latino, Latino 2006 p. 10) introduce an RCA process named as PROACT. The authors stress that the RCA effort should be rather focused on "significant few" than by looking all of the failures equally.

The PROACT process consists of 4 steps:

1. **Opportunity Analysis**

   Opportunity analysis is about sampling failures and classifying them to detect the most potential targets for RCA. Sampling and classification is then combined with a Pareto Analysis (see Section 3.5.2), thereafter the most significant types of problems are detected. (Latino, Latino 2006 p. 51)

2. **Data Analysis**

   In this step, cause-and-effect relationships are detected and structured by using a logic tree which is a combination of a logic diagram and a fault tree (Latino, Latino 2006 p. 117). The idea is to find root causes for a problem or a problem class, by listing and structuring hypothetic causes and either proving or disproving the causes with hard data (Latino, Latino 2006 p. 139).

3. **Developing Recommendations**

   The next step is to decide acceptance criteria for recommendations. Thereafter the recommendations are developed for the root causes. (Latino, Latino 2006 p. 139)

4. **Reporting**

   All the findings and recommendations, including failures, root causes, and recommendations, are documented. (Latino, Latino 2006 p. 141)

3.4.4 Defect Causal Analysis

Defect-Causal Analysis (DCA) was originally developed by IBM, and has later been used by other companies like Bellcore, Computer Sciences Corp., Boeing, Hewlett-Packard, and others (Card 1993). The goal in DCA is to prevent software defects by learning from actual defect data (Jalote, Agrawal 2005). DCA is conducted by a Causal Analysis Team consisting of a facilitator and participants (Card 1993, Grady 1996), or as Burnstein recommends, by using a separated causal analysis group and an action planning/tracking team (Burnstein 2003 p. 450).

Different variations of DCA process have been presented (Card 1998, Leszak, Perry & Stoll 2000, Grady 1996, Jalote, Agrawal 2005, Kalinowski, Travassos & Card 2008, Burnstein 2003, Al-Mamory, Zhang 2009).

Usually DCA is applied by using the following process (Card 1998):

1. **Select Problem Sample**

   The idea in this step is to sample defects to explore those that occur most frequently and have the most negative impact on the quality of the software (Card 1998, Leszak, Perry & Stoll 2000, Grady 1996, Jalote, Agrawal 2005, Kalinowski, Travassos & Card 2008, Burnstein 2003 p. 447). The defects should be as representative of the team's work as possible (Card 1998). The sample should not be restricted to high-priority defects (Card 1998), because other defect selection criteria, like location of the defects, serve DCA better (Kalinowski, Travassos & Card 2008).

2. **Classify Selected Problems**

   Clusters of systematic defects are identified by classifying the sample (Card 1998, Leszak, Perry & Stoll 2000, Grady 1996, Jalote, Agrawal 2005, Kalinowski, Travassos & Card 2008, Burnstein 2003 p. 447). The classification should be done by using a predefined classification scheme, for example: 1. Interface, Data, Logic, Initialization, and Computation (Card 1998); 2. Implementation, Interface, and External (Leszak, Perry & Stoll 2000); 3. Logic, Standards, Redundant Code, UI, and Architecture (Jalote, Agrawal 2005); or 4. Control and logic, Algorithmic, Typographical, Initialization, Data flow, Module interface, and External hardware-software interface (Burnstein 2003 p. 448).

3. **Identify Systematic Errors**

   Systematic errors are usually associated with a specific activity or part of the product (Card 1998). Usually the Pareto Analysis (see Section 3.5.2) is used to show the frequency of defect occurrence of defect classes (Card 1998, Jalote, Agrawal 2005, Kalinowski, Travassos & Card 2008, Burnstein 2003 p. 447). The greatest attention should be focused on the defect classes containing the greatest amount of defects (Card 1998, Burnstein 2003 p. 447). The moment of the defect introduction and detection, should be considered as well (Leszak, Perry & Stoll 2000, Kalinowski, Travassos & Card 2008).

4. **Determine Principal Cause**

   Usually it is not economical to address all the factors contributing to a systematic error, so attention should be focused on the principal cause (Card 1998, Grady 1996). If the principal cause is not obvious from the problem statement, it should be drawn out by using a cause-effect diagram (see Section 3.5.3) (Card 1998, Grady 1996, Jalote, Agrawal 2005, Kalinowski, Travassos & Card 2008, Burnstein 2003 p. 452). The cause-effect diagram should be organized under predefined defect categories, for example: 1. Methods, Tools and Environment, People, and Input and Requirements (Card 1998); 2. Process, People, and Technology (Jalote, Agrawal 2005); or 3. Requirements & Specification, Design, Coding, and Testing (Burnstein 2003 p. 450 and 45).

5. **Develop Action Proposals**

   Corrective actions are developed to either detect systematic defects earlier or prevent them (Card 1998, Leszak, Perry & Stoll 2000, Grady 1996, Grady 1996, Jalote, Agrawal 2005). The corrective actions are related to the principal causes and are usually focused on improving education, communication, review and/or management practices (Burnstein 2003 p. 452). Typically 10 to 15 principal causes result in 15 to 25 corrective actions (Burnstein 2003 p. 452).

6. **Document Results**

   All the results, including principal causes and corrective actions, are recorded (Card 1998, Jalote, Agrawal 2005). The document should also include the Pareto Analysis and cause-effect diagrams (Burnstein 2003 p. 453).

3.4.5 Summary

There are many different RCA related processes used in problem prevention, like PIC, PROACT, and DCA. The major differences between the processes are mainly in recommended practices. On the other hand, the processes have many similarities. First, each process includes an activity where an initial target event for RCA is defined. Second, each process includes an activity where information of the target event is gathered. Third, based on the gathered information, each process includes an activity where focus of RCA is sharpened. Fourth, each process includes an activity where causes of the target event is gathered and organized. Fifth, each process includes an activity where the most important causes are detected. And sixth, corrective actions are developed for some of the most important causes. These similarities are presented in Figure 4 as a general RCA process.

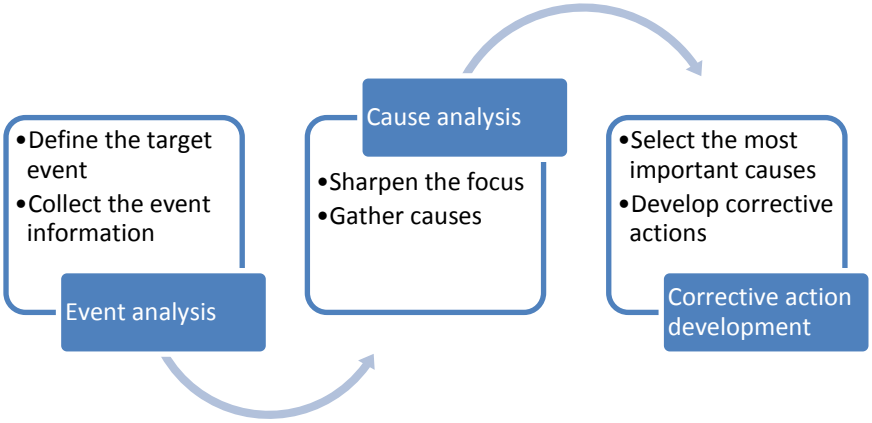

Figure 4: The general RCA process

3.5 RCA Practices

This section presents different RCA practices. These are presented as multipurpose-practices and practices following the general RCA process, as presented in Figure 4.

3.5.1 Multipurpose-Practices

Interviewing can be used in RCA to collect event and cause data from individuals separately. Ammerman (Ammerman 1998 p. 49) emphasizes that interviews are performed through RCA process and they should be designed for two types of interviewees: persons who are not directly involved in an event (as an example a senior in the chain of command), and persons who are directly involved in the event. The questions should be different depending on the type of the interviewee. Rooney and Heuvel emphasize that the analyst should ask open-ended questions and follow up with more detailed questions (Rooney, Vanden Hauvel 2003). This kind of an interviewing technique is also called "laddering" (Wikipedia 2009a, UX matters 2009), where the idea is similar compared to Five Why (see Section 3.5.3).

Questionnaire can be used to collect data about people's attitudes, feelings, or opinions (Andersen, Fagerhaug 2006 p. 75). The use of questionnaires is claimed to be the basis for identifying errors and defects. However, problems associated with the variability of the way the questionnaire forms are filled will make the data less reliable (Burr, Owen 1996 p. 234).

Brainstorming is a formal approach that can be applied throughout RCA when multiple ideas are required (Andersen, Fagerhaug 2006 p. 16). It is a creative and innovative way to develop as many good ideas as possible related to a given subject (Andersen, Fagerhaug 2006 p. 45). In brainstorming the participants work in a face to face manner. It's applications in RCA are in event analysis (Andersen, Fagerhaug 2006 p. 45), cause collection (Andersen, Fagerhaug 2006 p. 45, Burr, Owen 1996 p. 220), and corrective action development (Latino, Latino 2006 p. 14, Andersen, Fagerhaug 2006 p. 45). Brainstorming can be either *structured*, where each participant in turn launches one idea, or *unstructured*, where everyone can freely launch ideas (Andersen, Fagerhaug 2006 p. 45). Different variations are: nominal group technique, group passing technique, team idea mapping method, electronic brainstorming, directed brainstorming, individual

brainstorming, and question brainstorming (Wikipedia 2010). It is claimed that in most brainstorming sessions the group presents a variety of ideas but sometimes they lack the data to verify that the solution will work (Latino, Latino 2006 p. 14). Additionally, tacit persons might not be heard because of more noisy persons dictating the discussion (Andersen, Fagerhaug 2006 p. 49). Brainstorming is also claimed to be less efficient than individuals working independently (Wikipedia 2010).

Brainwriting is basically a written brainstorming session (Andersen, Fagerhaug 2006 p. 16). It is especially applicable when complex ideas are expected, or it is likely that some people might dominate the discussion if brainstorming was to be used (Andersen, Fagerhaug 2006 p. 49). Brainwriting is conducted by using either a gallery method or a card method (Andersen, Fagerhaug 2006 p. 50). In the gallery method, ideas are written on a number of whiteboards or flip charts and the participants circulate among them, adding related ideas or expanding on the existing ones. In the card method, ideas are written on small cards and circulated among the participants, who add related ideas or expand on the existing ones. Brainwriting has a couple of advantages compared to brainstorming: everyone has better access to the process, participants can describe more detailed and coherent ideas, and it is possible to protect the anonymity of the participants (Andersen, Fagerhaug 2006 p. 49).

3.5.2 Event Analysis Practices

This section presents practices used to analyze target events of RCA. These are needed to focus RCA effort into the most suitable event. Without complete information and understanding of the event, the causalities and root causes associated with the event cannot be identified (Rooney, Vanden Heuvel 2004). The initial event data can be either a sample of records, written evidence from documentation, interviews with witnesses, or any other sources which help to discover intangible and tangible conditions around the event (Rooney, Vanden Hauvel 2003). Rooney and Heuvel (Rooney, Vanden Hauvel 2003) present four different sources for the event data: *People* which are witnesses and participants, *Physical* which refers to the parts and samples, *Paper* which focuses on hard copies and electronic records, and *Position* which is about location of people and physical evidence. Data gathering should begin as soon as possible after an event occurs to prevent loss or alteration of the data (Rooney, Vanden Heuvel 2004, Rooney, Vanden Hauvel 2003).

Sampling (Latino, Latino 2006 p. 51) is a widely used practice in RCA, especially in the DCA processes, as presented in Section 3.4.4 (Card 1998, Leszak, Perry & Stoll 2000, Grady 1996, Jalote, Agrawal 2005, Kalinowski, Travassos & Card 2008). Sampling is used to surmise data on a large population by collecting only a small sample (Andersen, Fagerhaug 2006 p. 16). In most applications of RCA in the software industry, Sampling is combined with the Pareto Analysis (Card 1998, Card 1993, Leszak, Perry & Stoll 2000, Jalote, Agrawal 2005, Stålhane 2004, Kalinowski, Travassos & Card 2008).

Pareto Analysis is used in RCA to give a direct focus on a cause collection (see Sections 3.4.3 and 3.4.4). It is a task of ranking events in order of frequency of occurrence, importance, or cost (Burr, Owen 1996 p. 218, Stevenson 2005 p. 407). It helps to identify clusters in which systematic errors are likely to be found (Card 1998, Jalote, Agrawal 2005, Stevenson 2005 p. 407). The Pareto principle states that 80 percent of effects are the result of 20 percent of items (Andersen, Fagerhaug 2006 p. 92, Stevenson 2005 p. 407). It is also

expressed as 80 percent of problems can be fixed with 20 percent of the effort (Burnstein 2003 p. 447).

A flowchart is a visual representation of a process (Stevenson 2005 p. 407). In RCA it is used to draw out a process where an event has occurred (Andersen, Fagerhaug 2006 p. 32).

A check sheet is a tool frequently used for problem identification and it can be used in different formats, for example, to deal with type and location of defects (Stevenson 2005 p. 407). In RCA its main purpose is to ensure that all the data is registered correctly, and its main applications include registering of how often different problems occur and registering a frequency of incidents that are believed to cause problems (Andersen, Fagerhaug 2006 p. 79).

A critical incident is about understanding what the most troublesome symptoms in a problematic situation really are (Andersen, Fagerhaug 2006 p. 27).

A spider chart is used to understand RCA target problem from an external viewpoint. It is used to determine which problem is the most critical and compare the seriousness of problems and causes. (Andersen, Fagerhaug 2006 p. 31)

A performance matrix is used to illustrate performance and importance of its attributes simultaneously, helping to set priorities between them, thus helping to decide which aspect of RCA target problem is the most important to attack and which causes will give the most relief if removed. (Andersen, Fagerhaug 2006 p. 36)

Is - Is not matrices are used to understand plausible problem causes and identify issues that are definitely not related to RCA target problem. (Andersen, Fagerhaug 2006 p. 53)

3.5.3 Cause Analysis Practices

This section presents practices used in RCA to analyze cause-effect relationships of an event.

A fishbone diagram is commonly used in RCA (Andersen, Fagerhaug 2006 p. 119, Burnstein 2003 p. 449) to divide and present causes of a target problem as a cause-effect diagram (Andersen, Fagerhaug 2006 p. 119, Burnstein 2003 p. 449, Stevenson 2005 p. 411). The diagram is based on problem cause categories (Andersen, Fagerhaug 2006 p. 120, Burnstein 2003 p. 449, Stevenson 2005 p. 411). Andersen presents that there are at least two different ways to create a fishbone diagram (Andersen, Fagerhaug 2006 p. 119). First, *Dispersion Analysis* is a tree based structure which is built by using top-down strategy. There the target problem is presented as a root of the tree which is made by looking up the causes for the target problem and then collecting their sub causes. Second, *Cause Enumeration* is a strategy where all the causes are first brainstormed individually and then grouped under categories of problem causes. Thereafter a cause-effect diagram is built (see Figure 5).

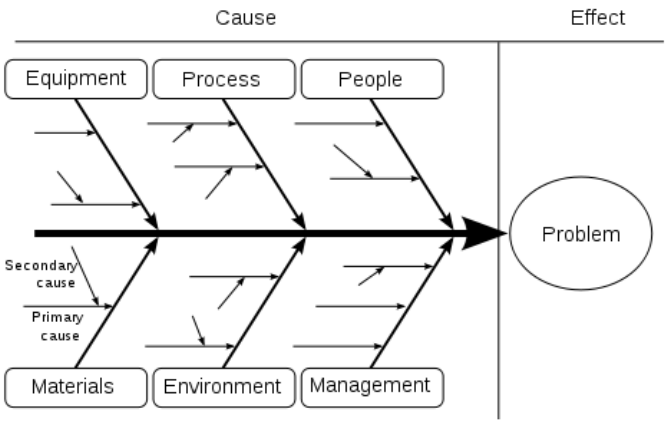

Figure 5: An enumeration Fishbone Diagram

Fault Tree Analysis is based on a cause-effect diagram which connects the causes together by using "AND" or "OR" relations. The relation corresponds to causes which create the problem only if occurring together (AND) and to causes formulating the problem individually (OR). It is claimed to help to produce a clear overview of the possible causes identified, but also see linkages between them. (Andersen, Fagerhaug 2006 p. 135)

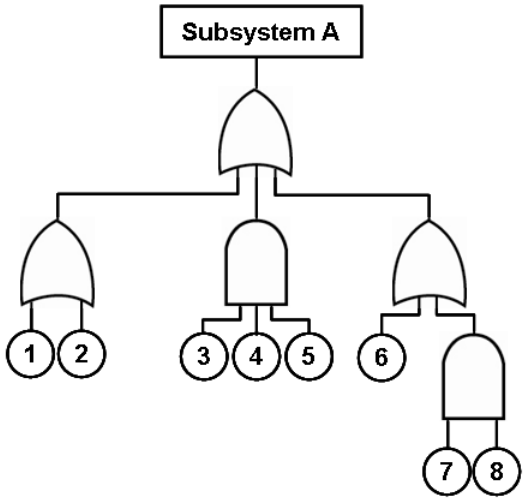

Figure 6: A general Fault Tree Diagram

In **Causal Mapping** causes are mapped into a network of causes depending on causalities between them. The causes are linked together by using arrows. If compared to a fishbone diagram it is claimed to allow more freedom in the diagram (Björnson, Wang & Arisholm 2009) (see Figure 7).

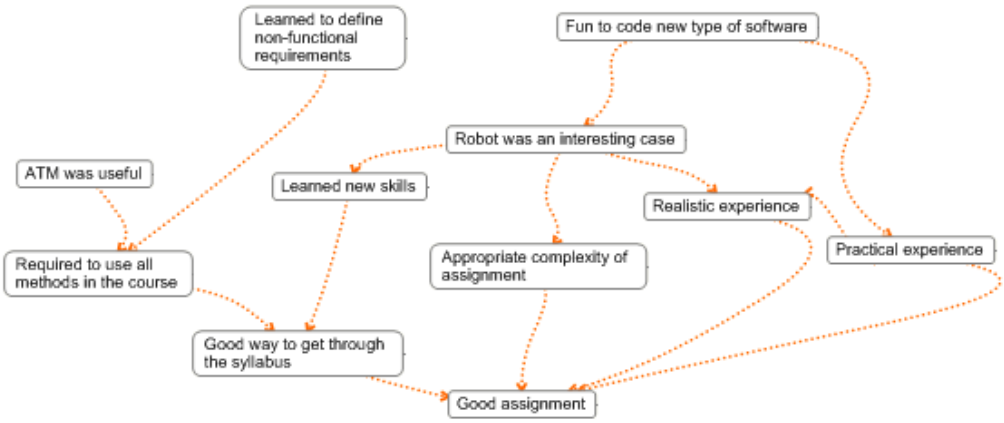

Figure 7: A causal Map (Björnson, Wang & Arisholm 2009)

Five Why is about constantly asking "why" as many times as possible, and its role is to delve more deeply into levels of causes. The Five Why can be used to analyze whether each identified cause is a symptom, a lower-level cause, or a root cause (Andersen, Fagerhaug 2006 p. 129). It is also called a *why-why chart*. Jalote stresses that the key for analyzing causes is constantly asking the question: "why does this cause produce this effect?" and repeating this "Why-Why-Why" process until all the root causes of the effect are identified (Jalote, Agrawal 2005).

Matrix diagram is a tool which helps to investigate a number of possible causes and determine which contributes most to the target problem. There are at least five different diagrams: Roof-shaped, L-shaped, Y-shaped, T-shaped, and X-shaped. (Andersen, Fagerhaug 2006 p. 124)

Scatter charts are used in RCA to identify the impact between causes at different levels (Andersen, Fagerhaug 2006 p. 97). They help to identify a possible correlation between two variables, and then may point to a cause of a problem (Stevenson 2005 p. 409).

3.5.4 Corrective Action Development Practices

This section presents practices that can be used to develop corrective actions.

TRIZ, also known as *The Theory of Inventive Problem prevention*, was developed in the Soviet Union to solve technical problems requiring inventive and novel solutions (Andersen, Fagerhaug 2006 p. 146, Zhao et al. 2007, Wikipedia 2009c). The idea is to apply known solutions to similar problems rather than to generate the same solution over and over again (Andersen, Fagerhaug 2006 p. 146). In practice, the problem is dissected into its core components to look for known solutions for them by using 40 inventive principles and 39 standard technical characteristics (Andersen, Fagerhaug 2006 p. 146, Zhao et al. 2007). TRIZ is an algorithmic and model based tool which consists of methodology, tools, and a knowledge base (Zhao et al. 2007, Wikipedia 2009c). It suits the project level best, but lacks usefulness on the enterprise level (Zhao et al. 2007).

Systematic Inventive Thinking (SIT) is a further development of TRIZ, in which a cause is broken into multiple components which are covered by 5 individual principles: *attribute dependency*, *component control*, *replacement*, *displacement*, and *division*. SIT is recommended to be used to find creative and feasible solutions which are embedded in an environment around the problem. (Andersen, Fagerhaug 2006 p. 150)

Six Thinking Hats rely on the principle that by viewing a problem from different perspectives, the problem is covered comprehensively, which is basically the same ideology as in SIT and TRIZ. The perspectives are divided into 6 roles named as the white, red, black, yellow, green, and blue hats. The white hat represents a cold, neutral, and objective perspective, while the red hat represents a role for anger. The black hat represents pessimistic and negative views around the problem, whereas the yellow hat represents positive and optimistic perspectives in which the focus is on overcoming obstacles. The green hat represents creativity and cultivation of new ideas, and the blue represents things from a higher perspective. The advantages of the tool are its ability to view problems and solutions from multiple perspectives and enabling of close scrutiny before decisions are made. (Andersen, Fagerhaug 2006 p. 143)

3.5.5 Summary of the RCA Practices

A target event for RCA should be carefully analyzed to focus RCA effort advantageously. For this many practices can be used. Sampling combined with the Pareto Analysis is recommended by many authors, especially in DCA (see Section 3.4.4). The Pareto Analysis helps to detect the most potential target for RCA.

The causal analysis practices are based on cause-effect relationships. The fishbone diagram seems to be one of the most recommended practices, whereas the Five Why is more like a strategy for delving deeper causes.

The recommended practices for developing corrective actions (see Section 3.5.4) are rather complex and more creative approaches should be used (Andersen, Fagerhaug 2006 p. 141). In most of the RCA processes, presented in Section 3.4, corrective actions are recommended to be developed, but the authors, however, don't present how the corrective actions should be developed. Brainstorming and Brainwriting are presented as methods which are feasible in generating many ideas (see Section 3.5.1).

3.6 RCA Organization

This section presents different viewpoints around the people attending to RCA.

3.6.1 RCA Team and Roles

According to Latino and others the ideal RCA team consists of at least 4 different core members: a team leader, experts, vendors, and critics. The size of the team should be from 3 to 5 at a minimum and 10 people at a maximum. Including technical diversity is recommended, to avoid seeing the target problem from only similar perspectives. The team leader should be a facilitator, not a participant. His responsibility is to administer the team effort, the facilitation of the RCA team members, and the communication of goals and objects to management oversight personnel. The experts are the core of the team and they should be selected based on their backgrounds in relation to the event being analyzed. The

role of critics in the team is to force the team to see the other side of the track and to find holes in the logic by asking persistent questions. Critics come in two forms: *constructive critics* and *destructive critics*. Constructive critics are substantial to success and enquiring persons who take nothing, or very little, at face value. On the other hand, destructive critics stifle the team progress and are not very interested in successfully accomplishing the team objectives. The vendors are an important source of information around their products and customers; however, they should not lead the team even when their products are the case. (Latino, Latino 2006 p. 105)

Card (Card 1998) emphasizes that a "*causal analysis team*" should consist of mainly software producers (developers and maintainers). He also claims that the ideal team size is less than 25 people, but unlike Latino (Latino, Latino 2006 p. 108) a team size of more than ten people is allowed.

Burnstein presents that RCA team members should be trained and motivated. The RCA teams should include testers, developers, project managers, software quality assurance staff, and process improvement group members. In addition, there should be two teams, one for a causal analysis and one for a corrective action development. (Burnstein 2003 p. 450)

3.6.2 Communicational Aspects

Communication comes up when thinking of the nature of the RCA related methods. Many of them, like brainstorming and interviewing, are used in a face to face manner. Additionally, in the RCA context, the methods are mainly focused on finding causes of a target problem (see Section 3.2). This increases the need for a gentle communication environment where people feel easy enough to discuss about and admit imperfection. Grady (Grady 1996) stresses that even though there are many possible ways to analyze root causes any successful way must be sensitive to project pressures and personnel motivation.

Burnstein presents that the tone of a causal analysis meeting should be constructive and positive and that the purpose of the meeting is not to lay blame on the defects, but to find root causes (Burnstein 2003 p. 452). Downs and Hazen (Downs, Hazen 1977) present that communication as an intervening variable leads to any of four results: 1. Productivity, 2. Satisfaction, 3. Labor-management relations, and 4. Profit.

It is important to recall that a dominating strong-willed RCA team member will tend to impose his personality on the rest of the RCA team members, thus potentially decreasing the efficiency of the innovative process and the corrective actions development (Latino, Latino 2006 p. 111).

Ammerman lists five reasons for miscommunication: 1. receivers' messages and counter-messages fight for predominance, 2. words chosen to communicate the message may not have meaning for the receiver, 3. the environment distracts from listening and watching, 4. the senders emotions and body language may override or undermine the sender's words, and 5. receiver has poor listening skills (Ammerman 1998 p. 57).

3.7 Strengths and Weaknesses of RCA

This section covers the strengths and weaknesses of RCA.

3.7.1 Strengths

Burnstein lists five benefits of defect analyses and prevention processes (Burnstein 2003 p. 442): 1. they help to reduce the costs of developing and maintaining a software, 2. they help to improve software quality, 3. they reduce the total number of problems we must look for, 4. they provide a framework for overall process improvement activities, and 5. they encourage interaction between a diverse number of staff members.

RCA is a pro-active method that can be used to forecast the likelihood of an event before it occurs (Wikipedia 2009b). It also helps an organization to move from reactive to pro-active development (Grady 1996).

By using RCA an organization can determine weaknesses and changes they need to make and where they are needed to be made. RCA based corrective actions lead to process changes that help prevent defects and ensure their early detection. Additionally, product quality increases (Card 1998, Leszak, Perry & Stoll 2000).

RCA has been claimed to be a low-cost and effective technique (Card 1998, Card 1993, Leszak, Perry & Stoll 2000), especially in identifying deficiencies and improvement areas (Leszak, Perry & Stoll 2000) which over the time can be used to target major opportunities for improvements (Rooney, Vanden Heuvel 2004).

In DCA (see Section 3.4.4), the mean effort to fix a defect is reduced and defects are detected earlier. Additionally the overall number of the defects is significantly reduced (Leszak, Perry & Stoll 2000).

RCA can be used to transfer process learning from individuals to organization (Card 1998, Grady 1996). Though RCA doesn't replace other learning and analysis techniques, it does evolve the producers' mindset for their own near-term benefit (Card 1993, Grady 1996). This way the root causes and relevant prevention actions are also more accurate (Card 1993).

3.7.2 Weaknesses

Rooney and others conclude that typically an RCA target problem has multiple root causes (Rooney, Vanden Hauvel 2003). Jalote and others present that most likely too many causes are detected, and thus attention should be focused on the top few causes (Jalote, Agrawal 2005). Thus, complete prevention of recurrence by a single intervention is not always possible (Wikipedia 2009b).

It is always the people making the changes, not RCA by itself (Latino, Latino 2006 p. 25). Latino and others claim that data collection is a weighty mission (Latino, Latino 2006 p. 99). As already mentioned in Section 3.3, a root cause analyst must be a skilled interviewer, and local expertise has to be available (Card 1998). Additionally, collected data from people is most easily altered or destroyed and it needs to be prioritized (Rooney, Vanden Hauvel 2003). Sometimes it might be no easy matter to concede one's own

mistakes: RCA can be seen as a “witch-hunting tool” that eventually may eliminate an employees’ job (Latino, Latino 2006 p. 109). If wrong root causes are detected then wrong corrective actions will be developed (Rooney, Vanden Heuvel 2004). Grady presents that the causal analysis mechanism is qualitative and labor intensive, and that with a large development effort RCA is akin to studying the ocean floor with a microscope (Grady 1996).

Classification of reported defects through the Pareto Analysis is recommended, as presented in the sections 3.4.3 and 3.4.4. However, the lack of a commonly accepted standard defect classification between software development and the complexity of a software product has been discussed and it is argued that there is a wide gap between the statistical defect models and the qualitative causal analysis (Chillarege et al. 1992).

As there isn’t a commonly accepted definition for RCA, its terminology is also varying. Flaws in common RCA terminology (Grady 1996) complicate the adoption of RCA.

3.8 Summary

This section summarizes the literature review by answering its research questions.

LRQ1: What are the generic parts of all the RCA processes used in problem prevention?

Even though there’s no unique and commonly accepted definition, RCA is usually defined as a systematic and structured cause detection process focused on an occurring problem. The processes result in corrective actions which are developed for the most important root causes. Interviewing, brainstorming, brainwriting, sampling combined with the Pareto Analysis, and a fishbone diagram are usual practices recommended to be used. The generic parts of the RCA processes used in problem prevention are summarized in Table 2.

LRQ2: What is required to adopt RCA?

Generally, requirements for the software company to adopt RCA are a defined development process, detected problems, reporting of the problems, a skilled root cause analyst, available local expertise, a sensitive atmosphere, and commitment of the managers. Additionally, the more mature the software company is, the more fertile is the environment for a process optimization (see Section 3.3). However, as presented in Section 3.2, RCA can be targeted on any kind of problems and it is about finding causes (see Section 3.1.2). Thus, probably the most important requirements are the skilled root cause analyst combined with the local expertise.

LRQ3: What sort of target problems can be analyzed by RCA?

There are two kinds of target problems that can be analyzed by RCA: sporadic and chronic. The chronic problems are claimed to be more suitable for RCA than the sporadic problems. The target problem can be represented by a single problem or a class of problems. It is important to highlight that the better the definition of the target problem the more advantageous the analysis (see Section 3.5.2).

LRQ4: How has RCA been used to prevent problems?

The found articles presenting RCA usage in the software industry are mainly based on DCA (see Section 3.4.4). DCA is about defect classification through the Pareto Analysis (see Section 3.5.2) combined with a cause-effect diagram (see Section 3.5.3) including a selection of the most important causes and the development of corrective actions against them.

Table 2: Summary of the RCA processes and recommended practices

RCA process	RCA target	Event Analysis		Cause Analysis		Corrective Action Development	
		Activity	Recommended Practices	Activity	Recommended Practices	Activity	Recommended Practices
RCA by Andersen 3.4.1	Single problem or a class of problems	Problem understanding	Flowchart, Critical incident, spider chart, performance matrix	Problem cause data analysis	Pareto Analysis	Problem elimination	SIT, TRIZ, Six thinking hats
		Problem cause brainstorming	Brainstorming, Brainwriting, Is-is not matrix	Root cause identification	Cause-and-effect chart, matrix diagram, Five Why, fault tree analysis		
		Problem cause data collection	Sampling, surveys, check sheets				
RCA by Rooney 3.4.1	Single problem	Data Collection	Interviewing, inspections	Causal Factor Charting	Sequence diagrams	Recommendation generation	-
				Root cause identification	Decision diagram		
PIC 3.4.2	Single problem	Problem definition and data collection	-	Event and Causal Factor Charting	Sequence diagrams	Corrective Action Development	Interviewing
		Task Analysis	Paper-and-pencil, Walk-through	Root Cause Determination	Interviewing, event and causal factor charts, Fault tree analysis		
		Change Analysis	Flow charts				
		Control Barrier Analysis	Flow charts				
PROACT 3.4.3	A class of problems	Opportunity Analysis	Sequence diagrams, Interviewing, Brainstorming, sampling, Pareto Analysis	Data Analysis	Flow chart, Fault tree chart, team meetings	Recommendations development	Writing individually, team meetings
DCA 3.4.4	A class of problems	Select problem sample	Sampling, team meetings	Determine principal cause	Cause-effect diagrams, causal categories, team meetings	Action proposals development	team meetings
		Classify selected problems	Classification scheme, team meetings				
		Identify systematic errors	Pareto Analysis, team meetings				

LRQ5: What sort of personnel should be included in RCA?

It has been presented in Section 3.3 that RCA requires a skilled root cause analyst, available local expertise, managerial commitment and a sensitive atmosphere. An RCA team should be trained and it should include a team leader, experts, vendors, and critics. These correspond in the software development to project managers, developers, testers, software quality assurance staff, product managers, and process improvement group members, as presented in Section 3.6.1. The personnel should also form a sensitive

communication environment, because RCA can be seen as a “witch-hunting tool” which eventually may eliminate an employees’ job (see Section 3.6.2).

LRQ6: What are the expected benefits of RCA?

The most expected outcome of RCA is to prevent or significantly minimize its target problems’ reoccurrence. It helps an organization to move from a reactive to a pro-active strategy. RCA has been claimed to be a low cost and effective technique, especially in identifying deficiencies and improvement areas. Over time these can be used to target major opportunities for improvements. RCA also reduces the costs of developing and maintaining a software, improves software quality, reduces the total number of problems, provides a framework for overall process improvement activities, encourages interaction between staff members, and transfers process learning from individuals to organizations. (see Section 3.7.1)

LRQ7: What are the expected challenges of RCA?

A major challenge of RCA is that collecting cause data is a laborious task, and most likely too many causes are detected. Thus, the attention should be focused on the top few causes. This means that complete prevention of a target problem reoccurrence is usually not possible. Additionally, the more causes the more challenging it is to organize them. The analyst must be willing to probe the data, and if wrong root causes are detected, then wrong corrective actions will be developed. Classification of reported problems through the Pareto Analysis is recommended, as presented in the sections 3.4.3 and 3.4.4. However, there is a wide gap between the statistical defect models and the qualitative causal analysis. As there is no commonly accepted definition for RCA, its terminology also varies (see Section 3.7.2).

4. Initial ARCA Method

This section presents the initial ARCA method and how it was developed.

4.1 Development of the Initial ARCA Method

The first step was to set down the requirements of the ARCA method. The requirements were based on the research objects (see Section 1.4) and the following principles: 1. if the method doesn't lead to advantages then it will not be used, and 2. if the method isn't easy to use and learn then it will most probably not be adopted because of resistance.

The requirements for the method were:

1. **The method helps to generate corrective actions which are feasible and which have a significant impact on the target problem**
    - The method helps to develop high quality corrective actions
    - This is the most important requirement, because otherwise the method doesn't lead to advantages

2. **Adaptability for different kinds of target problems**
    - All kinds of software development related problems can be analyzed with the method
    - This is an important requirement, because it enables the method to be used widely, not only for a specific target problem

3. **Easy to learn and use**
    - The method should be as compact as possible
    - All the practices recommended in the method needs to be easy to use and learn
    - This is an important requirement, because otherwise the people resist to use the method

4. **Low required effort**
    - This means that only the most advantageous causes are processed
    - This is an important requirement, because even if the method helps to generate major advantages, it will be useless if the required effort is too high

The second step was to develop a prototype of the ARCA method. It followed the recommended RCA practices and processes presented in the literature (see Table 2) and the requirements presented above.

The third step was to pilot the prototype in a student software project. Piloting was important, because it helped improve the method before the actual cases were conducted.

4.2 Description of the Initial ARCA Method

This section presents the description of the initial ARCA method after it was piloted and then improved (see Figure 8). The method follows the generic parts of the RCA processes which are used to prevent problems (see Table 2). Problem Detection corresponds to Event Analysis, Root Cause Detection corresponds to Cause Analysis, and Elimination corresponds to Corrective Action Development. The RCA practices in the initial ARCA method were selected by comparing the recommended RCA practices (see Section 3.5) to the requirements of the ARCA method. Additionally, the experiences from the pilot case were combined with the author's personal assumptions.

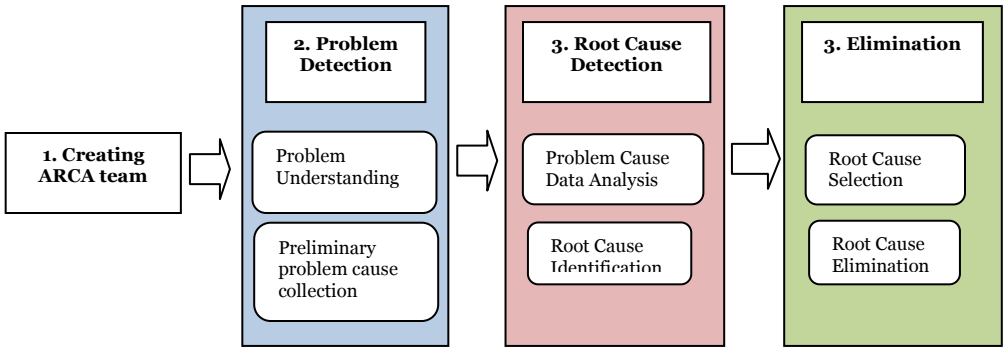

Figure 8: The initial ARCA method after improvements

4.2.1 Step 1 - Creating ARCA Team

The analysis should to be conducted with different kinds of stakeholders. Together the people are able to efficiently detect the causes which lead to the target problem. The recommended team size is four to ten people. The team includes at most a few RCA facilitators and several RCA team members covering the following stakeholders: developers, testers, quality assurance, project management, and product management. The RCA facilitators are mainly responsible for choosing the RCA team members, arranging workshops, creating documents, specifying the target problem, organizing collected causes, and selecting the most important causes and participating in all the steps in the method. The RCA team members contribute mainly to cause collection and corrective action development.

4.2.2 Step 2 - Problem Detection

This step consists of two sub steps, namely *Problem Understanding* and *Preliminary Problem Cause Elicitation*. The main goal of the step is to define the target problem, analyze its formation, and to find its main cause entities. The sub steps are described below.

4.2.2.1 Problem Understanding

Problem Understanding is about analyzing the target problem formation and recognizing its main causes, thus sharpening the focus of the analysis. The analyses should be

emphasized on the process where the problem occurs. It should recognize where and how the problem formulates. The output of this phase should be a document, which presents the problem and its formation.

4.2.2.2 Preliminary Problem Cause Elicitation

Preliminary Problem Cause Elicitation is about collecting preliminary problem causes and structuring them into a cause effect diagram (see Section 3.5.3) to help the RCA facilitators detect cause entities which are to be processed in Step 3. A cause entity means a cause and its sub causes, which together form an entity that is reasonable to process together. The preliminary causes are collected by using an email inquiry where the RCA team members are asked to list causes of the target problem.

4.2.3 Step 3 - Root Cause Detection

Deeper level causes are collected together with the RCA team members in a workshop session. There the cause-effect diagram is finalized, and the problem root causes are detected and prioritized. The duration of the workshop is two hours of a maximum. The step has two sub steps, namely *Problem Cause Data Analysis* and *Root Cause Identification*. The sub steps are described below.

4.2.3.1 Problem Cause Data Analysis

In the workshop session the preliminary cause-effect diagram is finalized by processing all its cause entities. The RCA team members are asked to write down new causes to a cause entity during a 10 minutes long period. Then they are asked to place the causes in the diagram one after another by presenting the causes to the RCA team. After an RCA team member has placed one cause in the diagram, the RCA team is immediately asked to brainstorm deepening causes for that cause. After all the causes are processed, the next cause entity takes turn.

The decisions above were made because there were problems in the pilot case. A whiteboard and postIT notes were used in collecting, organizing, and visualizing the causes. Unfortunately the whiteboard with postIT notes was problematic in practice, because organizing the causes was not flexible enough and the whiteboard was not large enough. A cause-effect diagram should be built on by using a software tool (for example, MindManager, FreeMind, or XMind) and a monitor. Additionally, the brainstorming was flown the coop all the time, because there were so many different paths to follow in the cause-effect diagram.

4.2.3.2 Root Cause Identification

The root causes are recognized in the finalized cause-effect diagram in this step. The RCA team members are asked to process the cause-effect diagram by discussing all of its causes. The RCA team members should detect and ignore the causes which aren't controllable. Thus the remaining causes are root causes. They should detect the root causes which are present in multiple branches of the cause-effect diagram. If one cause belongs to multiple branches, arrows are drawn from the cause to these branches. In the end, each root cause's impact for the target problem is valued.

The decisions above were made because there was a problem in the pilot. Many causes belonged to multiple branches of the cause-effect diagram. This meant that the same cause had to be copied to all of these branches. Unfortunately, this was experienced as a task far too laborious. Drawing arrows from the cause to these branches is recommended instead of copying. The same idea is applied in causal mapping (see Section 3.5.3).

4.2.4 Step 4 – Elimination

The development of corrective actions is to be conducted in a workshop session including the same RCA team members as earlier. The duration of the workshop session is two hours at a maximum. Before the workshop session is held, processed root causes are selected. This step has two sub steps, namely *Root Cause Selection* and *Root Cause Elimination*.

4.2.4.1 Root Cause Selection

Before the workshop session, the RCA facilitators select five to six important root causes including their sub causes to be processed. These are all documented on separate papers.

The decisions above were made because there was a problem in the pilot. Many root causes were detected, but only the last causes in the branches were selected to be processed. Thus, coverage of the corrective actions was focused on a narrow set of causes (3 causes out of 56).

4.2.4.2 Root Cause Elimination

Root Cause Elimination is conducted in a workshop session where the RCA team members are divided so that each root cause has at least one RCA team member. Corrective actions are developed by writing them on papers and rotating them through the RCA team members during 10 minutes long periods until each RCA team member has treated all the root causes:

- The selected root causes, including their sub causes, are on distinct papers which are divided for the RCA team members
- Each RCA team member writes corrective actions for a root cause by using premade templates
- Corrective actions written by other RCA team members should be supplemented from skeptical and positivist perspectives

The developed corrective actions are evaluated to find the best corrective actions. The evaluation is conducted similarly as was their development: the root causes including their corrective actions are rotated through the RCA team members. Each RCA team member evaluates a root cause's corrective actions by giving two attributes for each idea:

1. **Impact of the corrective action** for the problem [1=minor, 2, 3, 4, 5=major]
2. **Feasibility of the corrective action** [1=bad, 2, 3, 4, 5=good]

The last RCA team member evaluating corrective actions of a root cause calculates the sums of the evaluations of the corrective actions of the root cause. Each RCA team member presents the highest evaluated corrective action for the other RCA team members and the team is asked to discuss the idea.

After the workshop session is held all of the results are documented including the problem description, the finalized cause-effect diagram, the most important root causes, and all the corrective actions per a root cause.

The decisions above were made because there were problems in the pilot. A practice "Systematic Inventive Thinking" (see Section 3.5.4) was used, and it was experienced very hard to internalize. Additionally TRIZ and Six Thinking Hats (see Section 3.5.4) were felt to be even harder to use. Thus, it was decided not to continue working with these practices in later cases. However, one of their common principles was adopted: the corrective actions should be developed by looking at them from optimistic and skeptic perspectives. It was also concluded that in the brainstorming method the conversation will most likely flown the coop all the time. Thus, the card method brainwriting was decided to be applied in the development of the corrective actions. The brainwriting method is presented to be at least as advantageous practice as the brainstorming method to generate new ideas (see Section 3.5.1).

5. Applications of the ARCA Method

This chapter presents the cases and how the method was applied in each. Section 5.1 characterizes the target problems and Section 5.2 discusses the RCA team members of the cases. Sections 5.3 to 5.6 present the case overviews and how the method was conducted in each.

5.1 Target Problems of the Cases

This section presents the target problems of the cases in general. The target problems are presented by using the following data sources: the RCA facilitators of the cases were interviewed and the RCA team members were asked to estimate the target problems by using the feedback forms.

Table 3 lists the target problems which were selected by the representatives of the case companies. It also presents how they answered when they were asked to characterize the economical impact and the complexity of the target problem. It seems that each target problem was complex to prevent. Unlike the other cases, the target problem of Case B was not costly for the company.

Table 3: The target problems for the ARCA method

	Target problem	In an economical sense, how significant is the target problem for your company? (Interview 1, part 2, question 2)	How complex is the target problem and how would you characterize it? (Interview 1, part 2, question 3)
Case A	**Fixing and verifying defects delays project schedules**	*"Extremely costly"*	*"Extremely complex problem"*
Case B	**Blocker type defects in the product after releases**	*"Not very costly"*	*"Very complex, but not very severe problem"*
Case C	**New product installation and updates are challenging tasks**	*"Significant impact on our customer relationships"*	*"Very complex problem"*
Case D	**Issues' lead time is occasionally intolerable long**	*"Severe financial impact since the projects are not finalized in time"*	*"The problem is complex, because it is closely related to communication"*

Figure 9 presents how the RCA team members of the cases estimated the effort their company had used to prevent the target problem earlier. It seems that Company B had used more effort to prevent the target problem earlier than the other case companies. Thus the RCA team members in Case B might were able to list relatively more causes of the target problem than the RCA team members in the other cases.

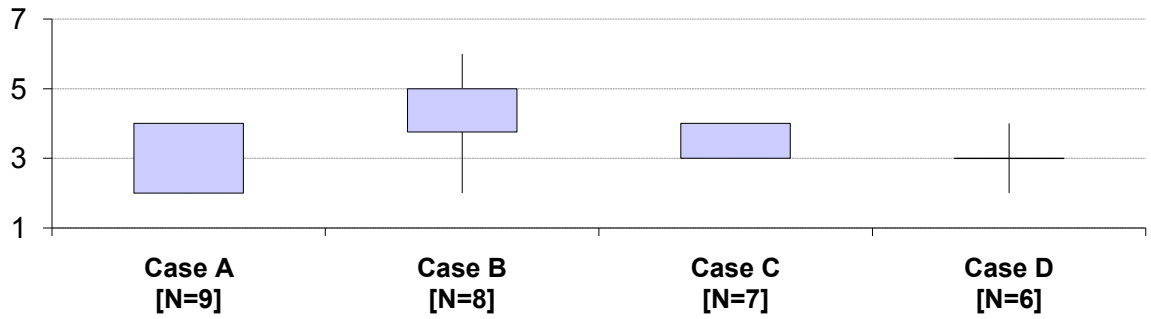

Figure 9: The effort the case companies has used to prevent the target problem earlier
[Scale 1=very low, 2, 3, 4, 5, 6, 7=very high]

5.2 RCA Team Members of the cases

As presented in Section 3.6, an RCA team should include different stakeholders, all experts in their own field. Additionally, the RCA team members should feel easy to discuss about and admit imperfection. The RCA team should also be motivated so that their personal contribution would be high. In the section, the perspective of stakeholders is presented as a table that divides the RCA team members into different roles. The perspective of the expertise of the RCA team members in the target problems is presented as a figure corresponding to how the RCA team members estimated the adverse effect of the target problem on their daily work. The easiness to discuss about and admit imperfection is presented as a figure corresponding to how the RCA team members estimated the openness in communication in both workshop sessions. The motivation of an RCA team member is presented as a figure corresponding how the RCA team members estimated their personal contribution in the workshop sessions.

Table 4 presents a division of the RCA team members into different roles. The roles correspond to the stakeholders that were present in the cases. An RCA team member was allowed to have multiple roles. It is possible that the more different roles were present in a case the more capable the RCA team members were in complementing one another's causes and corrective actions from the different perspectives. In Case B, mostly developers were included into the RCA team. Thus, they had a more homogenous RCA team than the other cases.

Table 4: The division of the RCA team members into different roles

Role	**Case A** [Team size=9]	**Case B** [Team size=9]	**Case C** [Team size=6]	**Case D** [Team size=6]
Managers	6	1	3	5
Developers	5	8	6	1
Testers	1	0	1	3
Sales & Marketing	1	0	0	1

Figure 10 presents the estimations of the RCA team members on the adverse effect of the target problem on their daily work. Perhaps the higher the RCA team members estimated the adverse effect the more experienced they were in general around it. It appears that in Case D, the RCA team members felt that the target problem has a high adverse effect on their daily work. In case B, the adverse effect was estimated the lowest. Surprisingly, the RCA team in Case D included the roles of testers and sales&marketing more than in the other cases, whereas the RCA team in case B consisted mostly of the roles of developers (see Table 4).

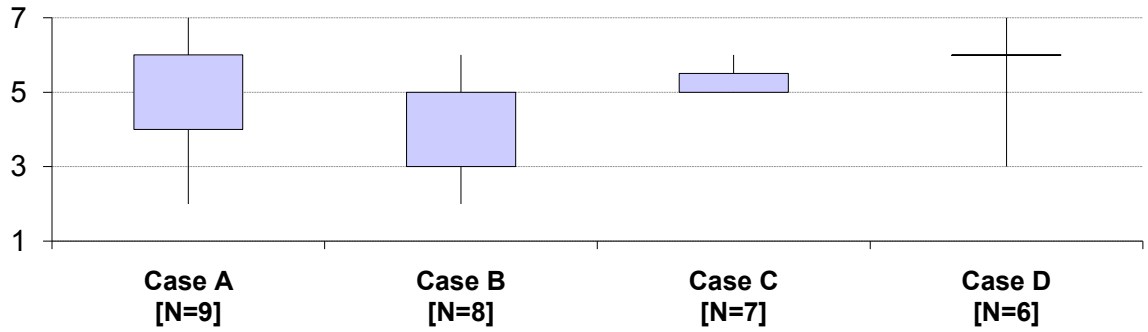

Figure 10: The adverse effect of the target problem on my daily work
[Scale 1=very low, 2, 3, 4, 5, 6, 7=very high]

Figure 11 presents how the RCA team members valued openness in communication in the first and second workshop session (WS1 and WS2). The higher the RCA team members valued the openness in the both workshop sessions the more honestly they listed the target problem causes and developed corrective actions. Is seems that the openness was estimated as high in the both workshop sessions in each case. This means that the RCA team members felt easy to discuss about and admit imperfection. However, there was one RCA team member in Case B who estimated that the openness in communication was lower than neutral in the second workshop session. Maybe the RCA team member felt that his opinions and insights were not supported by the other RCA team members.

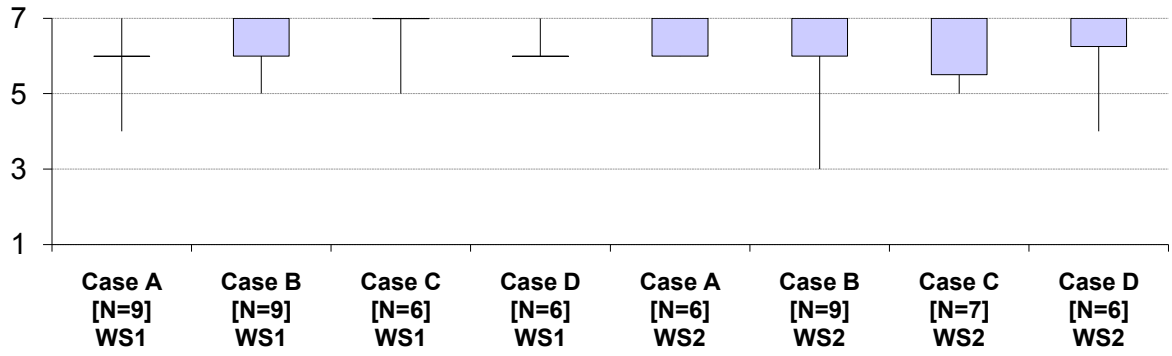

Figure 11: The openness in communication in the first and second workshop session (WS1 and WS2)
[Scale 1=very low, 2, 3, 4, 5, 6, 7=very high]

Figure 12 presents how the RCA team members valued their personal contribution in the first and second workshop session. It seems that in cases C and D the RCA team members valued their personal contribution higher in the first workshop session than how the RCA team members valued their personal contribution in cases A and B. The reason for this could be that the ARCA method was improved in-between. Additionally, in cases A, C, and D the RCA team members valued their personal contribution slightly higher in the second workshop session than in Case B (see Figure 12). The reason for this could be that the brainwriting method was applied in cases A, C, and D, whereas the brainstorming method was used in Case B.

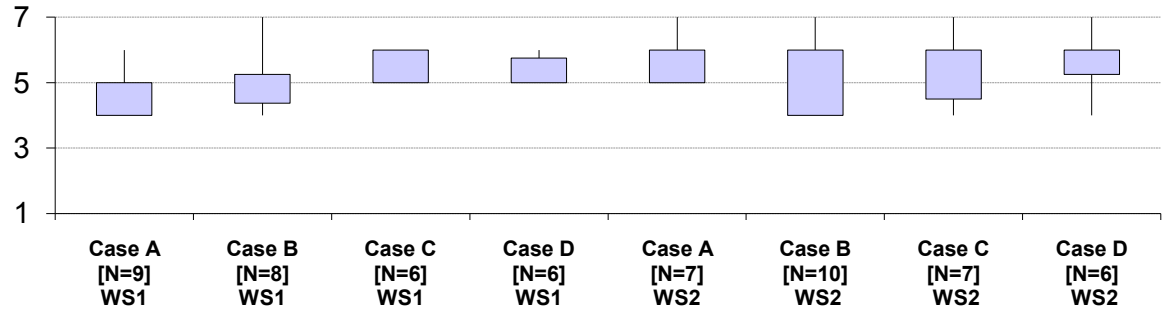

Figure 12: The RCA team members' evaluations on their personal contribution in the first and second workshop session (WS1 and WS2) [Scale 1=very low, 2, 3, 4, 5, 6, 7=very high]

5.3 Case A

5.3.1 Introduction

Company A is a medium-sized international software company with approximately 115 employees. The average size of the project organizations is about seven people. The company's product is released twice a year, consisting of a major and a minor release. The product can be characterized as a large and complex software system.

The company uses approximately 0.9 percent of its budget for the software process improvement (SPI) activities. These are managed by a quality assurance (QA) team consisting of three people. The QA team holds meetings where different kinds of problems based on their criticality are selected and processed. The selected problems are presented to the company's managing committee to ensure that the effort is focused on the correct problems. Then corrective actions are developed for the selected problems by the QA team by using the brainstorming method. The problems are initially detected by interviewing different stakeholders, like project managers and product owners. However, neither developers nor testers are interviewed, because the QA team believes that the scope in problem prevention is the way the projects are pushed forward. In Interview 1 with the company's representatives the QA team members stressed that their current problem prevention practices are not feasible enough and should be improved. Currently it seemed that the practices lead the company to bite more than one can chew. They hoped that by using the ARCA method, feasible and effective corrective actions could be developed and deeper level causes and correct root causes could be detected for a target problem. Their earlier experiences of RCA were fairly low.

The target problem for the ARCA method was that the company's releases were delayed due to a high number of software defects detected in the end of the process of the product releases. The company has continuously tried to prevent the problem during the past year. The QA team members' common opinion was that the problem is extremely complex and costly for the company. The team supposed that the main reasons for the problem were that the size of technical blocks in the software is too large and employees' attitudes are not fertile enough to develop high quality software at once. While asking the QA team to underline how to prevent the problem reoccurrence, they had two ideas: the first was to increase discipline, and the second was to release the product in shorter cycles.

5.3.2 Diagnosing and Action Planning

The case was planned to follow the initial ARCA method presented in Chapter 4.

5.3.3 Action Taking

Step 1 – Creating ARCA Team

The RCA team members were selected as recommended in the initial ARCA method. The RCA facilitators of the company consisted of the QA team.

Step 2 – Problem Detection

The step was done as planned. Additionally, the QA team had created a cause-effect diagram earlier around the target problem and suitable parts of that diagram were used as a part of the preliminary cause-effect diagram.

Step 3 – Root Cause Detection

In the initial ARCA method, the step was planned to be done during the first workshop session. However, because the session's duration was time-boxed to take two hours at a maximum, there was not enough time left in the end of the session neither to analyze the detected root causes comprehensively nor to prioritize them. The RCA facilitators cleaned up the cause-effect diagram after the first workshop session, and then they sent the diagram with an email inquiry to the RCA team members who were asked to propose and evaluate 10 to 15 important root causes to be processed. The RCA team members were given one weeks time to do this.

Step 4 – Elimination

In the beginning of this step the RCA facilitators created an Excel sheet of the root cause propositions, which helped the RCA facilitators select the root causes to be processed. The duration of the second workshop session was extended to 30 minutes, because the RCA team members wanted to continue the conversation on the best corrective actions. There was a pair of people working with one root cause simultaneously, while the rest of the people worked with a root cause individually.

5.3.4 Evaluating and Specifying Learning

Three major problems in the method were detected during the case. First, the duration of the first workshop session was too short to identify the root causes which were the most promising to eliminate. Second, since the corrective actions were written on paper and had been rotated through the RCA team members, the persons who last worked with a root cause did not have enough time to read and comment on the other RCA team members' corrective actions carefully. Third, a bottleneck in the prioritization of the corrective actions was noticed. This was due to the fact that all the corrective actions for a root cause had to be prioritized at once before passed on to the next RCA team member.

Table 5: The perceived challenges in the ARCA method during Case A

Perception	Source	ARCA step
More causes were detected in the email inquiry than in the first workshop session.	Participation	Step 1 & Step 2
There was not enough time in the first workshop session for Root Cause Identification.	Observation	Step 2
The RCA team members wanted more time to discuss the best corrective actions.	Observation	Step 3
Prioritization of the corrective actions created bottlenecks.	Observation	Step 3
The RCA team members who work with a root cause's corrective actions last do not have enough time to read the other RCA team members' comments and corrective actions carefully.	Observation	Step 3

5.4 Case B

5.4.1 Introduction

Company B is a large international software company with more than 450 employees. The company releases new software versions regularly and its products can be characterized as a complex and model based software.

Approximately one percent of the annual budget of the company is used on the SPI activities that are arranged into different levels of the company. While managers are asked to use five to ten minutes daily to think about how the software process could be improved, the developers and requirements engineers are involved in SPI meetings on a regular basis. To direct the development work, an annual action plan for the project organizations is made. The company has a software system for quality deviations. By the help of it the detected software defects from different sources are reported. The defects are prioritized on a daily basis by a group of 15 to 20 people. The company has planned to use RCA in the future, and they hoped to collect experiences from the case to understand how RCA can be applied in practice. They had conducted RCA earlier by using the Five Why (see Section 3.5.3) in SPI meetings.

The target problem for the ARCA method was that blocker type defects are detected after the product releases. The company had set a clear goal for the project organizations to lower the number of defects which are detected by the customers. In Interview 1 with the representatives of the company, the problem was characterized as very complex including many different causes. The main causes for the problem were believed to be the following: new code is built on the old low quality code, too many different methods are used in the development work, lack of the different hardware set-ups decrease the coverage of the software testing, and some of the defects take time to be detected causing that users instead of the company detects the defects. They said that the problem could be best eliminated by refactoring the old code. They also believed that the problem is not very severe, because the customers are currently highly satisfied.

5.4.2 Diagnosing and Action Planning

Step 1 and 2 were planned to be done as presented in the initial ARCA method (see Section 4.2).

In Step 3, based on the experiences collected from Case A (see Section 5.3.4), two changes were made to the method. The first modification was to change the practice of how the RCA team members presented the causes they written (see Section 4.2.3.1). The RCA team members were to be asked to place causes into a cause entity as a branch after another starting from the first branch. Immediately after the first RCA team member set the first cause to the branch a short conversation was to be held where causes from other RCA team members were to be added to the branch. After the first branch was analyzed, the attention was to be moved to the cause entity's second branch following the same process. The second modification was to remove the prioritization of the detected root causes from the first workshop session (see Section 4.2.3.2). That was planned to be done after the first workshop session through an email inquiry, as it was done in Case A. The RCA team members were given two weeks time to do this. This modification facilitated the first workshop session and this way the RCA team members were able to propose important root causes without disturbance.

In Step 4, the root causes to be processed were planned to be selected in the same way as in Case A, but two new approaches to develop corrective actions were to be tested. This was because in Case A (see Section 5.3.4) the RCA team members wanted more time to discuss the best corrective actions and the bottleneck problem persisted during the prioritization of the corrective actions. In this case the corrective actions were planned to be developed by using the approaches "*writing alone + brainstorming all together*" and "*writing in a team of three people + brainstorming all together*". In the first approach the RCA team members were first to be asked to silently write down corrective actions on papers during ten minutes and then to present them one after another. This was followed by a short conversation where the corrective action was to be complemented and written down by an RCA facilitator. In the second approach the RCA team members were first to be asked to write down corrective actions in groups of three during seven minutes and then to be asked to present the corrective actions one after another following a short conversation where the idea was to be complemented and written down by an RCA facilitator. In the both approaches the RCA team members were planned to work with a same root cause simultaneously. The prioritization of the corrective actions was to be done by putting up one's hand. The selected root causes were to be prioritized by the RCA team members in the beginning of the workshop session. The reason was to guarantee that if the time runs out the most important root causes are processed. Additionally, the name of this step was changed to "Elimination idea Innovation", since it described the step more clearly than "Elimination" and was a more systematic name alongside with other ARCA steps.

5.4.3 Action Taking

Step 1 – Creating ARCA Team

The RCA team members were selected so that they had no earlier experience on RCA and they were all developers. The reason for this was that the RCA facilitators of the company wanted to familiarize them with RCA. The RCA team members worked with the same product, but in different development teams. Three RCA facilitators represented the

company. Of these, two were quality managers and one was a senior development manager. However, the quality managers did not take part in step 3 nor step 4.

Step 2 – Problem Detection

As a total 54 blocker type defects were sampled, and ten of the most promising defects were included in the email inquiry to represent the set of blockers for the RCA team members. Additionally, the causes from the company's earlier RCA case around the target problem were used while structuring the preliminary cause-effect diagram. Otherwise the step was done as planned.

Step 3 – Root Cause Detection

The step was done as planned.

Step 4 – Elimination Idea Innovation

The corrective actions were developed for two of the most highly prioritized root causes out of five, because of the lack of time. Additionally, the RCA team members prioritized the impact of a corrective action on a root cause, and thus not on the target problem.

5.4.4 Evaluating and Specifying Learning

The researchers noticed that the RCA team members didn't voice all the causes they wrote down. This could have been due to the fact that they didn't want to say the cause they had written down or because the cause had been already mentioned.

In contrast to Case A, the conversation took a lot of time without a noticeable increase in the quality of the corrective actions in both approaches used in the second workshop session. Additionally, the number of corrective actions was almost three times lower than in Case A. In the second approach the groups were not able to generate corrective actions together as efficiently as they were able to individually generate in the first approach.

Organizing the detected causes was experienced as a challenging task by the researchers. Also the feedback data from the cases A and B pointed out that organizing the causes might be a challenging task.

Table 6: The perceived challenges in the ARCA method during Case B

Perception	Source	ARCA step
Some of the RCA team members didn't voice all the causes they wrote down.	Observation	Step 2
Organizing causes is a challenging task.	Participation & Feedback Forms	Step 1 & Step 2
The conversation is hard to keep in focus.	Participation	Step2 & Step 3
If corrective actions are developed by using brainstorming, it follows that the conversation takes a lot of time.	Observation	Step 3
All the selected root causes were not processed.	Observation	Step 3

5.5 Case C

5.5.1 Introduction

Company C is a medium-sized international software company with approximately one hundred employees. The company's software product can be characterized as a service which is highly configurable for different customer needs. The product is delivered for the customers through installation projects which occasionally include development of new features. New software versions are released regularly.

The company uses approximately three to five percent out of its annual budget on SPI activities. These are managed by a quality manager, assisted by a quality management system. To help the quality manager, the project teams use weekly meetings where both the good and bad project experiences are discussed. A written project report including the customer feedback is made after the most important installation projects. In Interview 1 the company's representatives hoped that the ARCA method could help them learn more about RCA and develop good corrective actions for a target problem. The company's earlier experiences on RCA were fairly low.

The target problem for the ARCA method was that the installation projects currently are very challenging. It follows that the projects' costs increase, because more effort is needed. The company's representatives stressed that the problem has a significant impact on their customer relationships and it is very complex to prevent. While asking the representatives to estimate the main reasons for the problem, they said that employees have too many different ways in which to make a product installation. The reason is that it hasn't been defined well enough how the installation projects should be preceded. Additionally, the number of different stakeholders is too high when comparing to the quality of communication between them. The representatives estimated that the target problem could be minimized by creating checklists and simplifying the installation process.

5.5.2 Diagnosing and Action Planning

Step 1 was planned to be done as presented in the initial ARCA method (see Section 4.2.1).

Step 2 was planned to be done in general as presented in the initial ARCA method. However, the preliminary cause-effect diagram was to be organized by using premade cause categories: *gratuitous large workload*, *hard to meet time schedules*, *labor-consuming tasks*, *lack of information*, *mistakes are made*, *defects are not detected*, and *installation and updates require a lot of information*. This kind of a cause-effect diagram is defined as an Enumeration fishbone diagram, as presented in Section 3.5.3. The idea was to facilitate the cause organizing task which was experienced challenging in the cases A and B.

Step 3 was planned to be done almost in the same way as it is presented in the initial ARCA method. The difference was that the conversation around a cause presented by an RCA team member was not to be held immediately. Instead all the RCA team members' causes were first to be added to a cause entity, thereafter a short conversation was to be kept around the whole cause entity. In the conversation, the RCA team members were to be asked to check if there were any insufficiently specified causes and to name the missing sub causes if discovered. The problem of the conversation being hard to keep in focus was the reason for these changes.

Step 4 was planned to be done almost in the same way as it was done in Case A (see Section 5.3.3). Unlike in Case A, the RCA team members were to be given seven minutes time to work with the first three root causes. Thereafter the time was to be extended to ten minutes for the last two root cases. The problem of the RCA team members not having enough time to read the other RCA team member's corrective actions carefully and to comment on them was the reason for this change. To tackle the bottleneck problem which was discovered in Case A, the corrective actions were to be prioritized one by one passing them immediately forward to the next RCA team member.

5.5.3 Action Taking

Step 1 – Creating ARCA Team

The RCA team members were selected as recommended in the initial method, however, stakeholders from neither quality assurance nor product management were not included. The RCA facilitator of the company was a project manager from a development team.

Step 2 – Problem Detection

The step was done as planned.

Step 3 – Root Cause Detection

The step was done almost as planned. However, the RCA team members unexpectedly decided to prioritize the most important causes in the finalized cause-effect diagram in the very end of the first workshop session. This was to give a focus for the RCA team members to propose the root causes to be processed in step 4.

Step 4 – Elimination Idea Innovation

The step was done as planned.

5.5.4 Evaluating and Specifying Learning

Organizing the causes under preliminarily defined cause categories was perceived to be an easy way to detect the most important cause entities to be processed in the first workshop session. However, organizing the diagram was experienced to be even harder than in the previous cases. The RCA facilitator of the company also commented that organizing the causes was very challenging. One potential reason for this could be that in Case C some of the cause categories actually explained one another. As an example, it is *hard to meet time schedules* because *mistakes are made* (see Section 5.5.2). Thus many causes belonged under multiple cause categories which aggravated the work.

Table 7: The perceived challenges in the ARCA method during Case C

Perception	Source	ARCA step
Organizing causes is challenging if they are organized under cause categories which explain one another.	Participation	Step 1
Organizing causes is a challenging task	Participation & Feedback form	Step 1 & Step 2

5.6 Case D

5.6.1 Introduction

Company D is a medium-sized international software company with approximately 110 employees. The company's product can be characterized as a highly complex software system. The product is delivered to customers through complex integration projects where the product is configured into a software system of the customer.

Approximately four to five percent out of the annual budget of the company is focused on the SPI activities. The company's management team is responsible for writing process guidelines and for developing the software development process in general level. Coding and testing teams are required to develop their daily work through regular SPI meetings. The teams work together regularly. The company uses software tools to assist SPI. In Interview 1 company's representatives said that the company's earlier experiences around RCA are fairly low, but that they do think about causes for problems. On the other hand, the representatives said that causes for problems are not analyzed deeply enough, because employees believe that the problem causes are already known. The managers hoped that the ARCA method could help them find concrete recommendations and confirmations on how to improve communication between different stakeholders.

The target problem for the ARCA method was that the lead time of an issue is occasionally intolerably long resulting in delays in projects. The company's representatives valued the target problem as high, because it has a severe financial impact. It follows that the projects are not finalized in time. They said that the complexity of the target problem is mainly dependent on two reasons: first, communication between different stakeholders and second, the way the company is dividing resources between the issues. Usually an issue with fairly low priority doesn't get enough resources. They concluded that preventing the problem is not an easy task. While asking the representatives to make a guess on how the problem could be best prevented, they answered that the best ways to prevent the problem are: increasing face-to-face meetings, increasing the number of inspections, and allocating skilled project managers to be responsible for the issues. The company hasn't tried to prevent the target problem earlier. However, they have tried to improve the communication between stakeholders.

5.6.2 Diagnosing and Action Planning

Step 1 was planned to be done as presented in the initial ARCA method.

Step 2 was planned to be done as presented in the initial ARCA method.

Step 3 was planned to be done almost the same way as it was done in Case C. Classifying the causes under preliminary cause categories was relinquished.

Step 4 was planned to be done exactly the same way as it was done in Case C.

5.6.3 Action Taking

Step 1 – Creating ARCA Team

The step was done as planned.

Step 2 – Problem Detection

The step was done as planned. Additionally, the issues were sampled to be presented as examples to the RCA team members.

Step 3 – Root Cause Detection

The step was done as planned.

Step 4 – Elimination Idea Innovation

The step was done as planned.

5.6.4 Evaluating and Specifying Learning

Organizing causes was experienced by the researches as a challenging task. The RCA team members added causes to wrong braches in the diagram. The reason could be that since the number of the detected causes was relatively high, it was impossible to get "a big picture" of the diagram easily. Thus the RCA team members added causes just "some place" and believed that the RCA facilitators would move them to the correct place after the workshop session.

In Step 4 some of the RCA team members did not have enough time to finalize their corrective actions, due to the given time for processing the root causes being too short.

Table 8: The perceived challenges in the ARCA method during Case D

Perception	Source	ARCA step
Organizing causes is a challenging task.	Participation	Step 1 & Step 2
In the first workshop session the conversation was hard to manage. New causes, which were detected from the conversation, were compacted under wrong branches.	Observation	Step 2
Some of the RCA team members did not have enough time to finalize all of their corrective actions, because the given time was too short.	Observation	Step 3

6. Evaluation of the ARCA Method

In this chapter the ARCA method used in the cases is evaluated from the following viewpoints: detected causes and corrective actions, used effort in the cases, easiness to use and learn the method, and feasibility of the method for problem prevention. The viewpoints represent the research questions 1 to 4 (see Section 1.5). The evaluation follows the empirical evidence from the cases and discusses what the results means. The conclusions to the research questions are presented and compared to previous research in Chapter 8.

6.1 Detected Causes and Developed Corrective Actions

This section discusses the corrective actions developed in the cases and analyzes their impact on target problems in general. The discussion follows the empirical evidence from the cases and represents the research question 1 (see Section 1.5).

To evaluate the corrective actions developed in the cases, three important aspects arise: 1. the correctness of detected causes in contrast to the target problem, 2. the importance of the root causes selected to the second workshop sessions, and 3. the number of high quality corrective actions per root cause. The correctness of detected causes means that the causes which are detected are actually concern the target problem or some of its causes. The importance of the selected root causes means that the more important a processed root cause is the higher is its impact on the target problem and the easier it is to eliminate. The high quality of a corrective action corresponds to a corrective action which has a significant impact on the target problem and is feasible in practice.

6.1.1 Correctness of the Detected Causes

The correctness of the detected causes is analyzed from two perspectives. First, the opinion of the RCA team members on the correctness of the detected causes in general. Second, the opinion of the RCA facilitators on the significance of detected root causes in general. While asking the RCA team members to value the correctness of the detected causes in general (see Figure 13) the answers supported the RCA facilitator(s) answers (see Table 9): correct causes were detected.

Figure 13 presents the evaluations of the RCA team members of the correctness of the detected causes in general. It seems that most of the detected causes were correct, because the correctness of the detected causes was estimated as high in each case.

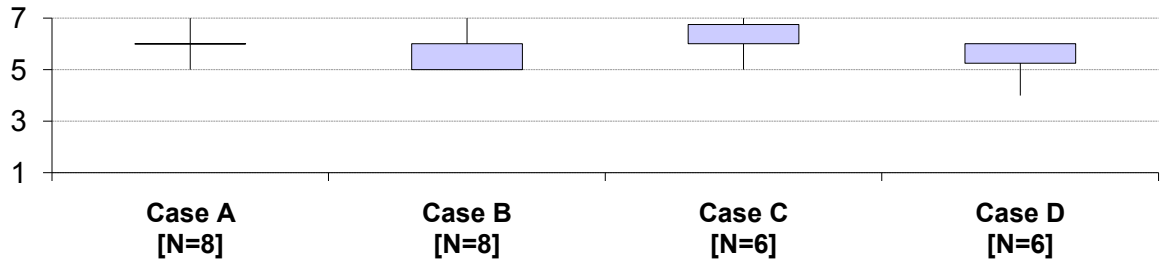

Figure 13: The correctness of the detected causes
[Scale 1=very bad, 2, 3, 4, 5, 6, 7=very good]

Table 9 presents the assumptions of the RCA facilitators on the significance of the detected root causes. Most of them thought that the root causes were significant if compared to the target problems.

Table 9: The answers of the RCA facilitators about the significance of the root causes

Question	Case A	Case B	Case C		Case D
	Person 1	Person 2	Person 3	Person 4	Person 5
In general, were the detected root causes significant if compared to the target problem? (Part 3, question 2)	*Most of the causes were significant. However, 10 to 20 percent out of those was unsatisfactory.*	*As a general rule, yes. We have already butt in one of the causes!*	*Yes they were. They matched well with my conception.*	*Yes they were. I already knew some of those.*	*Yes they were. The causes were mainly issues, which lead the problem.*

6.1.2 Importance of the Processed Root Causes

This section discusses the importance of the processed root causes. The main question is that did the RCA facilitators select such root causes to be processed in the second workshop session that had a major impact for the target problem and that were easy to eliminate. The importance of the processed root causes is analyzed by using three data sources presented in this section. First, the root causes proposed and evaluated by the RCA team members. Second, the general estimations of the RCA team members in the end of the first and second workshop sessions on the easiness to eliminate the detected and processed root causes. Third, the general estimations of the RCA team members on the importance of the processed root causes for the target problem.

Figure 14 presents the averages of the impact estimations and the elimination ability estimations of all the proposed and selected root causes. As presented earlier, the RCA team members were first asked to propose and evaluate 10 to 15 important root causes to be processed in the second workshop session. Then the RCA facilitators of the companies did the selection of the processed root cases based on these propositions and their personal experience. It seems that the processed root causes in Case B were slightly harder to eliminate and their impact for the target problem were higher than the proposed root causes. This could mean that the RCA team members of Case B proposed root causes, which were the easiest to eliminate. However, the RCA facilitator of Case B selected the root causes that had the highest impact for the target problem. Maybe the causes that have a high impact for a target problem are not the easiest to be eliminated in general. In the cases A, C, and D there was no clear difference between proposed and processed root causes.

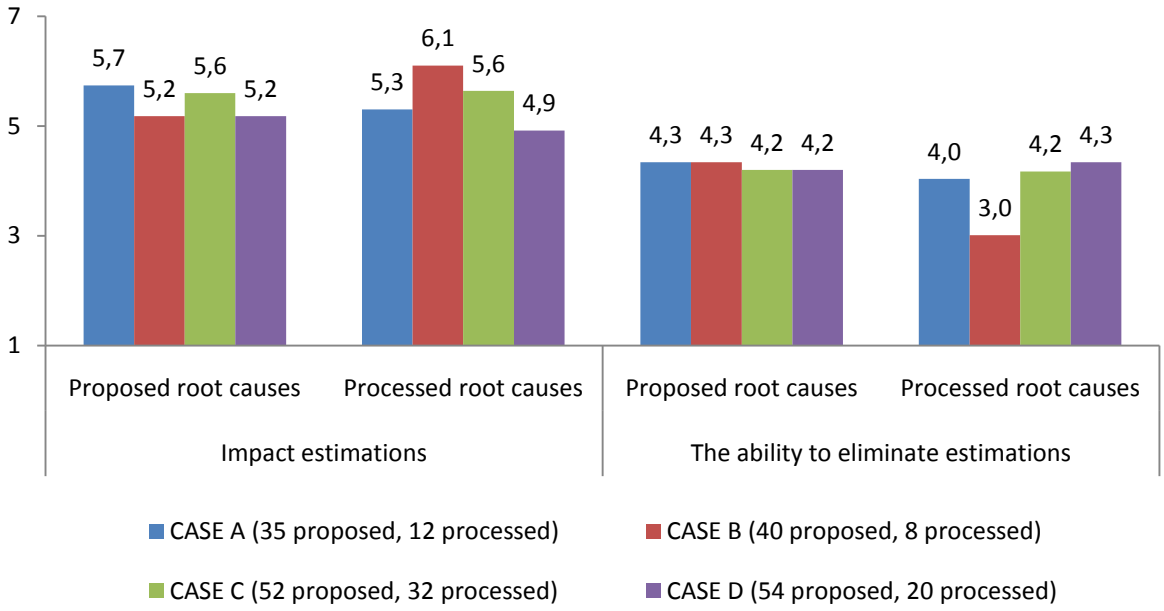

Figure 14: The impact and the ability to eliminate the detected and processed root causes (scaled to 1-7) [Original scale was 1=very low, 2, 3, 4, 5=very high]

Figure 15 presents the estimations of the RCA team members on the general easiness to solve the detected root causes and on the general ability to eliminate the processed root causes. The first estimation was performed after the first workshop session. The second estimation, thereafter, was performed after the second workshop session. It seems that in the cases A and D, generally the detected root causes were estimated slightly easier to eliminate than the processed root causes. On the other hand, in Case B, the processed root causes were generally slightly easier to eliminate than the detected root causes (see Figure 15).

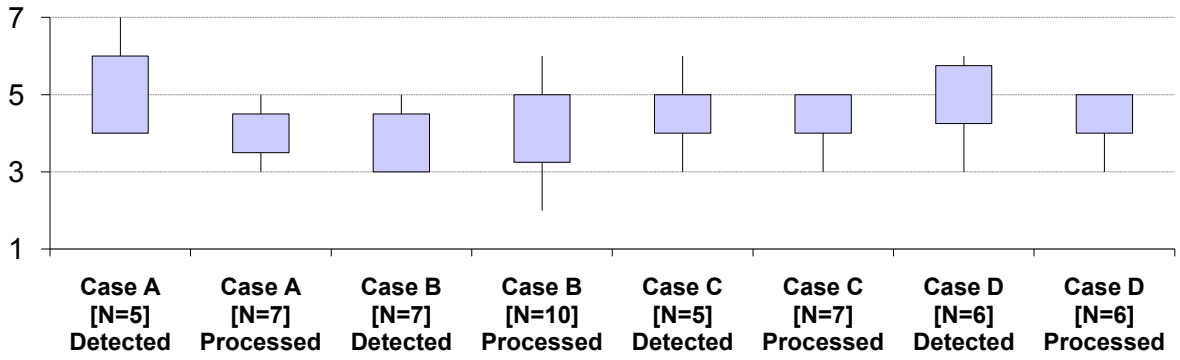

Figure 15: The ability to eliminate the detected and processed root causes in general [Scale 1=very bad, 2, 3, 4, 5, 6, 7=very good]

Figure 16 presents how the RCA team members evaluated generally an importance of the processed root causes in contrast to the target problem. Unfortunately this question wasn't asked the RCA team members in Case A neither in Case B, thus the figure includes only

answers from the cases C and D. It seems that the processed root causes were important for the target problems in both cases.

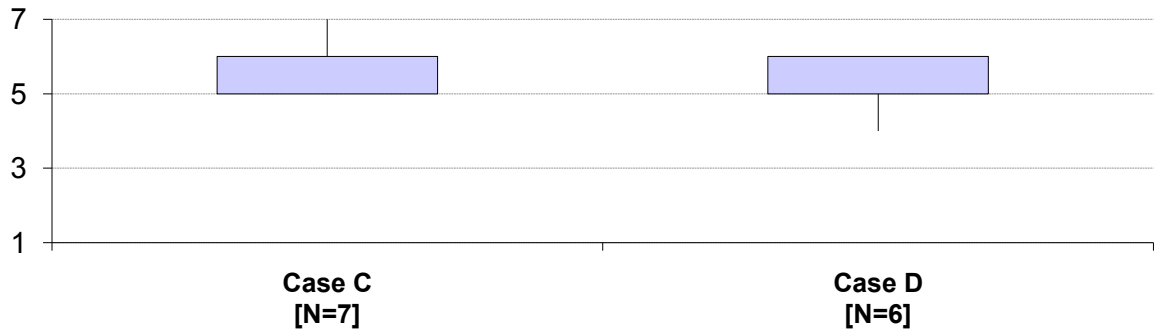

Figure 16: The importance of the processed root causes for the target problem in general [Scale 1=very bad, 2, 3, 4, 5, 6, 7=very good]

As a summary, the processed root causes were experienced a bit more difficult to develop corrective actions for than the detected and proposed root causes (see Figure 15 and Figure 14). On the other hand, the impact estimations of the proposed root causes were a bit lower than the processed root causes (see Figure 14). The RCA team members of the cases C and D valued the importance of the processed root causes as high, as presented in Figure 16. These lead to conclude, that the processed root causes were important, because their impact for the target problems was high.

6.1.3 Quality of the Corrective Actions

To estimate the quality of a corrective action two aspects were considered: a feasibility of a corrective action and its impact on the target problem.

Each corrective action was evaluated in each case by each and every RCA team member. This was conducted by using two attributes: impact [1=very low, 2, 3, 4, 5=very high] and feasibility [1=very low, 2, 3, 4, 5=very high]. In the cases A, C, and D, the impact of a corrective action was evaluated on the target problem. In Case B, the impact was evaluated on the related root cause. Figure 17 presents averages of the evaluations per corrective action as scatter charts. If the averages are interpreted so that a value of 4 or more corresponds to “high”, whereas a value of 2 or less corresponds to “low”, there was more high impact than low impact corrective actions. On the other hand, the feasibility of the corrective actions was distributed evenly including both high and low feasibility corrective actions.

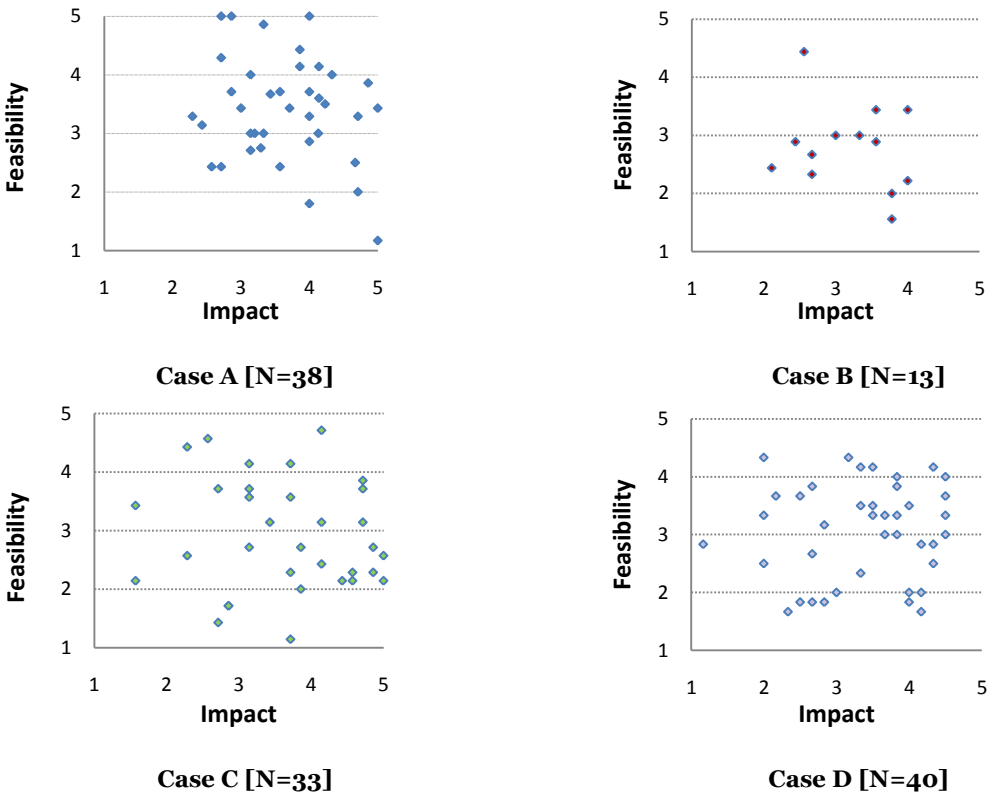

Figure 17: The corrective actions in the cases

Since the impact and feasibility rates of the corrective actions are between 1 and 5, their multiplication is between 1 and 25. I call this multiplication as a *combined effect*. The combined effect represents the goodness of a corrective action, because a very good corrective action has a high impact on the related target, but it is also highly feasible. In the worst case the combined effect is 1, and in the best case the combined effect is 25. Figure 18 presents all of the corrective actions of the cases distributed into three classes: 1. combined effect is less than 9 which corresponds to a bad or neutral corrective action, 2. combined effect is between 9 and 16 which correspond to a good corrective action, and 3. combined effect is more than 16 which corresponds to a very good corrective action. It seems that most of the corrective actions were good. Instead the cases A, C, and D, there were no very good corrective actions in Case B.

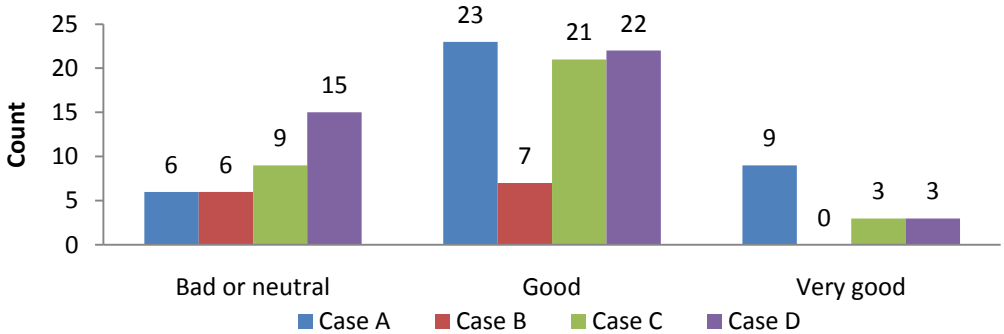

Figure 18: The distribution of corrective actions into classes of combined effects (N=124)
[Scales: Bad or neutral (Combined effect < 9), Good (9<=Combined effect<16),
Very good (Combined effect >=16]

Figure 19 presents the distribution of the evaluations of the RCA team members on the feasibility and impact of the corrective actions in general. It seems that in Case B, the feasibility of the corrective actions was evaluated lower than in the other cases.

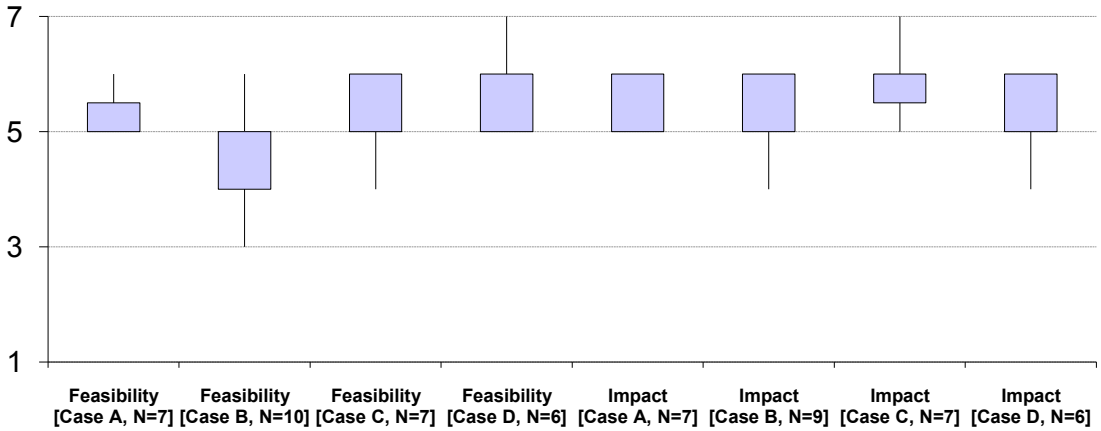

Figure 19: The perceived feasibility and impact of the corrective actions in general
[Scale: 1=very bad, 2, 3, 4, 5, 6, 7=very good]

Table 10 presents the RCA facilitators' answers in Interview 2 on the impact and feasibility of the corrective actions in general. It seems that the impact of the corrective actions was high, however, their feasibility varied.

Table 10: The RCA facilitators' answers about the impact and feasibility of the corrective actions

Question	Case A	Case B	Case C		Case D
	Person 1	Person 2	Person 3	Person 4	Person 5
In general, do the corrective actions prevent the target problem? **(Part 4, question: 3)**	*Yes, I think they do, because they have a major impact on the selected root causes. These in turn would minimize significantly the problem. Costs vs. impact are good.*	*No, I think that the corrective actions don't prevent the problem, but they do help us to improve our processes.*	*Yes they do! We even wouldn't need to implement them all to prevent the problem.*	*I think that the corrective actions won't remove the problem completely, but they do have a major impact on the problem's sub-fields.*	*Yes, the impact would be enormous.*
Are the corrective actions feasible? **(Part 4, question: 4)**	*The costs of the corrective actions are fairly low in a short term. On the other hand, the needed resources are taken away from somewhere else. Our organizational culture might form an obstacle.*	*The developed corrective actions are feasible.*	*Yes they are! We have already implemented some corrective actions for root cause 1 and 2.*	*There are a lot of feasible and upgradeable corrective actions in the set of them all.*	*The bulk of the corrective actions were feasible. However, some of the ideas are more challenging to implement than others.*

The general opinion of the RCA facilitators seems to be that the developed corrective actions do have a major impact for their target problem. However, some of them are unfeasible to be implemented because of lack of resources, organizational culture, or the fact that some of them just are too challenging (see Table 10).

One element of success in developing corrective actions is the number of corrective actions. Because of the practices used in the second workshop session in the cases A, C, and D were more efficient than in Case B, there simply were more alternatives to select from as a result. Only 13 corrective actions were developed in Case B, while in the other cases more than 33 corrective actions were developed (see Figure 17). Additionally, there wasn't any corrective action in Case B, which would have been valued at the same time with both a high impact and a high feasibility, as presented in Figure 17. By analyzing the combined effects of the corrective actions (see Figure 18) the corrective actions in Case B weren't very good. The RCA team members of Case B estimated the general feasibility of the corrective actions lower than in other cases (see Figure 19). However, in Interview 2 with the RCA facilitator of Case B, it wasn't highlighted that the corrective actions were unfeasible (see Table 10).

Another element of success might be the assemblage of RCA team members. Many managers were present in the cases A, C, and D, whereas in Case B only one manager was present (see Table 4). Perhaps the managers valued the corrective actions higher than the developers and testers.

6.1.4 Coverage of the Corrective Actions

The coverage of the corrective actions here means the proportion of processed causes with good corrective actions compared to the number of detected causes. In the cases hundreds of causes were detected and only two to six root causes including their sub causes, were processed in the second workshop sessions. This section discusses the coverage of the corrective actions in the cases.

Table 11 presents the number of detected and processed causes. The detected causes include all the causes collected from an email inquiry and from the first workshop session. The processed causes include all the processed root causes including their sub causes from the second workshop session. It can be concluded that there were a lot of root causes which were not processed.

Table 11: The detected and processed causes

	Case A	Case B	Case C	Case D
The number of the detected causes	173	245	171	168
The number of the processed causes	41	24	77	42
Proportion of processed causes %	23.7%	9.8 %	45 %	25 %

Table 12 presents the processed root causes which resulted in good or very good corrective actions. Good and very good corrective actions correspond here to the combined effect defined in Section 6.1.3 (see Figure 18). It seems that every root cause results at least in

good corrective actions. Additionally, in the cases A, C, and D, most of the root causes results to very good corrective actions.

Table 12: The root causes with good or very good corrective actions

	The number of processed root causes	The number of root causes with at least one very good corrective action [combined effect > 16]	The number of root causes with at least one good corrective action [combined effect > 9]
Case A	6	5	6
Case B	2	0	2
Case C	5	3	5
Case D	6	3	6

The number of the collected causes was almost the same in the cases A, C, and D. In Case B, the highest number of causes was collected, but the lowest number of root causes was processed (see Table 11). The ultimate reason for the lowest number of the processed root causes in Case B is most likely the practice used in the second workshop session which was not sufficient (see Section 5.4.4). On the other hand, the reason for the highest number of the detected causes in Case B could be that maybe the RCA team members of the case were analyzed the target problem earlier, as they evaluated the earlier effort their company has used to prevent the target problem clearly higher than the RCA team members in other cases (see Figure 9).

In no case very good corrective actions were developed for all of the root causes. However, good corrective actions were developed for all the root causes (see Table 12). These covered 45 percent of the causes in the best case (Case C) and 9.8 percent in the worst case (Case B).

6.1.5 Summary

In each of the cases the RCA team members' and the company's RCA facilitators' general opinion was that the correct causes in contrast to the target problem were detected (see Figure 13 and Table 9).

The processed root causes were important for the target problem (see Figure 16) and good corrective actions were developed for each of them (see Table 12). It also seems that the most of the corrective actions were generally good or very good (see Figure 18). The RCA team members and the RCA facilitators alike estimated that generally the corrective actions have a high impact on the target problem, while many of them also are feasible (see Figure 19 and Table 10). The corrective actions were focused on the processed root causes, thus leaving the other causes intact. This means that the case companies might have to deal with them later (see Table 11).

6.2 Required Effort to Conduct the ARCA Method

This section presents how much effort was required to conduct the cases. By decreasing the effort without impacting the results of the method output would make the method more efficient. In seems to be that decreasing the number of RCA team members will decrease the required effort best. The discussion follows the empirical evidence from the cases and represents the research question 2 (see Section 1.5).

Table 13 presents the used effort in the ARCA steps divided into individual activities. These include the effort used in the case companies and by the researchers alike. It seems that in the later cases the required effort was lower than in the earlier cases. The reason for this could be that the ARCA method was improved in-between the cases.

Table 13: The used effort in the cases

ARCA -step			Case A		Case B		Case C		Case D	
			Effort (h)	People	Effort (h)	People	Effort (h)	People	Effort (h)	People
Step 1 & Step 2	Creating ARCA team and Problem Detection	Meetings	17	10	10	5	6	6	5,5	4
		Preliminary cause collection	3,5	7	5	5	3	6	1,3	4
		Organizing the cause - effect diagram	9	1	10	1	17	2	9	1
		Focus selection and preparation work	4	4	5	5	11	3	2	2
Step 3	Root Cause Detection	First workshop session	20	10	20	10	16	8	14	7
		Root cause identification and selection	6	5	6	8	3	6	9,6	7
Step 4	Elimination Idea Innovation	Preparation work	8	1	8	1	8	1	8	1
		Second workshop session	19	7	20	10	14	7	12	6
		Final report	12	1	12	2	12	2	12	1
Total			**98,5**		**96**		**90**		**73,4**	

Figure 20 presents the number of detected causes in steps 2 and 3 which correspond to the email inquiry and the first workshop session (WS1).

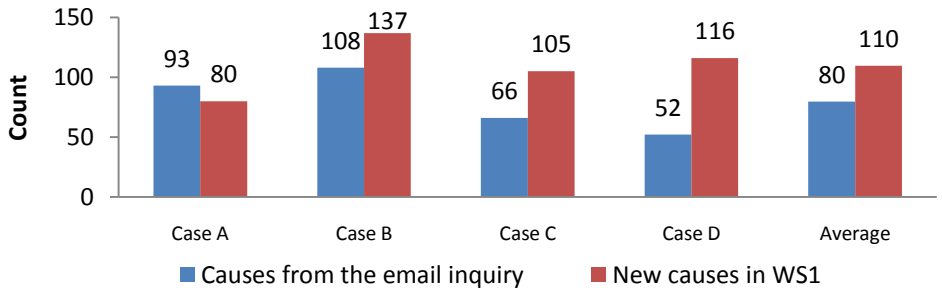

Figure 20: The number of detected causes in ARCA steps 2 and 3

6.2.1 Used Effort in Step 1 and Step 2

Steps 1 and 2 consisted mainly of four activities: meetings, preliminary cause collection, organizing the preliminary collected causes into a cause-effect diagram, focus selection for the first workshop and preparation work of the first workshop session. Most of the effort was used in meetings and in organizing the collected causes into a cause-effect diagram (see Table 13). The meetings were important and very much case context dependent, thus their duration was as long as needed. Otherwise the risk of selecting a worthless target problem or including wrong RCA team members to the RCA team could have been higher. Required effort to organize a cause-effect diagram depended on the number of the preliminary collected causes and the contextual expertise of the RCA facilitators. Comparing Table 13 to Figure 20, it seems that the more the RCA team members used effort on the preliminary cause collection, the more preliminary causes were detected.

6.2.2 Used Effort in Step 3

This step included the first workshop session and the identification work of the teams on important root causes. The required effort depended mainly on the number of RCA team members. Because the workshop session was time-boxed to take 2 hours, the more people there were, the higher was the required effort (see Table 13).

The proportion of detected causes in the workshop session was higher in later cases. This becomes evident by comparing the number of RCA team members to the number of detected causes between the cases (see Table 13 and Figure 20). The reason here could be that the researchers were more experienced in the later cases, and the way the causes were added to a cause-effect diagram improved as the workshop sessions progressed. As presented earlier, the RCA team members in the cases C and D estimated their personal contribution to the first workshop session higher than the RCA team members in the cases A and B (see Section 5.2 and Figure 12). Thus, there is a possibility that because the ARCA method was improved in-between the cases, the proportion of detected causes was higher and the RCA team members were more devoted. Another possibility is that the proportion of detected causes was higher only because the RCA team members were more devoted. However, many other things, for example a target problem (see Section 5.1) and the expertise of an RCA team (see Section 5.2), could provide an explanation for the higher proportion of detected causes.

As already presented in the case overviews (see the sections 5.3 to 5.6), the identification of the important root causes was conducted through an email inquiry where the RCA team members were allowed to use as much time as needed to propose the root causes to be processed in the second workshop session. Thereafter the RCA facilitator(s) of the company did the final selection of the root causes.

6.2.3 Used Effort in Step 4

This step consisted of the preparation work of the second workshop session, the second workshop session itself, and the documentation the case results. The workshop session was time-boxed to take 2 hours at a maximum, thus the more people were present the higher was the required effort. By comparing the number and the quality of the developed corrective actions (see Section 6.1.3), and then comparing the results above to the number of RCA team members present in the second workshop session (see Table 13), there is no

evidence that the more there are RCA team members present the better are the results of the ARCA method.

The documentation of the results was done by using a preliminary developed template, thus the needed effort, surprisingly, was the same in all the cases.

6.3 Easiness to Use and Learn the ARCA Method

This section evaluates the easiness to use and learn the ARCA method. The discussion follows the empirical evidence from the cases and represents the research question 3 (see Section 1.5). To evaluate the easiness to use and learn the method, two perspectives are considered: the perspective of the RCA facilitator and the perspective of the RCA team members. While the RCA facilitator is looking at the method more from the overall perspective, the RCA team members take part in its particular steps. The perspective of the RCA facilitator was analyzed by Interview 2 and the perspective of the RCA team members was analyzed by the feedback forms.

Organizing the causes into a cause-effect diagram was perhaps the hardest activity in the method since the RCA team members constantly estimated the easiness to organize causes lower than the easiness of the elimination method (see Figure 21). The RCA facilitator of Case C stressed that organizing the causes into the cause-effect diagram was challenging (see Table 14). This was also noted by the researchers during the cases B, C, and D (see the sections 5.4.4, 5.5.4, and 5.6.4). This could also have had an impact on the easiness to detect the root causes from the cause-effect diagram (see Figure 21). The method for developing corrective actions was experienced as the easiest activity of the ARCA method (see Figure 21).

Figure 21 presents how the RCA team members valued the easiness of different ARCA activities. The answers of the Case B RCA team members for "easiness of the elimination method" are removed, because a different method, in comparison to the other cases, was used to develop corrective actions in Case B. It seems that the easiness of the method used in the corrective action development was experienced very high, whereas the easiness to detect root causes and organize them was experienced only slightly better than neutral.

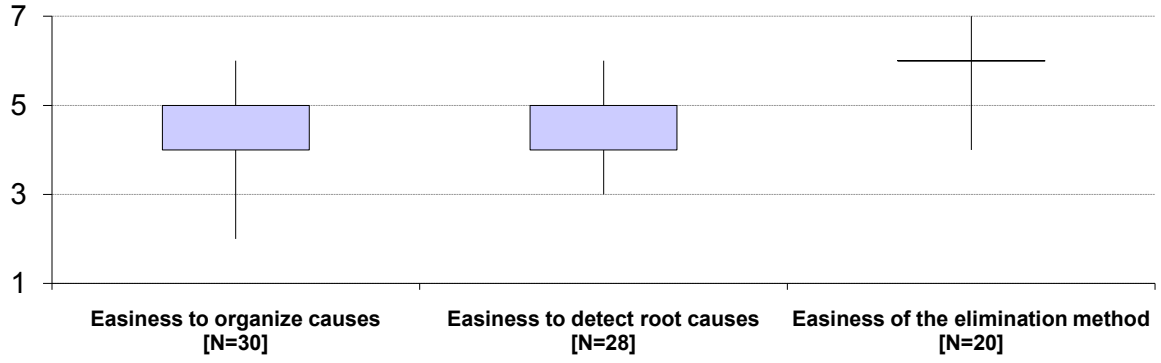

Figure 21: The easiness of the ARCA activities
[Scale 1=very bad, 2, 3, 4, 5, 6, 7=very good]

Table 14 summarizes how the RCA facilitators answered when they were asked to estimate how easy and learnable the ARCA method is. It seems that the ARCA method was experienced very easy to use and learn in general. However, the RCA facilitator of Case C stressed that organizing causes is challenging. Additionally, the RCA facilitator of Case D puzzled that learning the ARCA method requires motivation and that the ARCA method might be harder to perform without the assistance of the researchers.

Table 14: The answers of the RCA facilitators to a question about how easy and learnable ARCA is

Question	Case A	Case B	Case C		Case D
	Person 1	Person 2	Person 3	Person 4	Person 5
How easy and learnable is ARCA? **(Part 5, question: 1)**	*ARCA is very easy to use and internalize. Additionally, premade templates help a lot.*	*ARCA is easy and worthwhile in contrast to used calendar time and its output.*	*ARCA method is very easy to use and learn.*	*ARCA is not hard, it is fairly easy to use and learn. Organizing causes is challenging.*	*ARCA was easy with the assistance of the researches. I think that ARCA is easy to learn, if the motivation is high.*

6.4 Feasibility of the ARCA Method for Problem Prevention

This section discusses the feasibility of the ARCA method for problem prevention, by comparing it to current state-of-practices in the case companies. The discussion follows the empirical evidence from the cases and represents the research question 4 (see Section 1.5).

Figure 22 summarizes the answers of the RCA team members, when they were asked to compare the ARCA method for their company's current practices. It seems that the method was experienced fairly feasible to detect totally new process improvement targets. Additionally, the method was experienced very feasible to develop process improvement ideas.

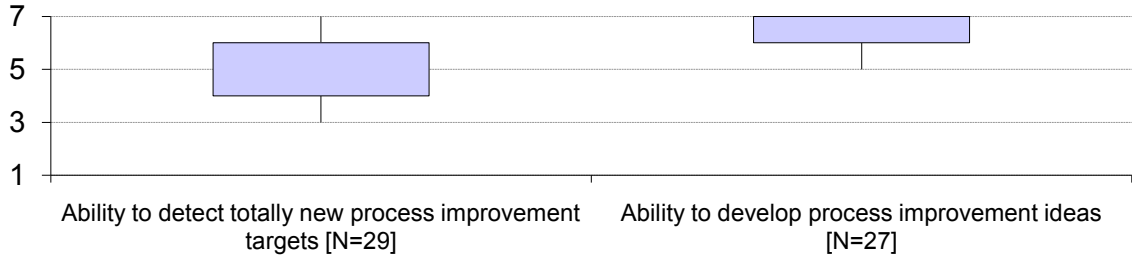

Figure 22: The ARCA method in contrast to the current state-of-practices in the case companies [Scale 1=very bad, 2, 3, 4, 5, 6, 7=very good]

Table 15 presents the companies RCA facilitators' answers to the questions which helped compare the method for the case companies' current state-of-practices. According the RCA facilitators, the same causes would not have been detected just by listing them generally. They also stated that with higher costs it would have been possible to develop similar process improvement ideas without the detection of root causes. On the other hand, many RCA facilitators stressed that the required effort of the method should be a bit lower. Their

proposal was that this could be reached by using a smaller number, but more talented RCA team members. When they were asked if their organization should adopt the ARCA method, most of them were acquiescent (see Table 15). By combining these results with the results presented in Section 6.1 it is reasonable to claim that the ARCA method is a feasible method for problem prevention when comparing to the current state-of-practices in the case companies. Additionally, the RCA team members experienced that the ARCA method is better in detecting totally new process improvement targets, and developing process improvement ideas than their company's current practices are (see Figure 22).

Table 15: The interviewees' answers about the ARCA method

Question	Case A	Case B	Case C		Case D
	Person 1	Person 2	Person 3	Person 4	Person 5
Would it been easier to detect the same causes just by listing them generally? (Part 3, question: 1)	*No, because this way we understand how the problem takes form. Additionally, communicating the causes for other people is easier if a cause-effect diagram Is used.*	*No, I think that this tree based approach is the best way to model the problem formation.*	*I don't think so. If only some of the causes could have been very easy to detect just by listing them generally. The email query worked well to collect the causes we already knew, but in Session 1 we got deeper understanding.*	*No, I don't think so. Cause-effect structure from the very beginning was very good. It helped us to understand the sub-sectors of the problem easily.*	*The systematic approach was the key here. I don't think that it would have been easier to detect the causes other ways. Some of the causes could have been possible to detect just by listing them generally.*
Would it have been possible to develop similar process improvement ideas without Root Cause Detection just by innovating generally "how could we improve our activities"? (Part 4, question: 1)	*Yes, but communicating them for supervisors would have been hard without the cause-effect diagram. Additionally, the ideas wouldn't have been as accurate.*	*Maybe.*	*It could have been possible to develop the same ideas, but ARCA did it more efficiently. ARCA gave clear weighting for the ideas thus helped us to decide what to process further.*	*I think it wouldn't be possible. ARCA divided the main challenge into smaller sub-challenges, and prioritization technique was good.*	*Yes, but not as efficiently.*
Would it have been possible to get the same results in lower costs by using some other practice? (Part 4, question: 2)	*No. We wouldn't be able to get this many relevant corrective actions. The elimination method used in this pilot case was very good and handy.*	*The method used in the case didn't take much time. There should be only one workshop session. I would drop the email inquiry.*	*I don't believe that. I don't know any such a method. It would have been very hard. Additionally, ARCA forced us to think both "good sides", but also "negative sides" of the ideas.*	*I think that "better practice" would be smaller group size and more talented experts in the second workshop.*	*I think that there's no better practice, but some other Brainwriting method, where ideas are developed in literal form, could work as well.*
Compared to the used effort, how would you characterize feasibility of ARCA? (Part 5, question: 2)	*ARCA is very feasible. 100 hours used in the case was basically nothing.*	*ARCA is a low cost method. By inviting lesser, but more talented people this would be very cheap method.*	*100 hours used in the case was fairly high for us. 60 hours would be feasible for us.*	*I think that the method was fairly economic. Maybe we could use this with lesser, but more talented people.*	*ARCA is fairly feasible, but costs should be a bit lower. I would say that 40 hours would be idealistic.*
Should your company adopt ARCA? (Part 5, question: 3)	*Yes we should. This works!*	*Very potential and easy method. Additionally, the costs are low.*	*I think that we should adopt this method. Coefficient of efficiency is good.*	*I would gladly try this method again. Formal prioritization was nice!*	*We should use this method, or very similar one.*

7. Improved ARCA Method

This chapter presents the further developed version of the method in the sections 7.1 to 7.4. Section 7.5 includes a discussion on how the improved ARCA method tackles the challenges detected in the ARCA method during the cases. The discussion follows the empirical evidence from the cases and represents the research question 5 (see Section 1.5). The conclusion to the research question is presented and compared to previous research in Chapter 8.

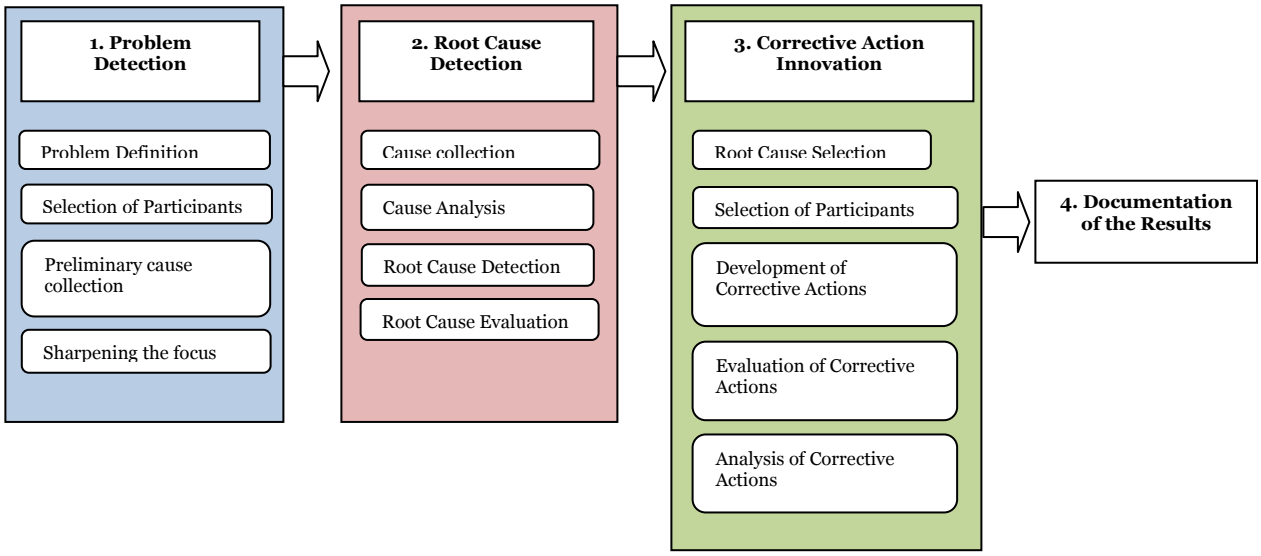

Figure 23: The improved ARCA method

7.1 Problem Detection

This is the first step of the improved ARCA method (see Figure 26). After this step has been conducted, the target problem is well defined, its preliminary causes are collected, and the focus of the analysis has been sharpened.

7.1.1 Problem Definition

RCA facilitator(s) and additional experts, if needed, define the target problem. The main task is to justify and document the following issues:

1. **What is the problem?**
   - The work process and its phases in which the target problem occurs, should be recognized

2. **Why exactly is this problem important to prevent?**
   - What are the reasons to why this particular problem should be analyzed?
   - It is recommended that:
     - The problem stands for the greatest and/or the most important set of problems
     - The problem is so critical, that its occurrence must definitely be avoided

7.1.2 Selection of Participants

In this phase, the RCA team members, who are to collect causes and to evaluate root causes, are selected. It is important to include as many experts and different stakeholders as possible. These should include project managers, developers, testers, software quality assurance staff, product managers, and process improvement group members.

7.1.3 Preliminary Cause Collection

Preliminary Cause Collection is an affordable and efficient way to collect indicative information on the target problem's causes. The preliminary causes are collected by the RCA facilitator, who sends an inquiry through email for the RCA team members. They are asked to list at least five causes of the target problem. Also, other participants can be included the inquiry. The inquiry should include the document that clarifies the target problem (see Section 7.1.1). Additionally, using causes detected in previous analyses should be exploited.

Since the causes in the email replies of the RCA team members most probably complement one another, the causes are organized into a cause-effect structure by the RCA facilitator(s) by using a cause-effect diagram (see Section 3.5.3). In the diagram each cause is written only once. If a cause belongs under several causes, arrows are drawn from the cause to the causes it explains. Usage of a software tool, like MindManager, XMind, or FreeMind, is recommended here as well as the later phases of the analysis.

7.1.4 Sharpening the Focus

Because available resources usually are constricted, the RCA facilitator(s) by using the cause-effect diagram, as presented in Section 7.1.3, should be able to recognize and select the most important cause entities to be processed in Workshop 1 (see Section 7.2.1). A cause entity means a cause and its sub causes, which together form an entity that is reasonable to process together. In Workshop 1, as a default three to four cause entities can be processed efficiently. That corresponds to circa 30 causes.

While selecting the cause entities the following issues should be noted:

- Can the cause entity be eliminated? If not, could its impact be decreased?
- Are the RCA team members capable to process the selected cause entities?

7.2 Root Cause Detection

This is the second step of the improved ARCA method, as presented in Figure 26. After this step, the cause-effect diagram is finalized and the most important root causes are detected and evaluated.

7.2.1 Workshop 1: Cause Collection and Analysis

Cause Collection and Analysis are conducted in Workshop 1, which has a recommended duration of a minimum two hours. The cause-effect diagram (see Section 7.1.3) should be projected on the wall by the RCA facilitator. Then the new causes should be collected under the selected cause entities (see Section 7.1.4).

7.2.1.1 Introduction

In the beginning of Workshop 1 the RCA facilitator presents the target problem, the preliminary causes collected by the email inquiry, and the cause entities, which are to be processed. Then the document which defines the target problem (see Section 7.1.1) is distributed to the RCA team members.

7.2.1.2 Cause Collection

In this phase, new causes are collected for each cause entity one by one. The new causes can either deepen or widen a cause entity (see Section 7.1.4). Collecting the new causes to a cause entity is done in two phases:

1. The RCA team members write causes on paper for each cause entity for five minutes
   - During the writing nobody is allowed to talk
   - Each RCA team member presents the causes he has written and tells where they should be placed in the diagram
   - The causes are attached to the cause-effect diagram by the RCA facilitator

2. The RCA team members discuss about the cause entity's causes
   - The RCA facilitator leads the discussion on the most important causes
     - The RCA facilitator asks: "*does anyone have something to add to this particular cause?*"
     - The RCA facilitator asks: "*does this cause belong also under some other cause in the diagram?*" (if so, the connection between the causes should be drawn by using arrows)
     - NOTE: during the conversation only one is allowed to speak at a time. That for, using a speech artifact (a doll, etc.) is extremely recommended. The speech artifact represents the permission to talk.

7.2.1.3 Cause Analysis

After all the cause entities have been employed, the cause-effect diagram is analyzed as a whole. The RCA facilitator asks the RCA team members to point out the most essential causes and to discuss them to reach a consensus. In the discussion the following viewpoints should be stressed:

- Is a cause in an essential role, and if so, why?
- How easy the RCA team members experience developing corrective actions for the cause?
- What are the achievements reached by minimizing the likelihood of the cause occurring?

7.2.2 Root Cause Detection and Evaluation

After Workshop 1, the RCA facilitator(s) smartens up the cause-effect diagram. This is done by marking all the causes, which definitely are not controllable, and thus developing corrective actions for them is not feasible. At this moment the unmarked causes are called "root causes" and the cause-effect diagram is finalized. The finalized cause-effect diagram

is then sent to the RCA team members by email. The RCA team members are asked to propose root causes for which corrective actions should be developed and evaluate them by using the following viewpoints:

1. **Impact of the root cause on the target problem** [1=minor, 2, 3, 4, 5=major]
2. **Easiness to develop corrective actions for the root cause** [1=hard, 2, 3, 4, 5=easy]

The RCA facilitator registers the propositions in to a table of candidates, which helps the RCA facilitator(s) in detecting the causes that are seen the most important as a whole and the causes that are feasible to develop corrective actions.

7.3 Corrective Action Innovation

This is the third step of the improved ARCA method, as presented in Figure 26. After the step the corrective actions for the most important root causes are developed.

7.3.1 Root Cause Selection

To focus the available resources as efficient as possible, the RCA facilitator(s) has to carefully select the root causes for which corrective actions are to be developed. The RCA facilitator(s) has to note the root causes proposed by the RCA team members. Additionally, it is important to evaluate the impact of each root cause on the target problem and easiness to develop corrective actions for the root cause.

While evaluating the impact of a root cause it is important to study:

- Impact of the root cause for its parent causes
- The number of causes the root cause explains

While evaluating the easiness to develop corrective actions for a root cause it is important to note that the more sub causes the root cause has the more labor consuming it is to develop corrective actions extensively for the root cause.

The ideal number of root causes to be selected is the number of RCA team members in Workshop 2 (see Section 7.3.2). Each of the selected root causes including its sub causes is documented by the RCA facilitator into a cause-effect structure, each for an individual paper.

7.3.2 Selection of Participants

In this phase, the RCA team members, who are included to develop, evaluate, and analyze corrective actions (see Section 7.3.3) are selected by the RCA facilitator(s). The RCA team members (four to six people) have to form an aggregate, which is as competent against the selected root causes as possible.

7.3.3 Workshop 2: Corrective actions development, evaluation and analysis

The development, evaluation, and analysis of the corrective actions are conducted in Workshop 2, which duration is at a minimum two hours. Each RCA team member works

sequentially with one root cause. The root causes are rotated through the RCA team members. Each of the corrective actions is evaluated in the end of the workshop. Thereafter the highest valued corrective actions are refined by a discussion.

7.3.3.1 Development of Corrective Actions

The corrective actions are developed by writing them on papers and rotating them through the RCA team members in ten minutes long iterations:

- The selected root causes including their sub causes (see Section 7.3.1), are on distinct papers, which are divided to the RCA team members
- An RCA team member writes the corrective actions for a root cause by using premade templates
- Corrective actions written by other RCA team members can be supplemented
    - The actions can be adjusted, expanded, and commented on

The root causes are rotated until every RCA team member has treated all the root causes. The duration of an iteration can be expanded (i.e. 15 minutes) for the last iterations so that the RCA team members have enough time to read and supplement the corrective actions written by the other RCA team members.

7.3.3.2 Evaluation of Corrective Actions

The developed corrective actions are evaluated to find the best corrective actions. The evaluation is conducted similarly as was their development: the root causes including their corrective actions are rotated through the RCA team members. Each RCA team member evaluates a root cause's corrective actions by giving two attributes for each idea:

1. **Impact of the corrective action** for the problem [1=minor, 2, 3, 4, 5=major]
2. **Feasibility of the corrective action** [1=bad, 2, 3, 4, 5=good]

A corrective action is immediately passed forward to the next RCA team member as an evaluator has first finished an evaluation of it. The last RCA team member evaluating a root cause's corrective actions calculates the corrective action's sum of evaluations.

7.3.3.3 Analysis of Corrective Actions

Each RCA team member presents sequentially from a root cause's corrective actions at hand, the corrective action that has the highest sum of impact and feasibility. The RCA team members are asked to discuss the corrective action to refine it. The presenter writes down the comments and improvement suggestions concerning the action he had presented.

7.4 Documentation of the Results

In this final step of the improved ARCA method (see Figure 26) the results of the method are documented into one document, which includes at least:

- The problem definition, as presented in Section 7.1.1
- The finalized cause-effect diagram, which includes at least:

  - The causes collected by the email inquiry (see Section 7.1.3) and Workshop 1
  - The root causes proposed by the participants (see Section 7.2.2)
  - The root causes including their sub causes processed in Workshop 2
- All of the corrective actions per a processed root cause (see Section 7.3.3)

7.5 Challenges in the improved ARCA method

This section lists all the detected challenges in the ARCA method during the cases and leads a discussion on how the improved ARCA method tackles them. The discussion follows the empirical evidence from the cases and represents the research questions 5 (see Section 1.5).

Table 16 lists the practical challenges detected in the ARCA method during and after the cases. It includes researchers' experiences, feedback collected from the RCA team members and RCA facilitators' answers from Interview 2. In the table, the status "Fixed" corresponds to that the challenge is fixed and tested, the status "Modified" corresponds to that the challenge is noticed in the improved ARCA method, but not comprehensively tested, and status "Open" corresponds to that the challenge is still open.

Table 16: The detected challenges in the ARCA method

ID	Challenge	Source	ARCA step	Case	Status
1	There was not enough time in the first workshop session for Root Cause Identification.	Observation	Step 3	A	Fixed
2	There was not enough time in the second workshop session	Observation	Step 4	A	Open
3	Prioritization of the corrective actions created bottlenecks.	Observation	Step 4	A	Fixed
4	The RCA team members who work with a root cause's corrective actions last do not have enough time to read the other RCA team members' comments and corrective actions carefully.	Observation	Step 4	A, D	Modified
5	Some of the RCA team members didn't voice all the causes they wrote down.	Observation	Step 3	B	Modified
6	Organizing causes is a challenging task.	Participation & Feedback Forms	Step 2 & Step 3	B, C, D	Open
7	Organizing causes is challenging if they are organized under cause categories which explain one another.	Participation	Step 2	C	Modified
8	In the first workshop session the conversation was hard to manage. New causes, which were detected from the conversation, were compacted under wrong branches.	Observation	Step 3	D	Modified
9	The conversation during the brainstorming is hard to keep in focus.	Participation	Step3 & Step 4	B	Modified
10	If corrective actions are developed by using brainstorming, it follows that the conversation takes a lot of time.	Observation	Step 4	B	Fixed
11	All the selected root causes were not processed.	Observation	Step 4	B	Fixed
12	10 to 20percent of detected causes were unsatisfactory	Interview 2	Step 3	A	Open
13	Some of the corrective actions are more feasible than others	Interview 2	Step 4	D	Fixed
14	The proportion of processed causes was only between 9.8% to 45%	Evaluation of the cases	Step 4	A,B,C, D	Modified
15	The used effort was a bit too high	Interview 2	All the steps	C,D	Modified
16	The email inquiry was seen unimportant	Interview 2	Step 2	B	Open

In Case A, the allocated time slot for the first workshop session was too short to include the task of Root Cause Identification (see Table 16, ID: 1). The problem was fixed by organizing an email inquiry after the workshop. In it the RCA team members were asked to propose the most important root causes to be eliminated and to evaluate them. The answers were saved in an Excel sheet, which was later used by the RCA facilitator(s) to select the root causes to be processed in the second workshop. Actually, this was a better way to conduct the detection of the most important root causes in comparison to what was originally planned, because now the RCA team members also had a flexible schedule and undisturbed environment while analyzing the finalized cause-effect diagram. Additionally, they were able to do this without public pressure forcing them to propose the root causes wanted by other RCA team members. This practice was further tested in other cases, and finally, adopted into the improved ARCA method, as presented in Section 7.2.2.

In the second workshop session in Case A, there was not enough time to comprehensively discuss the developed corrective actions (see Table 16, ID: 2). There were two main reasons for this: 1. during the evaluation of the corrective actions a bottleneck problem persisted (see Table 16, ID: 3) which slowed down the progress, and 2. the RCA team members were eager to discuss the corrective actions. The quick fix for the problem would have been to lengthen the workshop, but the bottleneck problem had to be solved sooner or later. A solution for the bottleneck problem was to pass forward a corrective action immediately as an evaluator had first finished the evaluation of it (see Section 7.3.3.2). In the later cases (the cases C and D) there was enough time to discuss all the corrective actions. Maybe the ultimate reason for that was that the bottleneck problem had been fixed, or because the conversation was lead better. Whatever the truth, the more root causes there are to be processed (see Section 7.3.1) the more likely it is that the allocated time slot for comprehensive discussion on each root cause's best corrective actions is not long enough, thus requiring more than the recommended two hours (see Section 7.3.3).

The way the corrective actions were developed in the cases A, C, and D (see Sections 5.3.2, 5.5.2, and 5.6.2) included a problem of some of the RCA team members not having enough time to work with all the corrective actions of a root cause (see Table 16, ID: 4). In Case A, the RCA team members were given ten minutes time to work with the corrective actions of a root cause. In the cases C and D, the RCA team members were given time gradually: first seven minutes, which was then expanded to ten minutes for the last two rounds. For most of the RCA team members the given time was enough. On the other hand, there were usually one or two RCA team members who said the given time was not long enough. The improved ARCA method recommends using ten minutes for the first rounds and expanding it (i.e. to 15 minutes) for the last rounds, as presented in Section 7.3.3.1.

In Case B, the RCA team members didn't voice all the causes they wrote down (see Table 16, ID: 5). Either the RCA team members wrote down the same causes, and thus they didn't mention them twice, or the RCA team members had another reason not to mention the cause. The way in which the causes were collected in Case B was different from that in the other cases: the RCA team members added causes to a cause entity as a branch after another following an immediate conversation (see Section 5.4.2). In the later cases (the cases C and D), the causes were added to a cause entity by one person after another, thereafter a conversation about the most important cause entity's causes was held. As a result, all the causes written down by the RCA team members were added to the diagram. The improved ARCA method follows this practice, as presented in Section 7.2.1.2.

Organizing causes into a cause-effect diagram was experienced a challenging task (see Table 16, ID: 6 and 7). It is unlikely that this was a consequence of unsatisfactory cause

analysis practices applied in the cases, since they were carefully studied in advance (see Section 3.5.3). Instead it is suitable to be stated that the target problems were complex to prevent (see Section 5.1) and that there were hundreds of detected causes in each (see Table 11). To organize a high number of causes listed by different people into a reasonable cause-effect structure is a challenging task even if done by a skilled RCA facilitator who truly understands what he is doing.

Conversations were hard to keep in focus (see Table 16, ID: 8, 9, and 10). While collecting causes the RCA team members were eager to discuss them. This was a positive thing of course, if thinking that new causes rise from the conversation. On the other hand, the conversation slipped easily to other things than the particular cause entity in focus. While corrective actions were developed by using brainstorming, the results were not as good as when brainwriting was used: some of the selected root causes were not processed due to lack of efficiency (see Table 16, ID:11). The improved ARCA method tackles these problems by applying the structured brainstorming (see Section 3.5.1) in the cause collection and the card method brainwriting (see Section 3.5.1) in the corrective action development, as presented in the sections 7.2.1 and 7.3.

According to the RCA facilitator of Case A, 10 to 20 percent of the causes were unsatisfactory (see Table 16, ID: 12). The challenge is that the more there are incorrect causes the more unreliable are the results. The better the RCA team members understand the target problem the more correct are the causes they are listing. The improved ARCA method tackles this by recommending, that before the cause collection takes place, the problem is first well defined, documented, and made clear for the RCA team members. This way the RCA team members might understand the target problem better and thus they don't guess the causes.

Some of the corrective actions were more feasible than others (see Table 16, ID: 13). That is very natural while thinking of how many corrective actions were developed. However, someone might think that it was a waste of resources. The improved ARCA method helps the RCA team members develop corrective actions efficiently and the greatest attention can be focused on the best corrective actions. In the end it is the RCA team members who develop the corrective actions, not the method itself. Thus, to avoid increasing the number of unfeasible corrective actions, selecting the RCA team members as recommended is suggested (see the sections 3.6, 4.2.1, and 7.3.2).

The proportion of processed causes was only between 9.8 to 45 percent, which means that many root causes were left intact (see Table 16, ID: 14). On the other hand, the method was required to be cost efficient (see Section 1.4) and in the end many important root causes were processed (see Section 6.1.2). It is claimed that it is a better idea to focus the attention on a significant few than all the causes (Jalote, Agrawal 2005). Thus, the companies don't have to change many things in their processes simultaneously and it lowers the required effort in the development of corrective actions too.

According to the RCA facilitators of the cases C and D, the used effort in the cases was a bit high (see Table 16, ID: 15). On the other hand, according to the RCA facilitators of the cases A and B, the used effort was very feasible (see Table 15). The effort was closely related to the number of the RCA team members, as discussed in Section 6.2. In case B, the RCA facilitator criticized the importance of the email inquiry to collect preliminary causes (see Table 16, ID: 16). On the other hand, the inquiry and organizing work of the preliminary causes was more cost efficient than was the first workshop session. This can be justified by comparing the number of detected causes to the used effort (see Figure 20 and Table 13).

However, this doesn't say much the nature of the detected causes. The RCA team members might be more outspoken if an anonymous inquiry is kept compared to what is spoken in public meetings. I believe as many RCA facilitators of the case companies: using a smaller number, but more talented RCA team members is the best way to lower the required effort (see Table 15).

8. Discussion

This chapter includes three sections. Section 8.1 discusses attaining the research objectives. Section 8.2 answers the research questions, and then discusses the answers in comparison to previous research results. Thereafter Section 8.3 evaluates this research and discusses threats to the validity of the results.

8.1 Attaining the Research Objectives

This section discusses attaining the research objectives presented in Section 1.4. The goal of the research was to:

1. *Develop an RCA method (ARCA), which is appropriate for software companies*
2. *Evaluate the method through four industrial cases*
3. *Further develop the method based on the evaluations*

The development of the ARCA method was conducted by combining the literature review (see Chapter 3), the pilot case and the evaluation of the prototype of the ARCA method (see Chapter 4). This resulted in the initial ARCA method that was used in the cases. There are no reasons to argue that the initial ARCA method is not an RCA method, because it included all the common steps and most of the recommended practices of the other RCA processes, as presented in Table 2.

The evaluation and further development of the ARCA method was based on field studies (see Chapter 5). In the field studies, the initial ARCA method was improved in-between the cases. The improvements were based on case analysis (see Section 2.3.1) by using the following sources of information: 1. Participant-Observation, 2. interviews and 3. feedback forms. After all the four industrial cases were performed, the data from the cases was combined and an evaluation of the ARCA method was conducted. The ARCA method was evaluated as cross-sections of the cases, as presented in Chapter 6. The detected causes and developed corrective actions, the used effort to conduct, easiness to use and learn, and feasibility of the ARCA method for problem prevention were taken into account.

The improved ARCA method, as presented in Chapter 7, is based on the evaluations of the cases and the initial ARCA method. It is the further developed version of the ARCA method. The cases collectively support the claim that the further developed version of the ARCA method is an appropriate RCA method for software companies.

As a summary, there are no reasons to argue that the research objectives were not attained. The research was conducted as planned and all its objectives were reached.

8.2 Answering the Research Questions

This section answers the research questions and compares the results to previous research. The answers are based on the evaluations made in Chapters 6 and 7.

8.2.1 The Feasibility and Impact of the Corrective Actions

The first research question was "*Does the ARCA method generate corrective actions which are feasible and which have a significant impact on the target problem?*" As a summary, the ARCA method helped the case companies develop corrective actions which were feasible and which had a significant impact on the target problem. On the other hand, also some unfeasible corrective actions were developed and many root causes were left intact. These sorts of results are not presented in previous research projects. However, it has been presented that the attention should be focused on the top few causes (Card 1998, Jalote, Agrawal 2005) which means that many root causes are left intact. It is also presented that RCA based corrective actions lead to process changes that help prevent defects, that ensure their early detection, and increase the product quality in general (Card 1998, Leszak, Perry & Stoll 2000). The research question was divided into four aspects:

1. *Were the detected causes correct with respect to the target problem?*

The detected causes were correct in contrast to the target problems. This conclusion is based on the estimations of the RCA team members and the RCA facilitators, as presented and discussed in Section 6.1.1.

2. *Were the most important root causes processed?*

The more important a processed root cause is the higher is its impact on the target problem and the easier it is to eliminate. From the set of all the detected causes, the corrective actions were focused on the important root causes. This conclusion is based on three sources of information, as presented in Section 6.1.2. First, the RCA team members proposed and then evaluated 10 to 15 root causes to be processed. These evaluations were compared to the selected root causes. Second, the RCA team members were asked to evaluate the easiness to eliminate the detected root causes in the end of the first workshop session. Thereafter, the RCA team members were asked to evaluate the easiness to eliminate the processed root causes in the end of the second workshop session. These two were compared. Third, the RCA team members were asked to evaluate the importance of the processed root causes for the target problem in the cases C and D. There was no evidence on the fact that the processed root causes were not important. However, the easiness to eliminate the processed root causes was estimated lower than the easiness to eliminate the detected root causes. On the other hand, the impact on the target problem was estimated slightly higher for the processed root causes.

3. *Were the corrective actions experienced feasible with significant impact on the target problem?*

Most of the developed corrective actions were estimated feasible with considerable impact on the target problem. This conclusion is based on four sources of information, as presented and discussed in Section 6.1.3. First, each corrective action was evaluated in each case by each and every RCA team member. The impact and feasibility of a corrective action was evaluated. Thus, it was possible to analyze the number of the high impact and feasibility corrective actions. Second, the multiplications of the impact and feasibility estimations were analyzed. The multiplication was called a combined effect. The combined effect represented the goodness of a corrective action, because a very good corrective action has a high impact on the related target, but it is also highly feasible. Third, the RCA team members were asked to evaluate the impact and feasibility of the corrective actions in

general. Fourth, the RCA facilitators were interviewed. The general evaluations of the RCA team members and the interviews with the RCA facilitators helped confirm the conclusions from the first and second sources of information.

4. *What proportion of the detected problem causes did the processed root causes cover?*

The coverage of the corrective actions here means the proportion of processed causes with good corrective actions compared to the number of detected causes (see Section 6.1.4). As presented earlier, the combined effect represented the goodness of a corrective action. The corrective actions were divided into three classes: 1. Very good (combined effect >= 16), 2. Good (combined effect >=9 and < 16), and 3. Bad or neutral (combined effect <9). As a result, good corrective actions were developed for each processed root cause and very good corrective actions were developed for many processed root causes. The coverage of the corrective actions was between 9.8 percent and 45 percent of the detected causes, which means that there were many root causes that were left intact.

8.2.2 The Required Effort to Conduct the ARCA Method

The second research question was "*How much effort is required to conduct the ARCA method?*" The used effort in the cases was registered and divided into individual activities, as presented in Section 6.2. The required effort to conduct the ARCA method is mostly dependent on the number of RCA team members who contribute mainly in preliminary cause collection, Root Cause Detection, and Corrective Action Innovation. The number of RCA team members was between six and ten, and the used effort was between 73.4 and 98.5 man-hours (89 man-hours as an average). Similar results are presented by Grady, who estimates that the required effort to conduct an individual RCA case is around seven hours of team work (Grady 1996). This would result in 42 to 70 man-hours if performed with six to ten people. However, Grady only estimates the required effort, thus he doesn't present in detail how much effort actually was used. Other researchers have presented the required effort to conduct RCA as a proportion of an annual budget, which is 0.5 (Mays 1990) to 1.5 percent (Card 1998) of the budget. The case companies of the ARCA method had reserved approximately 0.9 percent at minimum to five percent at maximum to software improvement activities. If these are compared together, it follows that most of the case companies budget would be spent on RCA, as the representatives of the case companies experienced the ARCA method as a method for software improvements.

8.2.3 The Easiness to Use and Learn the ARCA Method

The third research question was "*Is the ARCA method easy to learn and use?*" This question was approached by looking at two perspectives (see Section 6.3):

1. *How did the RCA facilitators of the case companies experience the ARCA method in general?*

The RCA facilitators of the cases were interviewed after the ARCA method was performed. They systematically said that the ARCA method is very easy to use and learn. However, one RCA facilitator stressed that organizing the causes is a challenging task and one RCA facilitator answered that it requires a motivation to learn the ARCA method (see Table 14).

2. *How did the RCA team members of the cases experience the individual activities of the ARCA method?*

After the first workshop session, the RCA team members evaluated the easiness to organize the causes and the easiness to detect the root causes as a number that was of higher easiness than a neutral or less (see Figure 21). After the second workshop session, the RCA team members evaluated the elimination method as a number that was of a clearly higher easiness than neutral or less (see Figure 21).

The ARCA method was experienced as easy to learn and use in general. However, organizing the detected causes into a cause-effect diagram was seen as a challenging task. In earlier research, it is argued that organizing the causes is a laborious and complex task (Latino, Latino 2006 p. 99, Grady 1996, Andersen, Fagerhaug 2006 p. 118). One reason for this is that too many causes are detected (Jalote, Agrawal 2005). The target problems of the case companies resulted in hundreds of causes each (as total 168 to 245 causes) and the causes explained one another. This could mean that too many causes were detected and thus organizing them was a challenging task. It is also possible that the RCA facilitators of the cases didn't understand the causes they were organizing. The target problems of the ARCA method were all characterized as complex. It is claimed that RCA requires a skilled facilitator (Card 1998).

8.2.4 The Feasibility of the ARCA Method for Problem Prevention

The fourth research question was "*Is the ARCA method a feasible method for problem prevention, if compared to the current state-of-practices in the case companies?*" The question was answered by analyzing how the RCA team members evaluated the method in contrast to their company's current state-of-practices, and by analyzing the opinions of the RCA facilitators about the ARCA method as an overall, as presented in Section 6.4. Additionally, the other research questions were first analyzed, because they had interdependence to this research question (see Section 1.5).

1. *How did the RCA team members experience the ARCA method in contrast to the current practices of the case companies?*

The RCA team members were asked to compare the ARCA method to the current state-of-practices of their company (see Figure 22). They evaluated that the ARCA method is a better method to detect totally new process improvement targets. They also evaluated that the ARCA method is clearly a better method in developing process improvement ideas than the current practices of their company.

2. *How did the RCA facilitators of the case companies experience the ARCA method in contrast to other known methods?*

The RCA facilitators were asked to evaluate if it would have been easier to detect the target problem causes by just listing them generally. They were also asked to evaluate if it would have been possible to develop similar process improvement ideas without collecting and organizing the target problem causes. For the first question they systematically answered that the same causes would not have been possible to detect by listing them generally. For the second question they answered that it would have been possible to develop similar process improvement ideas without collecting and organizing the target problem causes, however, it would have required more effort. (see Table 15)

3. *How did the RCA facilitators of the case companies experience the value of the output of the ARCA method in contrast to the required effort?*

The RCA facilitators were asked to evaluate three aspects. First, if it would have been possible to get the same results in lower costs by using some other method than the ARCA method. Second, if the ARCA method was feasible when compared to the used effort. And third, whether or not their company should adopt the ARCA method. In the first question, the RCA facilitators didn't know any better method to reach the same results than the ARCA method. In the second question, the RCA facilitators said that the required effort to conduct the ARCA method should be slightly lower. For the third question, each RCA facilitator answered that their company should use the ARCA method again. (see Table 15)

As a result, the ARCA method was experienced as a better method for problem prevention than the current state-of-practices in the case companies. We assume that the main reason for this is that currently the case companies aren't analyzing problem causes before developing corrective actions for them. It is argued that the key for effective problem prevention is to know why a problem occurred (Rooney, Vanden Heuvel 2004). Another reason for why the ARCA method was experienced as a better method for problem prevention than the current state-of-practices in the case companies might be that currently the corrective actions are developed in the case companies by using the brainstorming method. The advantages of the brainwriting practices in contrast to the brainstorming practices are discussed (Andersen, Fagerhaug 2006 p. 49). In Case B, the brainstorming practice was used to develop corrective actions whereas the card method brainwriting practice (see Section 3.5.1) was used in the other cases. The researchers concluded that to be applied in the development of corrective actions, the card method brainwriting practice is better than the brainstorming practice. Brainwriting resulted in a higher number of corrective actions than brainstorming and the quality of the corrective actions was higher when brainwriting was used. The explanations for this could be that: 1. brainstorming led to inessential discussions and 2. The card method brainwriting practice led to higher personal contribution of the RCA team members (see the cases A, C, and D in Figure 12). On the other hand, it is claimed that an RCA team should consist of testers, developers, project managers, software quality assurance staff, and SPI group members (Burnstein 2003 p. 450). In Case B, mostly developers were present whereas in other cases different stakeholders were present (see Table 4). RCA has been claimed to be a low-cost and effective technique (Card 1998, Card 1993, Leszak, Perry & Stoll 2000). It is interesting that in comparing the required effort and results, the ARCA method was evaluated as sufficient or slightly hard to carry through in practice. We assume that this has an impact for the adoptability of the ARCA method, but this doesn't mean that the ARCA method is an inferior method for problem prevention when compared to current state-of-practices in the case companies.

8.2.5 The Required Improvements in the ARCA method

The fifth research question was "*How could the ARCA method be improved?*" The research question was divided into the following aspects:

1. *How could the ARCA method be improved with respect to corrective actions?*
2. *How could the required effort be lowered without lowering the quality of the corrective actions?*
3. *How could the ARCA method be improved to make it easier to use and learn?*
4. *How could the ARCA method be more useful for the companies?*

This question was answered by listing all the challenges in the method detected during the cases and analyzing how the improved ARCA method tackles them, as presented in Section 7.5. It seems that there are two things that still require improvements in the ARCA method: lowering the required effort and facilitating the cause organizing task. Lowering the number of the RCA team members could be one way to decrease the required effort. There was no evidence on the fact that a smaller number of RCA team members results in a lower quality of corrective actions. On the other hand, as Andersen and others stress (Andersen, Fagerhaug 2006 p. 22), the required effort can be saved by giving a fertile focus on RCA. This means that a target problem should be carefully selected and that only the most important root causes should be processed. Facilitating the task of organizing the detected causes into a cause-effect diagram might be very challenging. As already mentioned, the earlier researches have argued the same. Perhaps this is the most challenging task in RCA as an overall. The number of problem causes should be as low as possible to make organizing them easier, but there are hundreds of causes lying under the problems of the software companies. Maybe focusing only on the top few causes could be the solution?

8.3 Evaluation of the Research

The contributions of this thesis are the ARCA method and its evaluation. This section discusses the validity of the ARCA method and the study results.

8.3.1 The Construct Validity

The construct validity here means that the ARCA method is a valid RCA method and that it can be applied in the software industry. The ARCA method also meets its other requirements (see Section 1.4). It was concluded that the ARCA method is a valid RCA method that can be successfully applied in the software industry, and it fulfills most of its requirements. However, the ARCA method does not follow all the recommended practices from the earlier RCA studies in the software industry, like sampling of the defects and the Pareto Analysis. It was also concluded that the required effort of the ARCA method should be slightly lower and that organizing the causes should be facilitated.

The ARCA method is an evolutionary work, which reassembles the work of many authors (Rooney, Vanden Heuvel 2004, Latino, Latino 2006, Card 1998, Leszak, Perry & Stoll 2000, Ammerman 1998, Andersen, Fagerhaug 2006, Björnson, Wang & Arisholm 2009, Burnstein 2003). Most of the earlier RCA cases in the software industry have focused on defect prevention. The ARCA method, however, was planned to be applied in problem prevention in software development in general. There weren't any reported cases of RCA used in a similar context earlier.

The first version of the ARCA method was developed according to the literature. The literature review included RCA applications used in the software industry but also other RCA applications used in the assembly line industry. These were put together to help understand the similarities and differences of them. This approach helped cover the scope of the thesis well, but it made possible that the development work went in the wrong direction, because the literature also included recommendations that were not based on the software industry.

The further development of the ARCA method was based on the evaluation of the ARCA method used in the cases. It is possible that the evaluation was not focused enough and

thus something important, that would have required attention in the ARCA method, was not noted.

8.3.2 The Internal Validity

The internal validity here corresponds to the validity of the conclusions based on the study results. These correspond to the reliability of the literature review, feedback collected from the case participants, and observations during the cases.

The literature available is relatively exiguous. A major part of the articles were found in journals of recognized scientific publishers. The literature review was scoped and it followed specific research questions.

The feedback forms were developed according to research questions. The forms were tested by students before they were used in the cases. The total number of the case attendees was 30 people.

The interview questions were developed to answer the research questions. The questions were reviewed by the researchers before using them in the cases. The interviews were conducted with selected experts who represented the RCA facilitators of the case companies. Thus, they were the key persons to give feedback on the ARCA method. The relatively small amount of interviewees might, however, slightly skew the interpretation of the results. The interviews were recorded.

The data during the cases was collected in an unstructured manner. Participants were given a freedom to focus on the questions they felt important. The researcher took care that all the most important questions were covered during the workshop session. To secure that everything was covered, the workshop sessions were also video recorded. The researchers also had a possibility to complete the missing items later on.

Even though there are minor shortages in the methods used in the research data collection, the data analyses were based on several sources and cases. Triangulation of the data sources and the data collection methods (Yin 1994 p. 90, Runeson, Höst 2008) increases the reliability of the results. As a conclusion, the internal validity of the results is sufficient for further analysis.

8.3.3 The External Validity

The external validity here corresponds to the extent to which the results of the research can be held to be true for other cases. All of the cases considered the ARCA method from slightly different perspectives. As mentioned, their internal validity was estimated sufficient for future analysis. The value of the cases externally relates to the evaluation of the ARCA method. Though the cases were conducted in four different companies all with different attendees, and though the interviews slightly differed between the cases, the results collectively confirmed the suitability of the ARCA method in software companies. The conclusion of the external value of the study is that though the results slightly differ case by case, they collectively support the external validity of the ARCA method.

9. Conclusions and Future Work

This chapter summarizes this thesis and discusses the future work around the ARCA method and RCA in general.

9.1 Conclusions

The ARCA method is an efficient RCA method for corrective action development in software companies. The high number and the high quality of the developed corrective actions, the easiness to use and learn the ARCA method, and the feasibility of the ARCA method compared to the current state-of-practices in the case companies, support this conclusion.

The ARCA method helped develop a high number of corrective actions which were estimated by the RCA team members to be feasible with considerable impact on the target problem.

The ARCA method was in general experienced as easy to learn and use. However, as an exception, organizing the detected causes was experienced as challenging due to the high number of detected causes.

The effort of applying the ARCA method was experienced as proper or slightly too high considering the value of the results. The effort used depends mainly on the number of RCA team members. The number of the RCA team members was between six and ten people resulting in 89 man-hours as an average. There was no indication that a smaller number of RCA team members results in a lower number or a lower quality of corrective actions.

The ARCA method was evaluated as a better method for corrective action development than the current state-of-practices. We assume that the main reason is that currently the case companies are not analyzing problem causes before developing corrective actions for them. Additionally, the case companies use the brainstorming method to develop corrective actions whereas in the ARCA method the corrective actions are developed by using the brainwriting method. The greatest challenges of the ARCA method are lowering the required effort and facilitating the task of organizing the detected causes.

9.2 Future Work

We collected 757 target problem causes and developed 124 corrective actions by using RCA in the cases of this study. The causes and the corrective actions need to be analyzed further in the future. Analyzing the similarities between the target problem causes, and understanding the type of the causes that were seen as the most important is an interesting task. The similarities between the developed corrective actions should be analyzed as well. These would better help us understand how the software companies try to tackle their target problems.

To understand the feasibility and the impact of the developed corrective actions better, the corrective actions which were and which were not implemented should be analyzed. Also finding the reasons to why the corrective actions were or were not implemented might be fruitful. It would as well be worthwhile to study the impact of the change through studying the impact of the implemented corrective actions for the related root causes.

The defect classification has been used in the software industry to give a target for RCA, but the ARCA method does not follow this practice. There is no commonly accepted methodology on how to define the correct defect classes, on how to classify the defects without mistakes and a laborious workload, and on who are the experts for doing this. Additionally, no research reports on the effect of the defect classification based RCA in comparison to RCA, where the target problem is defined by hand, have been published. Thus the question remains: Is the laborious defect classification feasible or not?

Finally, to increase the validity of the study the ARCA method needs to be tested in action in different kinds of case contexts. This means that software companies should adopt and apply the ARCA method repeatedly.

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Appendix A. Questions Asked in Interview 1

Part 1

1. How many employees work in your company?
2. How problem prevention is organized in your company?
3. How much your company spends effort to software process improvement (SPI)?
4. What are the stakeholders attending to SPI in your company?
5. How your company tries to avoid quality deviations?
6. How quality deviations are detected in your company?
7. Are other quality deviations than software defects recorded?
8. How your company reacts on the quality deviations?
9. Are the causes of the quality deviations detected?
10. If so, how it is conducted and how many people are included to the analysis?
11. And if so, what stakeholders are present (developer, testers, designers, sales)?
12. How would you characterize the communication environment of your company?

- Personal feedback
- Communication climate
- Horizontal informal communication
- Managerial communication

Part 2

1. How much you think your company has used effort preventing the target problem earlier?

- How it is done?

2. In an economical sense, how significant is the target problem for your company?
3. How complex is the target problem and how would you characterize it?
4. What are the root causes of the target problem?
5. How these causes can be eliminated?
6. What do you assume to be important while defining the target problem?

Appendix B. Questions Asked in Interview 2

Part 3

1. Would it been easier to detect the same causes just by listing them generally?
2. In general, was the detected root causes significant if compared to the problem?
3. Were major deficiencies detected or were they more like minor problems?

Part 4

1. Would it have been possible to develop similar process improvement ideas without Root Cause Detection just by innovating generally “how could we improve our activities”?
2. Would it have been possible to get the same results in lower costs by using some other practice?
3. In general, do the corrective actions prevent the problem?
4. Are the corrective actions feasible?
5. What is the impact of the corrective actions for other problems in your company?

Part 5

1. How easy and learnable is ARCA?
2. Compared to the used effort, how would you characterize feasibility of ARCA?
3. Should your company adopt ARCA?
4. What are the most relevant challenges in the ARCA method that makes it unfeasible for your company?

Appendix C. Questions Asked in Feedback Form 1

1. The target problem

Answer to the questions by giving a value [1=very minor, 2, 3, 4, 5, 6, 7 = very major] that corresponds the question best.

- The impact of the target problem for the quality of the product
- The adverse effect of the target problem to my daily work
- The difficulty to prevent the target problem
- Effort the company has used to try to prevent the target problem earlier
- Technical consequences of the target problem
- The impact of the target problem for the end users of the product
- The impact of the target problem for the customer relationships
- The internal impact of the target problem for the company
- My experience of the technical causes of the target problem
- My knowledge of the impact of target problem for the end users of the product

2. The quality of the causes and root causes

Answer to the questions by giving a value [1=very minor, 2, 3, 4, 5, 6, 7 = very major] that corresponds the question best.

- The method used to collect the causes of the target problem
- The easiness to organize the causes
- The method used to detect the root causes of the target problem
- The easiness to detect the root causes
- The ability of the ARCA method to detect totally new process improvement targets if compared to the current state-of-practices of your company
- The openness of the communication in the workshop session 1
- The correctness of the detected causes
- The correctness of the detected root causes
- The easiness to solve the detected root causes
- My own contribution in the workshop session
- The ability of the ARCA method to detect process improvement targets if compared to other know practices

3. Your duty in your company:_____

4. Select the roles that describe your responsibility in the company best

- I am a manager
- I am a developer
- I am a tester
- I am a salesman
- I am a trader
- Something else, what? _____

5. Communication environment

Answer to the questions by giving a value [1=very unsatisfied, 2, 3, 4, 5, 6, 7 = very satisfied] that corresponds the question best.

How satisfied you are…

- On the information about how your job compares with others
- On the information about how you are judged
- On the recognition of your effort
- On the reports on how problems in your job are being handled
- On the extent to which your superiors know and understand the problems face by subordinates
- On the extent to which the company's communication motivates and stimulates an enthusiasm to meeting its goals
- On the extent to which the people in your company have great ability as communicators
- On the extent to which the company's communication makes you identify with it or feel a vital part of it
- On the extent to which you receive in time the information needed to do your job
- On the extent to which conflicts are handled appropriately through proper communication channels
- On the extent to which my supervisor listens and pays attention to you
- On the extent to which your supervisor offers guidance for solving job related problems
- On the extent to which the organizations communication are interesting and helpful
- On the extent to which your supervisor is open to ideas
- On the extent to which you are monitored
- On the extent to which the grapevine is active in your company
- On the extent to which horizontal communication with other organizational members is accurate and free flowing
- On the extent to which communication practices are adaptable to emergencies
- On the extent to which your work group is compatible
- On the extent to which informal communication is active and accurate

6. How would you improve the ARCA method?

……
……
……

Appendix D. Questions Asked in Feedback Form 2

1. **How much you used time to propose and evaluate the root causes to be processed before this workshop session**:_____

2. **Were the processed root causes the most important in contrast to the target problem?**

   (Select one of the following)
   - Absolutely YES
   - More than YES
   - Yes
   - Neutral
   - No
   - More than NO
   - Absolutely NO

3. **Were the processed root causes the most important in contrast to the quality of the product?**

   (Select one of the following)
   - Absolutely YES
   - More than YES
   - Yes
   - Neutral
   - No
   - More than NO
   - Absolutely NO

4. **Were the processed root causes easy to eliminate?**

   (Select one of the following)
   - Absolutely YES
   - More than YES
   - Yes
   - Neutral
   - No
   - More than NO
   - Absolutely NO

5. **The method used to develop the corrective actions**

   Answer to the questions by giving a value [1=very bad, 2, 3, 4, 5, 6, 7 = very goof] that corresponds the question best.

   - The easiness of the corrective action development method
   - The feasibility of the corrective action development method
   - The usefulness of the corrective action development method to develop process improvement ideas in contrast to the current state-of-practices of your company
   - The openness of the communication in the workshop session 2
   - My own personal contribution in the workshop session 2
   - The impact of the corrective actions for the target problem
   - The feasibility of the corrective actions
   - If implemented, the impact of the corrective actions for your company in general

6. How would you improve the ARCA method?

.....
.....
.....

Appendix E. The Output of the ARCA Method in the Cases

Table 17: The number of detected and processed causes in Case A

	Email inquiry	Session 1	Session 2	Total
The number of detected causes (**ADC**)	93	80		173
The number of processed causes (**APC**)			41	41
Proportion of processed causes %				23,7 %

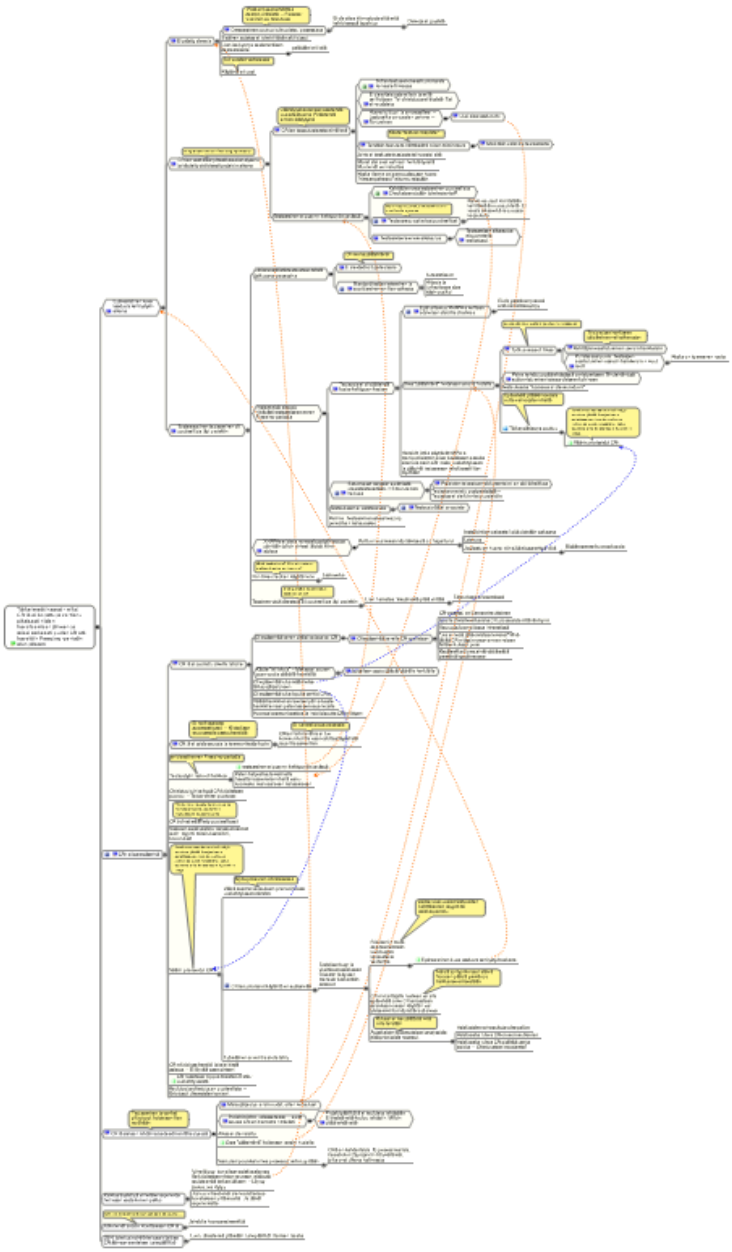

Figure 24: The cause-effect diagram after the first workshop session in Case A

Table 18: The corrective actions developed in Case A

Root Causes and top 2 corrective actions	The number of corrective actions	Impact avg. (1=low, 5 = strong)	Feasibility avg. (1=difficult, 5 = easy)	Impact*Feasibility
RC1	7	3,53	3,05	11
1. Top Idea		*4,9*	*3,9*	*19*
2. Top Idea		*3,9*	*4,1*	*16*
RC2	7	3,88	3,42	13
1. Top Idea		*4,3*	*4*	*17*
2. Top Idea		*3,3*	*4,9*	*16*
RC3	3	3,19	2,98	10
1. Top Idea		*3,1*	*4*	*13*
2. Top Idea		*2,4*	*3,1*	*8*
RC4	9	3,82	3,19	12
1. Top Idea		*5*	*3,43*	*17*
2. Top Idea		*4,14*	*4,14*	*17*
RC5	6	3,93	3,26	13
1. Top Idea		*4,71*	*3,29*	*15*
2. Top Idea		*4*	*3,71*	*15*
RC6	6	3,21	4,41	14
1. Top Idea		*4*	*5*	*20*
2. Top Idea		*3,86*	*4,43*	*17*
Total	38	3,65	3,39	12

Table 19: The used effort in Case A

ARCA step	The number of RCA team members	Used hours Company A	Used hours ESPA	Sum
Problem Detection	10	21	13	33,5
Root Cause Detection	10	24	12	36
Elimination	10	19	10	29
Total	**10**	**63,5**	**35**	**98,5**

Table 20: The number of detected and processed causes in Case B

	Email inquiry	Session 1	Session 2	Total
The number of detected causes (**ADC**)	108	137		245
The number of processed causes (**APC**)			24	24
Proportion of processed causes %				9,8 %

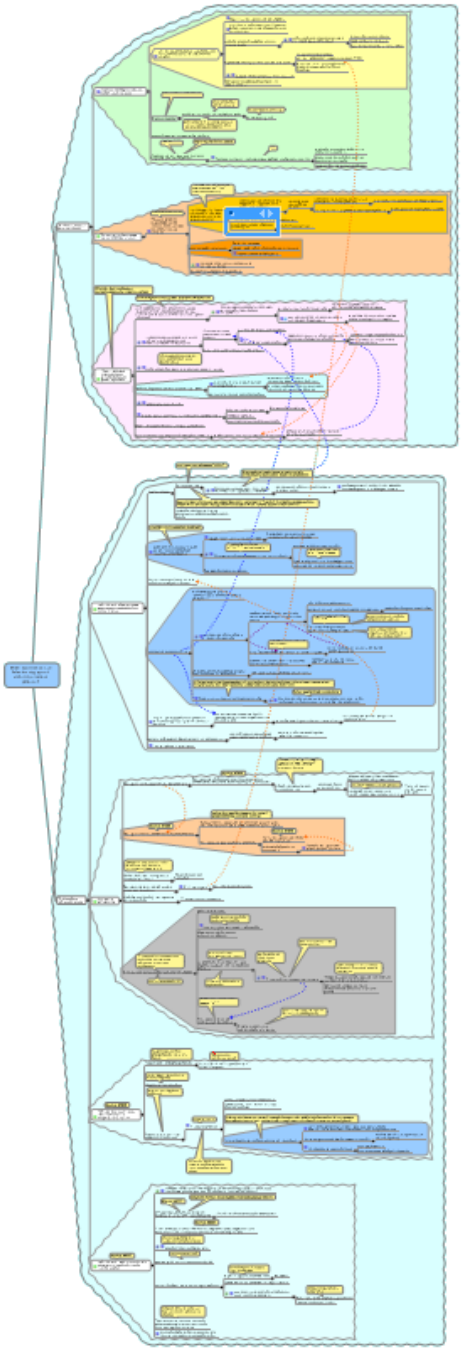

Figure 25: The cause-effect diagram after the first workshop session in Case B

Table 21: The corrective actions developed in Case B

Root Causes and top 2 corrective actions	The number of corrective actions	Impact avg. (1=low, 5 = strong)	Feasibility avg. (1=difficult, 5 = easy)	Impact*Feasibility
RC1	5	3,33	2,78	9
1.Top Idea		*4*	*3,44*	*14*
2. Top Idea		*3,56*	*2,89*	*10*
RC2	8	3,1	2,8	9
1. Top Idea		*3,56*	*3,44*	*12*
2. Top Idea		*2,56*	*4,44*	*11*
Total	13	3,19	2,79	9

Table 22: The used effort in Case B

ARCA step	The number of RCA team members	Used hours Company B	Used hours ESPA	Sum
Problem Detection	5	14	16	30
Root Cause Detection	11	24	12	36
Elimination Idea Innovation	11	20	10	30
Total	**15**	**58**	**38**	**96**

Table 23: The number of detected and processed causes in Case C

	Email inquiry	Session 1	Session 2	Total
The number of detected causes (**ADC**)	66	105		171
The number of processed causes (**APC**)			77	77
Proportion of processed causes %				**45 %**

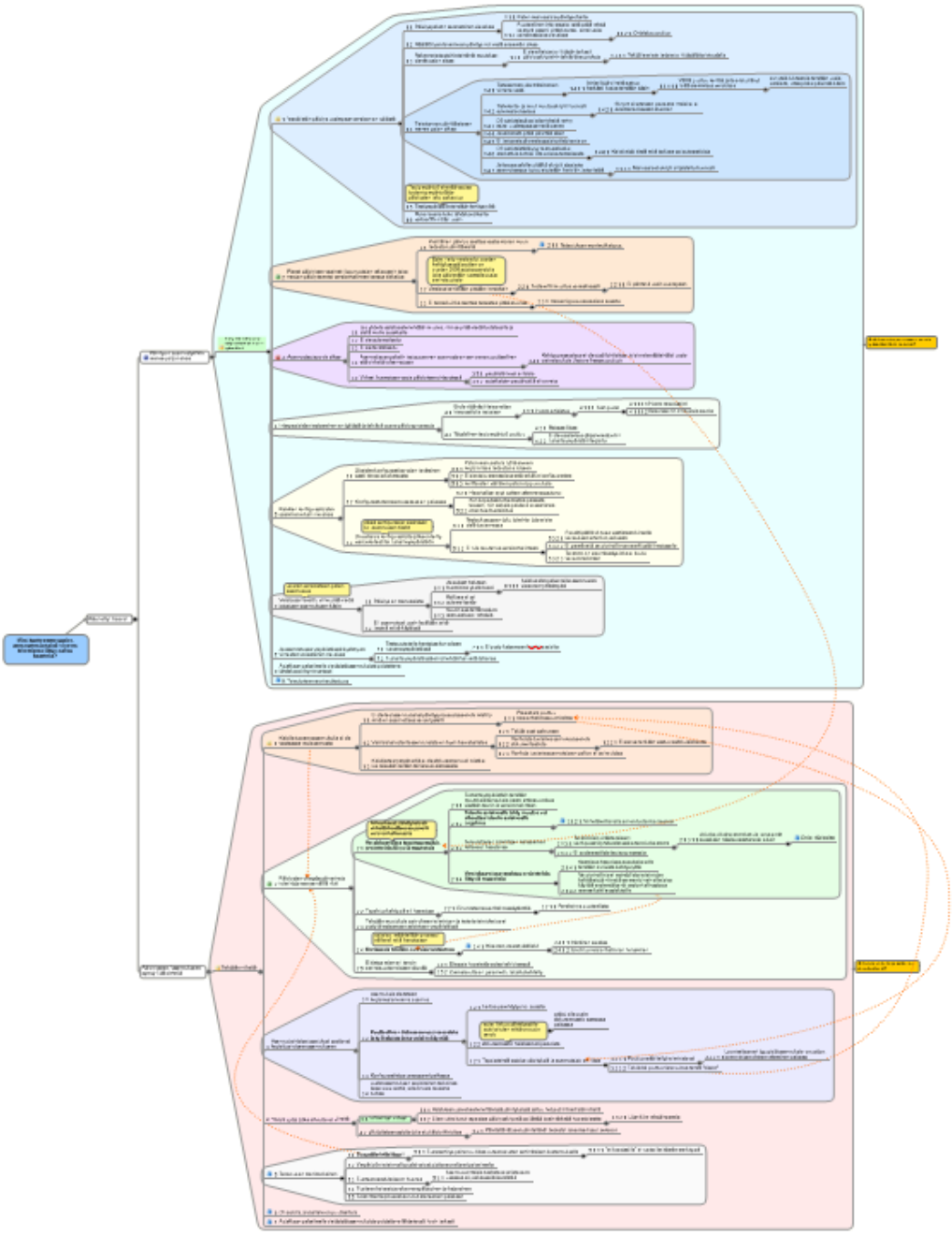

Figure 26: The cause-effect diagram after the first workshop session in Case C

Table 24: The corrective actions developed in Case C

Root Causes and top 2 corrective actions	The number of corrective actions	Impact avg. (1=low, 5 = strong)	Feasibility avg. (1=difficult, 5 = easy)	Impact*Feasibility
RC1	6	3,64	3,57	13
1. Top Idea		*4,71*	*3,86*	*18*
2. Top Idea		*4,86*	*2,71*	*13*
RC2	8	3,13	2,73	9
1. Top Idea		*4,14*	*4,71*	*20*
2. Top Idea		*5*	*2,57*	*13*
RC3	8	3,77	3,02	11
1. Top Idea		*4,71*	*3,71*	*18*
2. Top Idea		*3,71*	*3,57*	*13*
RC4	5	3,49	2,69	9
1. Top Idea		*3,71*	*4,14*	*15*
2. Top Idea		*4,86*	*2,29*	*11*
RC5	6	4,24	2,55	11
1. Top Idea		*4,71*	*3,14*	*15*
2. Top Idea		*5*	*2,14*	*11*
Total	33	3,63	2,91	11

Table 25: The used effort in Case C

ARCA step	The number of RCA team members	Used hours Company C	Used hours ESPA	Sum
Problem Detection	9	9,5	21,5	31
Root Cause Detection	9	17	10	27
Elimination Idea Innovation	9	14	18	32
Total	**9**	**40,5**	**49,5**	**90**

Table 26: The number of detected and processed causes in Case D

	Email inquiry	Session 1	Session 2	Total
The number of detected causes (**ADC**)	52	116		168
The number of processed causes (**APC**)			42	42
Proportion of processed causes %				**25 %**

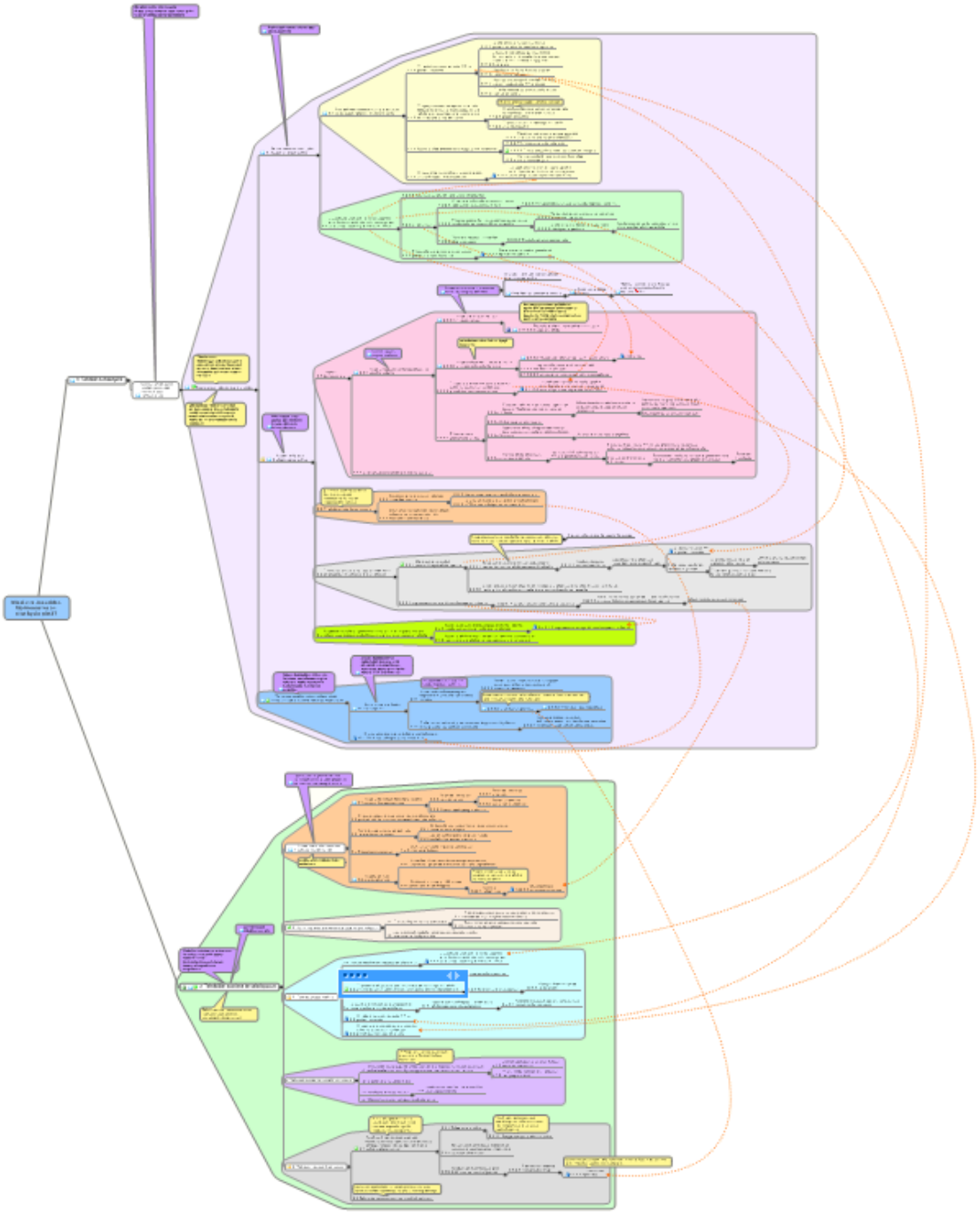

Figure 27: The cause-effect diagram after the first workshop session in Case D

Table 27: The corrective actions developed in Case D

Root Causes and top 2 corrective actions	The number of corrective actions	Impact avg. (1=low, 5 = strong)	Feasibility avg. (1=difficult, 5 = easy)	Impact*Feasibility
RC1	6	3,75	2,64	10
1. Top Idea		*4,5*	*3,3*	*15*
2. Top Idea		*4,17*	*2,83*	*12*
RC2	7	3,4	3,64	12
1. Top Idea		*4,5*	*4*	*18*
2. Top Idea		*4*	*3,5*	*14*
RC3	7	3,1	3,14	10
1. Top Idea		*3,83*	*4*	*15*
2. Top Idea		*3,5*	*4,17*	*15*
RC4	7	4,02	2,71	11
1. Top Idea		*4,5*	*3*	*14*
2. Top Idea		*3,83*	*3,33*	*13*
RC5	9	2,87	3,02	9
1. Top Idea		*4,33*	*4,17*	*18*
2. Top Idea		*3,17*	*4,33*	*14*
RC6	4	3,29	3,21	11
1. Top Idea		*4,5*	*3,67*	*17*
2. Top Idea		*3,83*	*3,83*	*15*
Total	40	3,38	3,06	10

Table 28: The used effort in Case D

ARCA step	The number of RCA team members	Used hours Company D	Used hours ESPA	Sum
Problem Detection	9	5,3	12,5	17,8
Root Cause Detection	8	17,6	8	25,6
Elimination Idea Innovation	8	12	18	30
Total	**9**	**34,9**	**38,5**	**73,4**