CHALMERS

Multi-Perspective Analysis of Software Development:
a method and an Industrial Case Study

Master of Science Thesis in Software Engineering

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Abstract

In November 2009 a project was started between Chalmers University of Technology and a Swedish company developing safety critical software, in this report referred to as CompanyA. The goal of the project is to investigate and improve CompanyA's Verification and Validation practices. A large contributing factor to why the research project was started is because of a European project that will affect CompanyA's market domain.

   The study, from which the data for this report was taken, was conducted as a master thesis at CompanyA with the goal of producing a state-of-practice description of the company. The research design was based around an analytical method using an analytical matrix that was developed specifically for the study. The matrix consisting of two dimensions where the first dimension consists of the four BAPO aspects of Business, Architecture/Technology, Process and Organization. The second dimension of the matrix consists of three points in time, Past, Current and Future (PCF). The matrix was constructed in this way to allow collection and analysis of data from multiple perspectives as well as from a chronological perspective. The matrix provides a broad yet defined scope giving a good basis for practice oriented exploratory research. The analytical matrix can be used to structure the research in all aspects of a study, from the definition of research questions to result demonstration. Data elicitation was conducted using several different research methods, such as interviews, structured observation, document analysis, watercooler discussions and surveys. The methods were used in different stages of the study to triangulate the findings and increase the validity of the collected data.

   The focus of this report is to describe the research design and the general methodology that was used during the study, primarily the BAPO/PCF analytical matrix, and to show its strengths and weaknesses through an industrial case study. By using the matrix it was possible to show how the company evolved over time in the BAPO aspects and to discuss how these changes are tied to each other. An example would be how the company's expansion in the international market has affected the company's processes and the process evolution. The methodology hence proved to be effective in finding information on a broad scale, which is beneficial for exploratory inductive research. The results from the industrial case study show that the methodology, with the analytical matrix at its core, is a powerful research tool for any exploratory empirical research within the domain of software engineering.

Keywords: Exploratory research, Research Methods, Software Engineering, BAPO, Analytical matrix, Chronological and Aspect oriented alignment, Safety critical software

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1. Introduction

In November of 2009 a project was started between Chalmers University of Technology and an industrial Swedish company, in this paper referred to as CompanyA, developing safety critical software systems. The research project was initiated because of two reasons, the first to improve CompanyA's Verification and Validation activities (V&V) with the goal to help them develop higher quality software quicker, cheaper and in general more efficient. The second reason is because of a large European project, in this paper referred to as EUPROJECT, which aims to set/change standards and requirements that may have an impact on CompanyA's market domain. For instance new requirements on safety and quality, which will also affect the research project since all process or practice development must follow those same standards. EUPROJECT may affect CompanyA on many levels of the organization, from how systems are being developed to market strategies.

The continuation of this paper will present the industrial case study conducted at CompanyA which constituted the first part of the larger cooperative project mentioned above between Chalmers and CompanyA. The purpose of this paper is however not to present the data collected during the study, but rather to present how the study itself was conducted, and by doing so present a powerful research methodology that could be reused for future exploratory empirical research in the field of software engineering.

1.1 Project description

The purpose of the project between Chalmers and CompanyA is to investigate how the company conducts verification and validation (V&V) of their software, and to find ways to improve upon these practices to make them faster, less expensive and in general more efficient. These improvements can either be based on state-of-practice or introduction of practice, which are state-of-art. The project is spread over a four-year time-period, where this thesis constitutes the initial phase that aimed to elicit and analyze the state-of-practice at the company. The research project will continue by using the elicited data and look at CompanyA's practices and among other subjects look at analysis of current verification methods to evaluate their performance, automation of tests for current and legacy software, etc. The project will also include investigation of the development of an agile development process that may be used for the development of Safety-critical software systems.

1.2 Research Questions and Purpose

The purpose of this paper is to present the research design used during the study at CompanyA, rather than the results of the study. The paper will in a detailed manner describe how the design was developed and how it was implemented. Some of the collected data from the case study has been added to the report to provide support of the strengths and weaknesses with the design, but such data has been left on a high level for confidentiality purposes.

The case study initially had the following set of research questions that were to be answered:

1. Which software development processes are currently used?
2. How can agile development processes and practices (ADPP) be used to efficiently develop safety-critical software systems?
3. What are the challenges with ADPP, in particular when it comes to verification and validation?
4. How does legacy software impact the use of ADPP's?
5. How is EUPROJECT likely to affect the business situation and thus the general requirements on the development processes used by CompanyA?

However, since the research questions are case specific, and the objective of this report, as mentioned, is to present the method rather than the findings of the study these questions are not relevant for this paper. They have mainly been presented here to provide the reader with an understanding of what the case study aimed to achieve. The research questions for this thesis report are:

1. Which organizational aspects can/should be used to provide a multi-perspective view of an organization developing safety-critical software systems?
2. What research methods are applicable for an exploratory case study?
3. How can the research methods be tied together to form a study design for exploratory research?
4. What are the advantages and disadvantages of defining a research method-design around an analytical matrix?

The continuation of this paper aims to answer these questions through discussion around the use of the design used during the study, as well as validation of the design through examples taken from the case study itself.

1.3 Case Study

The Master thesis from which the data in this report was taken was conducted at CompanyA during the winter of 2009 and the spring of 2010. The purpose of the thesis was to define the current state of the company with focus on the company's V&V practices.

The case study was of an exploratory nature since very little was known about the company before the thesis started. It had been presented that the company was developing Safety critical software, that they were using agile development processes and that they had encountered obstacles with their legacy software, but otherwise very little was known.

The study followed a top down approach where the researcher first collected information to get an overview of the organization, followed by deeper investigation of certain areas to get more detailed information. The study was divided into different elicitation steps that have been roughly presented graphically in the Figure 1. The x-axis shows the time-line and the boxes indicate which subjects were investigated during different points in time. The sections between the boxes included analysis and preparation for the continued study.
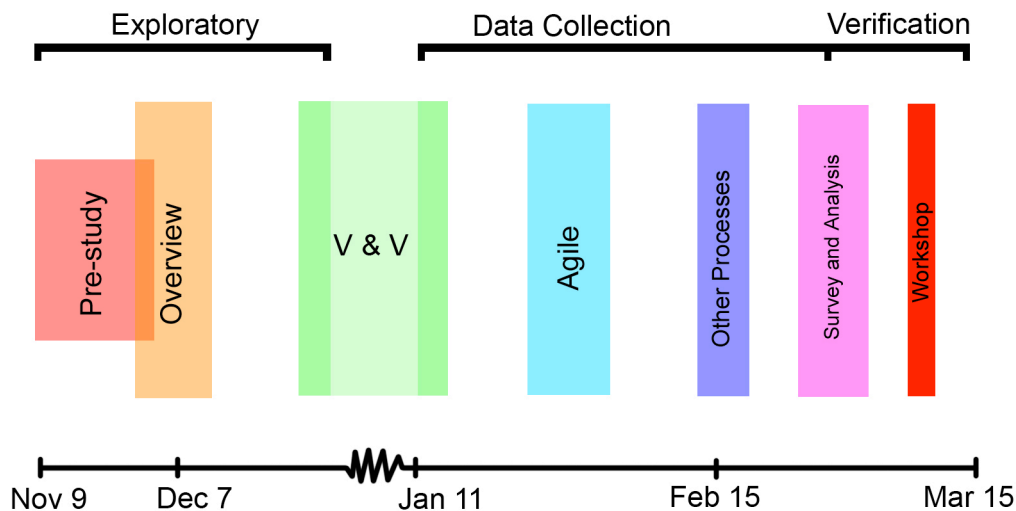
Figure 1: Time schedule for the project

In Figure 1 it can be seen that the study was divided into three main steps: Exploratory, Data collection and Verification. The first step was to collect general data to get a grasp of the organization as a whole, what processes were used at the company, which documents were available, what roles were defined in the organization, etc. The second step, the data collection, was the largest part of the study. The focus in this step was on processes and architectures, but business and organization was also investigated. Lastly, the study included a verification step where the results were verified within the organization. The verification was done through a survey but also through meetings with stakeholders during which misconceptions and faults in the results were sorted out and corrected.

Because of the exploratory layout of the study, with the chosen top down design, data analysis was conducted continuously during the entire study, in an agile fashion, with increasing intensity towards the latter parts of the study.

2. Background

2.1 BAPO

There are several analytical frameworks used for organizational definition through the use of well-defined organizational aspects. Among these frameworks are BAPO[1] and PESTEL[2]. The framework names are acronyms for Business, Architecture, Process and Organization (BAPO) and Political, Economical, Social, Technical, Environmental and Legal (PESTEL) aspects respectively. The BAPO framework is used within different fields as part of analytical frameworks. For instance the Family Evaluation Framework [3], which is used to define the level of implementation of Software Product Lines (SPL), more specifically Software Product Line Engineering, is based on BAPO. In the FEF framework the four aspects are ranked individually, on a scale between 1 to 5, according to a set of requirements defined for each level. The higher the level, the more of the SPLE process has been implemented. The four aspects of BAPO hence provide a good set of view-points for organizational analysis.

PESTEL, just as BAPO, is also an aspect oriented analytical framework. The main difference is that PESTEL focuses on the business side of an organization, whilst BAPO is more general. PESTEL is derived from the old PEST framework, which was developed in the 1980s, a few years later followed by PESTEL in the end of the 1980s. PESTEL is mainly used for inductive future reasoning based on current factors.

2.2 The Analytical Matrixes and Research type

An analytical matrix is a matrix with at least two dimensions of interest for the researcher. The dimensions can be domain specific as well as general. The choice of dimensions and domain is related to the type of research that is being conducted and what is being studied. These matrixes can often be used as multi-purpose tools. One of the more common matrixes is the decision matrix, which provides the researcher with decision support during the study. This can be of higher value for exploratory research. Exploratory research is a term used for inductive research where very little is known about the organization or general subject being studied. These types of studies usually follow a top down design, where data is iteratively collected to form a more and more complete view of the situation. The research type can be used for many different purposes, such as to find the current state of a problem, to find a solution to a problem, to find the state of practice of an organization, etc. Exploratory research is most often conducted using case studies since the case study provides a general tool for more open data elicitation. Combining the case study with a decision matrix can therefore be valuable to structure the case study and refine the project scope.

Case studies can be both practice and theory oriented, which depends on what the goal of the study is. If the study is empirical in nature, and the goal of the study is to provide the studied company with data explicit to them, then the research is practitioner oriented. However, if the goal of the study is to study a specific practice or process within a set of organizations then the research is most likely theory oriented, and more general in nature. Hence, theory oriented research provides data with higher external validity whilst practitioner oriented research does not. The analytical matrix does not provide additional support for the external validity, but the internal validity as well as reliability can be raised using this method. Depending on matrix-design, the matrix can highlight data relations and dependencies, which is tightly connected to internal validity. Reliability may also be affected by the same factors since the matrix could outline the research design such that it can be reconstructed in another case.

2.3 CompanyA

For the purpose of giving the reader a view of CompanyA, a shorter summary of the general characteristics of the company has been presented here. CompanyA is a small company spread over several geographically distributed locations. The company has a family styled organization, meaning that everyone within the organization talks to everyone else, and spend time with each other both on and off site. Peer-to-peer communication is used within the organization as the primary way of spreading information. Development is primarily conducted in small development

teams of three to five developers, usually with one project manager for each project. For larger projects that include sub-projects the project managers of the root projects sometimes have assigned sub-project managers to help them.

The company has been active for approximately 20 years and have during this time grown quite rapidly within the domestic as well as international market. Most sales are done through personal connections in the market, but since the company aims to expand alternative marketing methods have also been investigated. The company's primary source of brand building is done through expos and similar events.

The company is very innovative, and have several top of the line solutions on the market. The organization constantly strives towards improving their core business, which has, for example, resulted in them testing and adopting new processes, tools, etc. The organization has for many years been working with iterative development processes, but has also adopted the agile development process SCRUM successfully. The use of these processes makes the company flexible in dealing with customers, an asset which is also one of the organizations greatest strengths. The agile development processes has thus far only been used in projects developing non-safety-critical software, but there is a willingness from within the organization to test the agile way of working also for safety-critical system development. A safety-critical system is in this context defined as a system, that if it fails, which would cause considerable (economic) damage to property or personal injury.

To further verify the quality of their developed systems, the company has adopted a rigid quality assurance process (QAP) based on a meta-framework called ESARR 6[4]. The meta-framework defines the guidelines for development of a quality assurance process that the company has chosen to base on the RTCA DO-278[5] and RTCA DO-178B[6] frameworks from 2002 and 1992 respectively. These back-end frameworks are quite big and complex and include many practices such as QAP specific documentation, QAP specific testing etc. The QAP is used to define system quality, but most of the verification work is handled through stand-alone activities in league with the QAP. Five of the more common practices used by the company are free testing, integration testing, system testing, Factory- and Site-acceptance tests. The customer is often present during the two latter tests to run their own tests on the system. Other verification activities that are used include long-time tests, stress tests, scheduled free testing and more.

3. The Research Methodology

This section of the report will present the research methodology design and the methods that were used during the case study. The section will provide a deeper discussion of the motivations to why certain research methods were used and what concepts were used to link the methods together to raise internal validity. The research in this case study was fully practitioner oriented, and therefore external validity, generalizability, of the research is low. It is important at this stage to clarify that even though the results of the industrial case study are practitioner oriented the results in this paper, which focuses on the research method, are theory oriented and are therefore more general, as well as applicable in other contexts.

The continuation of the section will discuss the design-method in general, how it was developed, how it is used in general, etc, whilst the following sections will go into details how the method-design was applied in the industrial case.

3.1 Developing the Methodology

The research design-method described in this paper was developed in the early stages of the industrial case-study as a tool for the study. Because the study would be practitioner oriented it was clear from the start that internal validity would be the primary concern, and therefore the practice of triangulation would be very important. Triangulation is conducted by comparing different data sources to validate data and/or conclusions. Several different research methods were therefore used for each step of the study such that the data could be triangulated not only between different sources but also method results. The top down data collection governed the order in which the different

methods were used, normally starting with interviews, followed by data analysis, and so on to gain data depth and validity.

Data validity is always important when doing any type of research. There are different types of validity, such as internal validity, which indicates if all the elements of the study seem to fit together. Internal validity can be achieved by answering the question: is the data connected and valid in the domain? Another type of validity is External validity, which can be achieved by answering the questions: is the research generalizable? Can the findings be applied on another company or organization or are the results bound to just the studied company? There are also other validity types such as construct validity, ecological validity and more, which are all of importance, but of different importance for different types of research. There are different ways of increasing the validity of research. For instance the choices of research type and design are important, what research methods are used, etc. As mentioned, the concept of external validity would be very low for the study results, since the objective was to get the current state-of-practice of CompanyA, and CompanyA alone. Which meant that if all of the results and conclusions drawn for CompanyA were to be applicable for another company, that company would have to have the exact same state-of-practice as CompanyA, which is unlikely. Once more it is important that the reader differentiates between the discussions regarding the case study and the results presented in this report, since this report concerns the methodology used for the data collection rather than the data itself.

As mentioned, the primary practice that was used in order to raise internal validity was triangulation. The purpose of using triangulation is to ensure that the data has been interpreted correctly, such that it is valid, and without bias.
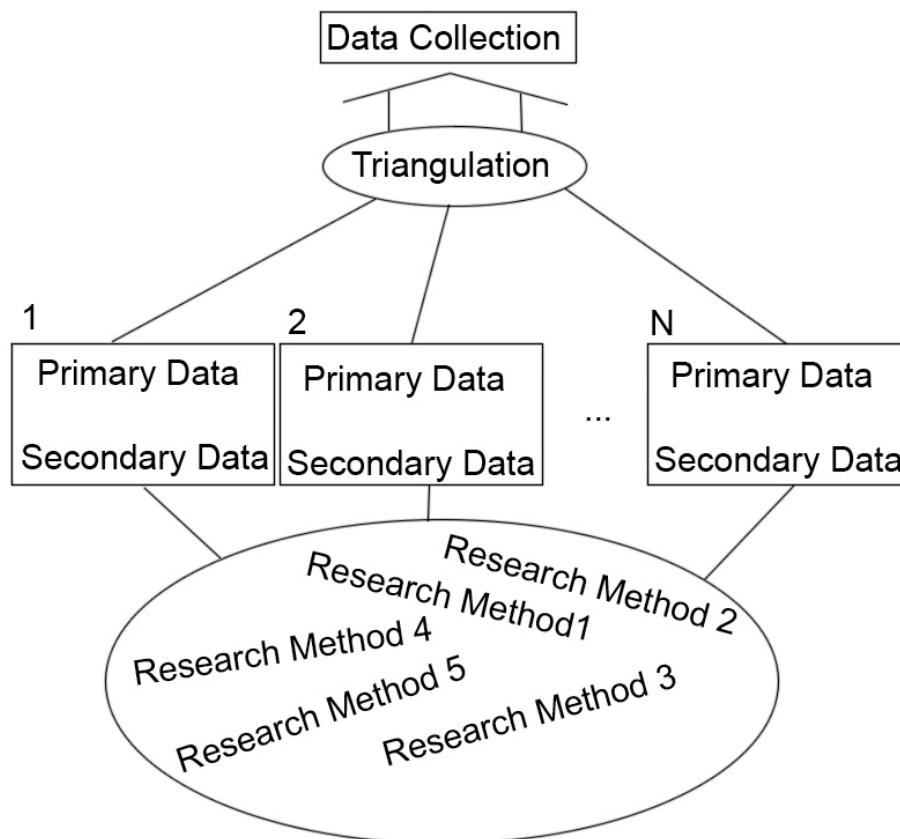
Figure 2: Triangulation

Figure 2 shows N sources and in this case five research methods. The number of sources and methods are often not known at the start of an exploratory study. What is important to note here is that one or several methods can be applied on anyone of the sources, if the prerequisites for the research method X are fulfilled. As an example interviews require that there is a person to interview. The picture also shows that several sources are connected to the triangulation box

indication that several of the sources can/should be used for triangulation during the data collection phase. This will greatly improve the results, raise validity, and make the analysis simpler. The main limitation during this type of research is often cost, which limits the amount of redundant sources that can be used for the triangulation. Because of this constraint the researcher should chose carefully among the available sources as to ensure maximum triangulation coverage of the concepts he or she is concerned about.

   The research methods that were chosen for the study were chosen with the nature of the study in mind, since there are many different methods to choose from, but not all, are applicable for all types of research. The pre-requisite for the chosen methods were that they should be good at inductively finding data, since so little was known beforehand to base deductive methods on. In order to tie the research together an analytical matrix was developed, using the BAPO perspectives discussed in the introduction, as one axis of the matrix, and time on the other. The matrix includes twelve cells, each row providing data for a specific aspect of the organization, and each column providing chronological data for a generically defined time-period. The advantages of having this matrix are several. First of all the matrix provides a good general design for what should be elicited to begin with, as well as a roadmap of the order to elicit the data. During the analysis phase the matrix also provides support since it will automatically provide the researcher with the data in chronological order, and it is therefore much easier to align it. This alignment in time and data separation according to the BAPO perspectives also makes it possible to draw generic conclusions within the future column. This requires inductive reasoning based on the previous columns, and provides data open to speculation, but the data could still serve as a viable guideline either for future research and/or decision making within the studied organization.

3.2 Graphical Overview of the Methodology

Figure 3 shows the steps that the study followed from definition of the study to presentation of the results. The boxes show the steps of the method, which are independent, except for the execution and data collection and analysis steps, which have some dependencies since analysis should be conducted concurrently with the data elicitation. This is important to ensure that enough sources are available during the analysis for triangulation purposes. If the data collection is mutually exclusive from the analysis there will not be any possibility for further elicitation if during the analysis any of the data sources prove to be contradictory to one another.
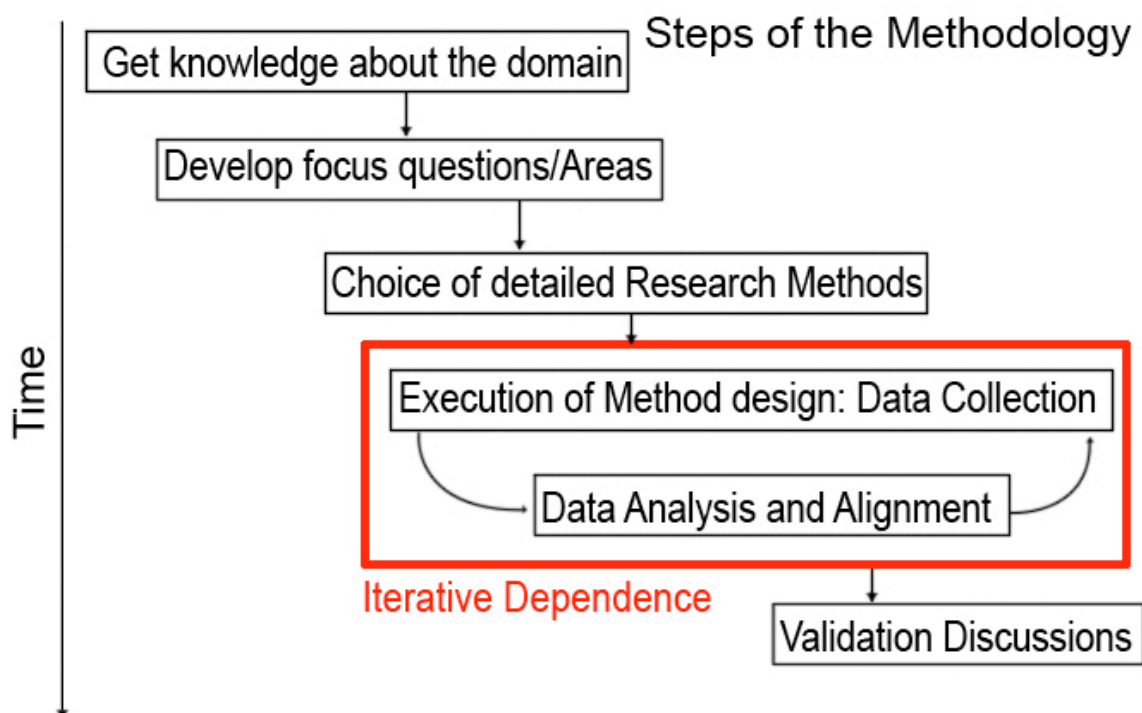

Figure 3: Methodology

3.3 Research Methods

3.3.1 Structured and Semi-Structured Interviews

During the study there were eight interviews conducted with seven people. These interviews were all of a semi-structured and consisted of a pre-defined set of questions. The questions were defined based on what role was being interviewed, and for which stage the study was in, see picture 1. The questions were written down on interview guides, including anticipated possible follow-up questions. Unanticipated follow-up questions were also asked during the interviews in the spur of the moment.

Each interview was conducted with a single person for a period of 30 minutes to one and a half hours. Longer interviews were split into two pieces to provide the interviewee with a small brake to collect his or her thoughts.

The main benefits of the semi-structured interviews are that they make it possible to instantly go into more detail on subjects that are of more interest for the research, by allowing the research to ask one or more follow-up questions. The method also provides a lot of data and may open up new research tracks worth pursuing. The issues the interviewer is faced with when using this method is that the interviewee can feel uncomfortable in the interview setting and therefore answer questions in accordance with what the politically correct views of the organization are, rather than what is actually state-of-practice. Because of this phenomenon it is important to validate the collected data from the interviews through one or several other sources. Misconceptions can be shared among several people, and therefore the roles, which are interviewed, must be evaluated, or a large enough sample-group must be chosen to eliminate the erroneous data. It is possible to improve the outcome of a single interview by ensuring that the interviewee is as comfortable as possible. This includes assuring the interviewee that all data from the interview will be completely confidential, as well as to describe how the data will be used, how the data will be handled, etc. This activity is so important that it is recommended to have a checklist with these points as part of the interview-guide, and to present them at the start of each interview. It is also recommended that the interviewer take notes rather than record the interview since taking notes is mentally less intrusive for the interviewee. The note-taking technique also makes it possible to control the interviewee, for instance when the interviewee strays from the topic the interviewer can simply stop taking notes. The interviewee will notice this and realize that what is being discussed is not important to the interviewer and stop talking so that the interview can proceed. The problem with taking notes rather than recording the interview is that there is so many things to think about during the interview session, such as thinking up follow-up questions whilst handling everything else that happens during an interview. An alternative is to use several interviewers, one who asks the questions and one who takes notes. As mentioned, recording the interview may add political correctness to the answers but has the benefit of preserving all the information collected at the interview such that it is possible to go back and listening to the details again, which also makes it possible to re-interpret what the interviewee said to filter out political correctness and bias.

The semi-structured interviews can end in different ways, but it is recommended to end them by asking about three strengths or weaknesses that the interviewee has recognized regarding the subject being discussed in the interview. In order to get a sense of how the interviewee is as a person it can also be a good thing to start each interview with some personal questions.

Once the interview is over there are different ways to handle the raw data. If the interview was documented with notes it is important that the notes are rewritten as text as quickly as possible so no important details are forgotten. If the interview was recorded it is not as important to write it down right away, even though it is recommended in order to get a searchable text document that can be used in a quantitative manner later during the analysis. It is also a good idea to write it down as quickly as possible to capture any thoughts or ideas the interviewer had during the interview that might be worth looking into. Once the interview has been transcribed, the transcript should be sent to the interviewee for validation to ensure that all the data is correct.

3.3.2 Structured Observation

This method, unlike normal observation, includes having an observation guide similar to the interview guide for the structured or semi-structured interview. This guide contains a checklist of actions that the researcher believes he or she will observe during the session. As the session progresses the researcher check-off the actions on the guide as they happen. During a structured observation it is not suitable to ask questions or interact with the person being observed. This will minimize the so called "observer effect" which states that whatever you observe you also change. For instance if a developer is being observed, and there is a company mandate that all developers should click on the save button after finishing each snippet of code, he or she will most likely do this continuously as you observe him or her, even though that same developer normally never clicks on the save button. This is just a toy example, but the lesson is that the observed person will behave differently whilst being observed than he or she would normally behave when working alone.

Observations can be conducted in different ways, which are more or less experimental. Different techniques have different advantages and disadvantages and should therefore be applied during different contexts. If what is being observed includes day to day activities with the observed person randomly interacting with other people then the observation should probably be conducted in a more natural setting. If the actions that are to be observed are just a fragment of a long chain of events, a more experimental approach is preferred were the observed object is cut off from outside interference such that the object can focus on the task at hand. An example of a specialised method of such experimental nature is the talk aloud protocol (TAL). TAL is a method where a person is given a specific task to solve and told to explain continuously what he or she is doing whilst solving the task.

In the same way as interviews, the structured observation technique provides the researcher with a lot of data, usually more than expected and documented on the observation guide. A common problem with the observation technique is that much of the collected data can be hard to interpret for the researcher since the data is often domain specific. This includes jargon and domain specific activities that the researcher does not have any prior knowledge of, which may make the analysis much more difficult and tedious.

Just as for the interviews it is important for the researcher to write down his or her notes and thoughts after the session such that no important details are forgotten. Since observations are usually both visual as well as auditory the alternative is to film the entire session such that it can be played back and studied later.

3.3.3 Document Analysis

Document analysis includes studying documentation from the company or organization that is being studied. There are different methods for doing it, but for this case study the document analysis was primarily conducted using the visual inspection method. The visual inspection included studying everything from requirements specifications, process documentation, customer and QAP specific documentation and more. During the study this was done both in an inductive and deductive manner, since sometimes the data from the analysis was for triangulation of data gathered from another method and/or source, and other times it was more exploratory to get basic information for writing questions for an interview, investigate new concepts and so on.

Document analysis is a good way of getting data, but it should not be the only source used since it can be quite tedious, and it may require quite complex analytical tools in order to get good quantitative results. However, as a secondary source it is usually quite good, especially if the data is tagged or indexed in some way that makes it easy to navigate and/or search in.

Document analysis is also handled differently for different research designs. For a case study the document analysis can be simple where the documentation is simply read and a few notes are taken. For a longitudinal or cross-sectional design however the analysis may be more complex and requires more structure and analysis. Data is handled differently for a case study compared with a longitudinal or cross-sectional design. For a qualitative case study all data is taken as input and then the output is filtered. For the other designs mentioned above which are quantitative, which require

well defined measurement points, the input is filtered and all the results become output.

3.3.4 Watercooler discussion

This research method was found to be one of the most effective elicitation techniques during the study when it came to elicitation of the actual state-of-practice at the company. The method resembles that of an open interview but instead of a scheduled interview meeting the method is conducted during a lunch- or coffee break. Most often the interviewer should have one or two quick questions prepared and then just ask them to the person or people that may be able to answer them. The more relaxed setting around the coffee machine or watercooler has shown to make it easier for the interviewee to open up. The most common use of this technique is however that the researcher just jumps into a conversation between the people having their brake and ask some spur of the moment questions. According to Sarker et al., most information and knowledge sharing takes place during the coffee brake, which is also what makes the watercooler discussion technique so powerful. [7]

There are a few issues with this technique. The first being that the interviewer must be light on his or her feet and continuously think of follow up questions, whilst still absorb and remember what was being said. In order to start such a conversation it helps if the interviewer is an open person that has an easy time talking to people, but it is not a necessity. The interviewer should also focus on not to sway too far from track, since it might be troublesome to steer the conversation back on track. Once the session is over it is extremely important that the interviewer writes down what was discussed before he or she forgets the details of what was discussed. In order to remember as much as possible these sessions should be held short, about 10 to 15 minutes, but it is not uncommon that these sessions stretch for much longer.

What was mentioned above are just guidelines since, as mentioned, it is not always easy to plan these sessions. The technique also works if the interviewer simply walks up to the office of the person he or she wants to interview and quickly ask a few questions. It is important in these cases to make sure that the person being interviewed has some time to spare to talk, otherwise it can cause annoyance that can lead to that person not wanting to answer anymore questions later during the study. The technique should not be used to often either, since that could have the same outcome as above.

The technique is good at eliciting the actual state-of-practice as well as thoughts and opinions of people, but there are also some dangers here that must be considered. It is important to think about if the elicited data corresponds to the company views, or just the views of that person or those people being interviewed. Since this is not clear from the start, all data collected by this method must be triangulated. Triangulation can be done through further watercooler discussion if there are enough people to use as sources, but for the most part other methods should be used as well. The method is also a good choice to determine stakeholders with whom to conduct more structured interviews with.

3.3.5 Surveys and Questionnaires

During the study two larger questionnaires were sent out to people within the company. The first questionnaire regarded CompanyA's quality assurance process and was sent out to a smaller sample-group of people that had been identified through interviews and watercooler discussion as people with knowledge within the area. The questionnaire consisted of approximately 70 yes or no questions that all referred to practices within the QAP process. The results were later analysed through a combination of visual inspection and a statistical tool to provide the result.

The second questionnaire was of a more general nature and was sent out to about half of everyone at the company. The results from this questionnaire were handled in pretty much the same way as the first, which included inputting them into a software tool to create graphs, which were the end result. The purpose of the second questionnaire was mainly to validate previously collected and to triangulate the results.

There are a few things to think about when doing Questionnaires. For instance it is important to

think about what the result of the questionnaire are going to be used for, which also helps to determine if the questions should be inductive or deductive. Once you have settled what the results are going to be used for you should decide what type of questions you are going to put in the questionnaire. The questions can be of an open-ended nature, but it is usually recommended to have forced answer questions with a scale of some sort. There are many different types of scales that can be used. For instance for the first questionnaire used in this case study the scale was binary, meaning that there were yes or no answers. This is however not a good alternative, instead it is better to use scales of some sort, such as for instance the Likert scale [8] that was used in the second questionnaire also mentioned above. The Likert scale consists of a number of forced answer items ranging from "totally agree" on one side of the scale and "totally disagree" on the other. The scale can have a middle point or have an even number of points to choose from. You can also have different amounts of items to choose from. In the second questionnaire five different options were available to the participants, but if you want finer granularity you can have as many as you see fit.

Questionnaires can be designed in different ways, but it is a good idea to keep them anonymous to get a better result. It also a good idea to state similar information regarding how the data will be handled and presented as for the interview data discussed above.

Another important aspect to consider when doing a survey is the response rate. As a guideline the minimum response rate should be at least 60 percent, but preferably or more 80 percent, even if the number of sent out questionnaires is large. Other matters to consider, even before sending out the questionnaire, is to whom the questionnaires are being sent? Is the sample-group representative for the organization? Are there enough people in the sample-group? And so on. The response rate for the questionnaires in the study was high, but the sample group for the first questionnaire might have been a bit small. The answers from the first questionnaire were however well triangulated to ensure data validity, such that the questionnaire was not the primary source of data. When the researcher does not have the option of using other methods to triangulate questionnaire data from a small sample group, the researcher should look at other means of eliciting the data instead of questionnaires since questionnaires require a "suitably" large sample group to provide valid data.

4. Case Study

This section of the paper will present some of the results that were gathered during the industrial study conducted at CompanyA. These results have been embedded in the process description, which shows how the design-method was developed and applied during the study. The aim of this section is to provide the reader with a description of the design-method in a hands-on, real-life application to show the methods strengths and weaknesses when applied to an actual case. The section has been formatted according to the chain of activities defined in Figure 3. Each of the following sections includes a bullet-point list presenting the method specific artefacts developed or handled during that particular stage of the method execution, as well as which research methods were used to acquire data.

4.1 Get Knowledge about the Domain

In the case of an exploratory case study the first step is usually to define the domain of the study. Since it is not always the case that the researcher has previous knowledge about the area or domain, he or she must start by getting acquainted with the subject. For the CompanyA study, the domain and problem-description was established in three stages. The first stage was for the researcher to read the overall project description and get an understanding of what the purpose of the project/master thesis was. The second step was to have an initial meeting with the primary stakeholders in the project. During the meeting, the outline for the project was once again presented, and a deeper understanding of what the company expected was developed. This meeting also made it possible for the researcher to ask questions regarding concepts that he had not understood and for the entire research team to get an initial feel of the company. The third step was for the researcher to read up on the domain. In this case the thesis was part of a larger project, which in turn had requirements, and that project in turn was part of an even bigger project with requirements of its

own. In order to understand the impact of these requirements the researcher had to read up on documentation regarding the larger projects to define the domain and how the requirements from the larger projects would affect the thesis.

In a general project there might not be that many requirements to consider, but it is still of importance to the researcher to consider in what context the research is conducted. Is it practitioner oriented or theory oriented? How will the results be used? Etc. Only once this is clear the project can proceed.

The following concepts were handled in this stage:

    1. Create an initial view of the domain. Some of the questions that should be considered are, but not limited to:

        1. What does the organization look like?
        2. What products do they produce?
        3. What problems are present?
        4. How and where can more information about the domain be gathered?
        5. etc.

    2. Find the requirements and relations of connected projects to the study in focus

The primary research methods that were used for this specific study in this stage were:

    1. Document analysis of documents collected regarding the domain and the company
    2. "Open Interviews" (Meeting with stakeholders)

4.2 Develop focus questions/areas

Once the researcher has established an overview of the project, he or she can move on to define his or her research in more detail. Using the information from the first step the researcher should define the research questions and start drawing up an initial research design that will be used later during the study. Bare in mind that the discussion here regards exploratory research, and that the most common choice of design is the case study approach. This is mostly because of the inductive nature of the research, which rules out research designs such as cross-sectional or longitudinal designs since there are no initial data to set up the designs around.

The level of abstraction when defining the design should still be kept on a rather high level because of two reasons, the first being that there is still not that much information available at this stage, and secondly, as we keep coming back to, the nature of the research is explorative, usually with a top down approach. This means that the research will be heavily influenced by the findings during the study, which may take the research in unexpected directions. As such, it is not possible to draw a complete detailed research plan, instead the researcher should try to define the guidelines for what should be done, roughly describing what roles and documents to investigate based on literature and experience. In the case of the study at CompanyA the analytical matrix, that has been mentioned and discussed earlier in the paper, heavily influenced the plan. The matrix was used in all aspects of the study, and was defined during this stage in the study as a tool for guiding the research.

The matrix was not just defined during this stage, but it was also used to break down the research questions, defined in section 1.3, into smaller pieces defined as areas of interest. The intended idea was that once the area(s) connected to a specific cell had been elicited the researcher would be able to answer the research question from which the areas of interest had been defined. The scope of the matrix was through this process narrowed by the research questions and connected to the goal of the study. The areas of interest were produced through brainstorming sessions where the research questions and what was known about the domain and organization was used as input to the discussions. The resulting matrix for this particular study can be seen below.

	Past	Current	Future
Business	Legacy cost, Market history	Expanding markets, pre-EUPROJECT	Market establishment, EUPROJECT, Branding
Architecture/Technology	Testing issues,	Agility	Continued agility,

		Architectural choices		Improving quality
Process		Transitional issues	Scrum and Life- and Safety-critical systems	Improving quality, Scalability, Reducing cost
Organization		Transitional issues, Growth of organization	Management control, Reliance on individuals	Project size, Scalability

Matrix 1: Research questions derivative matrix

The areas of interest should be used when developing specific interview and/or detailed research questions in the following stages of the study. The matrix can also at this stage serve as a guideline for how to conduct the study. Either the elicitation can follow the matrix row by row, column by column or some other defined pattern that the researcher sees fit. An ad hoc approach of jumping back and forth between the cells is also possible, but not recommended since this defies the purpose of using the matrix as a roadmap for the study. The roadmap defined for this study was to start with the process row, continuing with the architecture row followed by the organizational row and finally the business row. This pattern was chosen because stronger dependencies were found between the process and architectural rows and between the business and organizational rows which made it suitable to elicit the information for these rows following one another in close correlation.

The main bullet-points covered during this stage of the study were:

1. Create an initial research plan and research questions for the study
2. Develop areas of interest, for instance through brainstorming, from the research questions and connect these to the cells of the matrix

No particular research methods were used during this stage, since the focus of this stage was to refine the actual process rather than the data it would provide.

4.3 Choice of detailed Research Methods

Once the design, research questions and sub-research questions have been defined the planning can continue to select research methods. The most common research method for this type of study is interviews because of their ability to elicit a lot of information in a short session. The interview can be conducted as open-, semi-structured- or structured-interviews, but the experiences from the study indicate that open- or semi-structured interviews work the best. During this stage it may also be a good idea to conduct one or more initial interviews, preferably open, to get an initial deeper overview of the organization being studied. This interview should be conducted with a person from management with a larger view of the organization such that he or she can provide the researcher with information from all of the BAPO and time aspects. Because the interview questions will be of such a broad nature the interview should possibly be longer than the standard 30 minutes to an hour. Because this will be tiresome for the interviewee as well as interviewer there should be a break in the session or the interview should be split over several days. The purpose of the interview is to get a deeper understanding of the domain, but also to identify roles and possibly documentation that can be used later in the study, so called Snowballing [9].

The initial interview that was held for this study was held with the project manager for the research project at CompanyA. This person was known to have general knowledge of the organization with larger expertise of the business perspective. This was known before the interview and therefore several of the questions were guided towards the business row of the analytical matrix, but the overall purpose of the interview was still to elicit general information for all of the cells of the matrix. Example data that was gathered include roles of the organization, projects and products the company manufacture, etc.

In the general case this initial interview should provide the researcher with information that makes it possible to make narrow the research design further in the choice of what research methods should be used. If the company for instance has very little documentation and instead utilize personalization practices, then focus should be on interviews and observations, whilst if the company is documentation heavy, documentation review might be preferred. Aspects that should

influence the choices during this stage are the company's commitment to the project, how much resources are delegated to the study, and what the purpose of the study is. The aspects all fall into the context of the research, which will influence all choices taken in the early stages of the study. For this study the methods were selected based on available resources for the study and the methods various ability to collect data. The methods chosen for this particular study have been described in previous parts of the report and include interviews, structured observation, document analysis, watercooler discussion and surveys. The matrix does not limit which methods are used, and therefore the researcher should chose methods based on the studied domain, available resources and information he or she aims to capture.

Once the methods have been selected a rough plan can be drawn for which matrix cells the different methods should be connected to, in short define which methods should be used to collect what information in the matrix. Note that this plan is just a preliminary guideline since the exploratory nature of the study will force the researcher to adopt the use of different methods to resource availability during the course of the study.

The main bullet-points of practices that are conducted and artefacts that are developed for this stage are:

1. Conduct initial interviews to gain further information. Use the Snowballing technique in order to get information about new roles to interview further

2. A revised more detailed research design including specific research methods connected to the analytical matrix. Below the matrix for this study has been provided, Matrix 2, where the different methods have been connected to the matrix according to how they were initially planned to be used.

	P	C	F
B	Interviews	Interviews Surveys	Interviews
A	Interviews Document Analysis	Interviews Document Analysis Surveys	Interviews
P	Interviews Document Analysis	Interviews Structured Observation Document Analysis Surveys	Interviews
O	Interviews Document Analysis	Interviews Document Analysis Surveys	Interviews

Matrix 2: Research methods connected to the BAPO/PCF matrix

The particular research methods that were used during this stage were:
1. Open Interviews
2. Semi-Structured interviews

The research methods that were used initially were interviews to get a better view of the organization as well as data of other roles to interview and documents to analyze, so called Snowballing.

4.4 Execution of Method design: Data Collection

This stage of the study is where most of the raw data is collected. Because of the initial interviews described in section 4.3 there is some overlap between this stage and the previous. The elicitation should as much as possible follow the research plan developed in the earlier stages using the research methods in the way they were previously connected to the analytical matrix.

This stage of the study was planned to be conducted following the plan that was described in the end of section 4.2, starting with elicitation of the company's processes and then moving over to architecture followed by elicitation of the company's organization and finally how the company conducts its business. This plan is not expected to generally applicable, but should rather be revised

for different projects. The dependencies between the four perspectives can also put constraints on the data collection, making one elicitation plan more favourable. It was soon clear during the study that it would not be possible to follow this plan completely since opportunities continuously arose that forced the researcher to jump between the cells of the matrix. The decision to stray from the initial plan was based in the fact that these opportunities would most likely not rise again later during the study. For instance during the elicitation of the process row the researcher had the opportunity to observe a customer meeting which provided information for the business row. This opportunity only arose once and valuable data had been lost if the opportunity had not been taken. This case was a minor deviation from the plan since the meeting only took a few hours, but it exemplifies the fact that the research plan should not be followed blindly for this kind of research.

The study as a whole was divided into three parts, which encapsulated the six stages defined in Figure 3 in section 2.2, following the plan defined in section 4.2. The first stage was to get an overview of the domain, the second part was the primary data collection stage and finally a stage for verification of the results. During the second stage interviews and document analysis were the primary methods of elicitation, as described in Matrix 2, however the method that proved to be the best to elicit the actual state-of-practice in the organization was the watercooler discussion method. The method was not part of the initial plan, and therefore not documented in Matrix 2, but was soon adopted during the study for its ability to capture data. The main advantage of the technique, as described above, is its ability to capture the actual state-of-practice, but it also has the disadvantage of being prone to produce biased data and therefore all data captured with this method must be triangulated.

As mentioned, the primary source of data was interviews. After each individual interview the interviews were transcribed in a text document that was sent to the interviewee for review. If any issues or misconceptions were found these were corrected before they were used to develop the final results.

Other than to serve as a roadmap for this stage, the analytical matrix was also used for triangulation purposes, since internal validity was a high priority. The following overview of the matrix, Figure 4, was therefore used to visualize which methods had been used where to show that data had been properly triangulated. Missing from this visualization is how many instances of each research method were used during the elicitation.
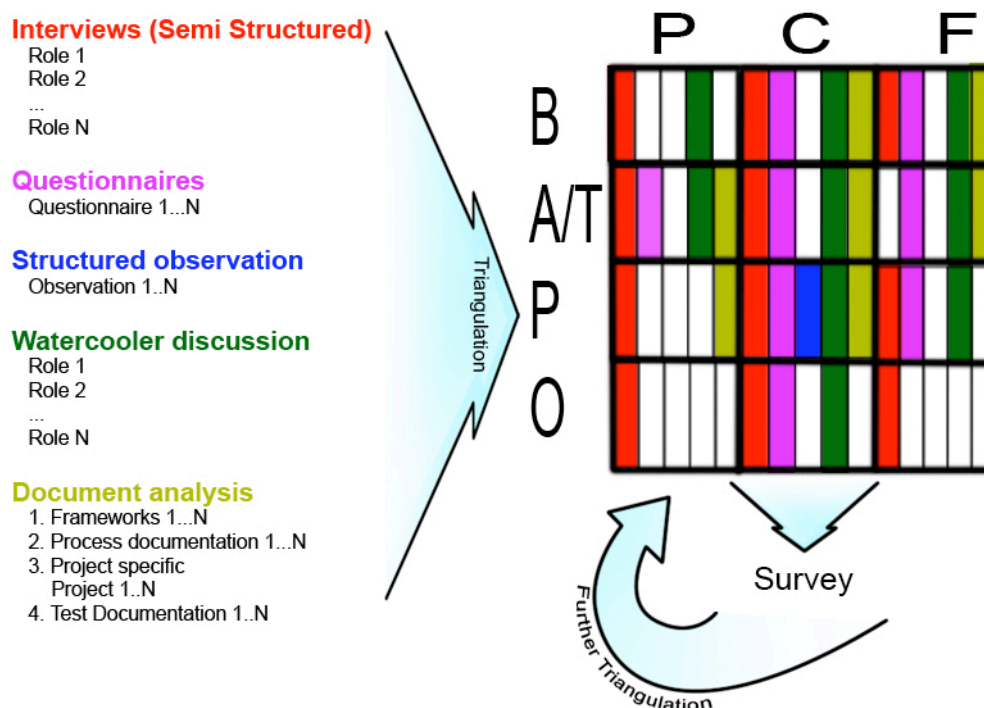

Figure 4: Research Method Triangulation

Figure 4 shows that there are only two cells with less than two research methods. These cells were instead triangulated through several interviews, where redundant or similar questions were asked in order to get the final result. This practice is closely connected to the analysis phase of the study, which will be discussed in the following section, but triangulation of the data must be considered in the data collection stage to ensure that enough data sources and methods have been used within each matrix cell to ensure data validity. This is important because it may be difficult to elicit further data after the primary data collection stage of the study has been completed, unless further resources can be devoted to this activity.

Figure 4 also shows that there are some differences between which methods were used to collect data for the different cells compared to the initial plan. These differences are connected to the opportunities that were discussed in the beginning of this section, but also because of prioritization because of budget constraints and or possibility of using the particular method within the specific cell. For instance

The main artefacts produced during this stage are defined in the bullet-list below.
1. Primary raw data
2. A visual representation of the research method triangulation

The research methods that were used to gather data during this phase included all of the mentioned practices, which are:
1. Open- and Semi-Structured interviews
2. Document analysis
3. Water-cooler discussion
4. Survey's and Questionnaires
5. Structured observation

To show the strength of the matrix approach the following examples have been taken from the elicited actual data. There are examples for each of the BAPO aspects, which have been chosen to show the correlations of the data both over the BAPO perspectives as well as over time.

4.4.1 Business

CompanyA has grown and expanded rapidly in both the international and domestic market since their conception, which they aim to continue to do in the future as well. They have also started marketing the company in new ways to build their brand and to gain further market share. The international expansion has presented the company with new challenges, for example new requirements on safety for their products related to the new market segments they have expanded to. Depending on the customer and process, the amount of validation work that is conducted varies. For the larger products, new releases are normally developed using the iterative development process where the acceptance testing is conducted at the end of the development cycle. For the projects that are conducted using the agile development process, acceptance tests are conducted more often hence the customer is more involved in the development.

4.4.2 Architecture

The software architectures developed at the company have also grown and evolved in accordance with the business expansion. The systems that were once "stand-alone" have been integrated into the current, more advanced products. The architectures have been based on components, and will probably continue to so in the future since the company has started looking into Service oriented architecture (SOA) development. Safety-requirements have forced architectural changes and further focus has been put on automated testing during the evolution of the products. The company also has to struggle with legacy code, which has become a bit of an issue because it does not currently support all the testing practices that the company wants to implement. Architectural design is kept on a high level, as are the requirements, which helps the company to be flexible when it comes to changing requirements. Harsher constraints on quality may however force the company to develop the high level requirements into low-level requirements in the future. Because of the EUPROJECT project the company may also face a future where they have to use the Nato Architectural

Framework (NAF). NAF is quite large and rigid and may therefore also require process as well as organizational change.

4.4.3 Process

The more complex products has forced the development processes to evolve as well, and therefore the company has moved away from the traditional rigid development practices towards more agile development. The company has used an iterative development process for a very long time, but have during recent time also adopted the agile development process Scrum for systems that are not considered safety-critical. Along side the development processes the company has a rigid quality assurance process defined according to ESARR6[4] and based on RTCA DO-278[5] and RTCA DO-178B[6].

In the future it may be possible that the company's repertoire of processes will also contain an agile process for Safety critical development, which will also help facilitate the company's increasing interest of automated testing. At the moment the company has an extensive toolbox with tests ranging from unit-tests to system tests conducted by different roles at different stages of development. Because of changing requirements, and the expansion on the market, new practices and processes may be added to the company toolbox in the future.

4.4.4 Organization

The organization has grown together with the company, both in size and to some degree in complexity. More roles have been added and more people have been hired. This development is expected to continue both currently and in the future because of the company's current business goals. A future organization may also include more roles to coop with the increasing focus on quality requirements. Such roles could for instance include testers, architects and more. The adoption of the Scrum development process has also caused changes in the organization, with new roles and teams working according to the practices set by the process.

4.4.5 Summary of the Examples

To summarize the results above to provide an overview for the reader the following matrix has been defined. It contains the above information in bullet-points that will be used later to show the actual alignment between the elicited data.

	P	C	F
B	• Domestic and international market	• Domestic and international market expansion • Dedicated Salespeople • New Marketing	• Domestic and international market expansion • More Salespeople • New Marketing
A	• Stand alone system components	• Systems of several integrated components • Legacy software • High level requirements	• SOA • NAF • New Architectural design and low level requirements
P	• Waterfall Dev. • Iterative Dev.	• Waterfall Dev. • Iterative Dev. • Agile Dev. • QAP	• Waterfall Dev. • Iterative Dev. • Agile Dev. • Safety critical

			Agile Dev. • More Stringent QAP • Larger V&V toolbox
O	• Organizational Growth • Growth in complexity	• Organizational growth • Growth in complexity • Scrum teams	• Organizational growth • Growth in complexity

4.5 Data Analysis and Alignment

In this stage of the study the analytical matrix played one of its most important roles by helping the researcher to draw conclusions regarding the correlations between the data in the different matrix cells. The following examples show how these correlations were drawn, they have also been graphically visualized. The purpose of these examples is not only to show the matrix strength when it comes to providing data correlations but also to show that internal decisions, external factors, changing requirements, etc, have a larger impact on an organization, not just within one perspective.

The first example drawn is related to how the company has grown over the years. Because of the expansion within the domestic and international market, the company has been forced to expand their organization, which has also added complexity to it. The growth also required new processes, both for development and quality, which in turn affected the architectures of the products since they had to follow the new standards and development methods. Hence a chain of events can be drawn as follows: From BP to BC to OC to PC to AC. Figure 5 shows the chain graphically.
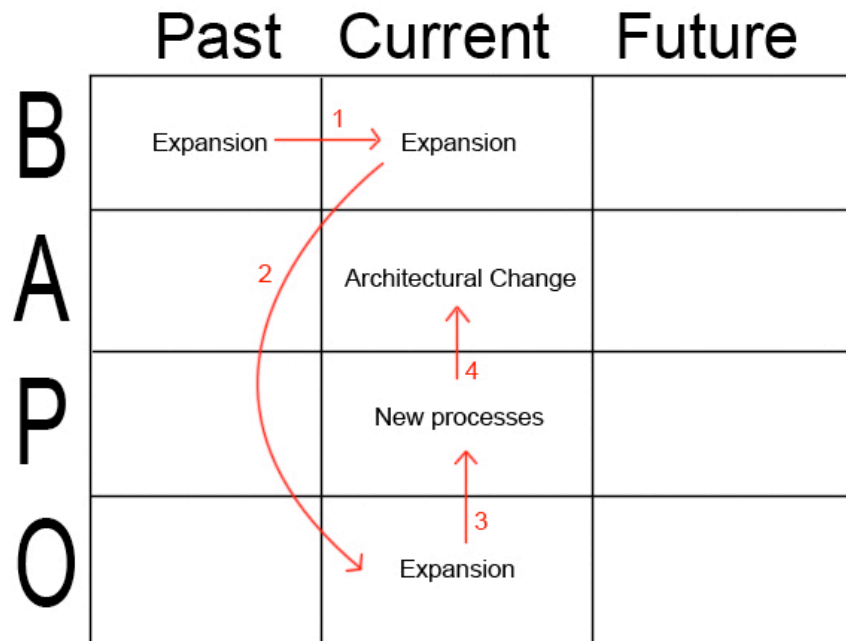

Figure 5: Cause chain for company growth

The second example is of finer granularity and relates to how the adoption of the agile development process has affected the company. Because of the process change in the current, the organization had to change to facilitate Scrum teams. This change was however moderate since Scrum was chosen from a recognized compatibility with the companies current organization at the time. The change also affected business since this process made the company more flexible when dealing with changing requirements, and it will also have affects on the processes in the future since the process was so well liked by the developers that there is a willingness to adopt it also for safety critical safety development. This example therefore has several effect chains, which are as follow:

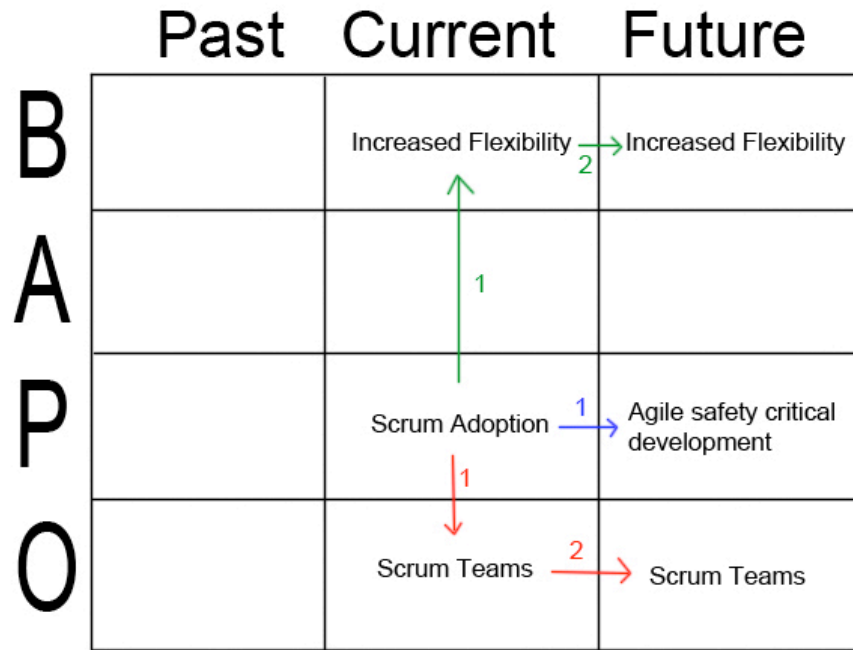PC to PF and PC to BC to BF and BC to OC to OF. The chains have been illustrated in Figure 6 graphically.

Figure 6: Cause chain for Scrum adoption

The above examples show how decisions within the organization have changed the organization, but what about external factors? The last example therefore aims to show what effects the EUPROJECT project will have on the overall organization. EUPROJECT will among other things affect quality requirements, but the project will also change what system requirements will be required within CompanyA's market domain. This will in turn affect how companies do business since product systems will be sold differently than today, with more customers requiring the same systems. Through EUPROJECT it has also been proposed that NAF and SOA development should be introduced for development of the domain specific systems, which will affect both how systems are developed, but also how they are documented, which may require new expertise which will lead to organizational changes. All these affects can be summarized by the following effect chain where EF stands for external factor: EF to PC to AC to PF to AF to OF. The effect chains have been graphically defined in Figure 7 below.
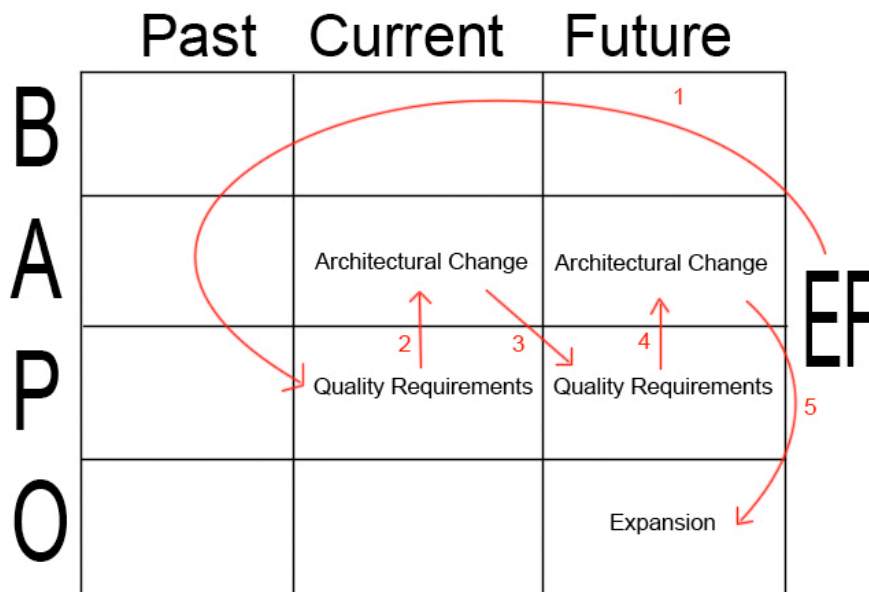

**Figure 7: Cause chain for EUPROJECT's influence**

Further examples of mixed granularity can easily be found, but these examples provide a base of how the correlations can be found depending on initial cause and on different levels of abstraction.

The examples show that the matrix can be used to find correlations between the different BAPO perspectives as well as in time, but the correlations are explicit for the different examples. It is not possible to draw any complex general conclusions of how different matrix cells correlate to one another for any given example. Note that the correlations are described as complex, which are to be differentiated from the simple correlations that are defined within the matrix. An example of this is the correlation of the past column to the current column for each BAPO aspect, which are based in the chronological attribute of the matrix. It can be speculated that there may be more complex correlations between some of the matrix cells, but no strict correlations like the simple ones discussed above can be defined.

Connecting the data through these correlations also strengthens the internal validity of the research since the logical connections of the research data are exposed. Hence if data is found that does not make logical sense in correlation to the other findings the validity of that piece of data may be compromised.

From the discussion above it should be noted that the conclusions drawn for the future aspect, for each of the BAPO aspects, are mainly based on data from the past and current columns of the matrix supported by interviews. The data is produced by exploiting the matrix natural chronological attribute. By looking at the data in the "past" column it is possible to see which events, opportunities, decisions and similar that has lead to the state in the "current" column. By then looking at the "current" column and comparing possible new opportunities, decisions, etc, it is possible to draw reasonable conclusions about the future. In short the analysis for the future column make use of the previous time-columns deductively to define a chain of events that is used to draw the conclusions, as described by the following cause effect illustration, Figure 8.
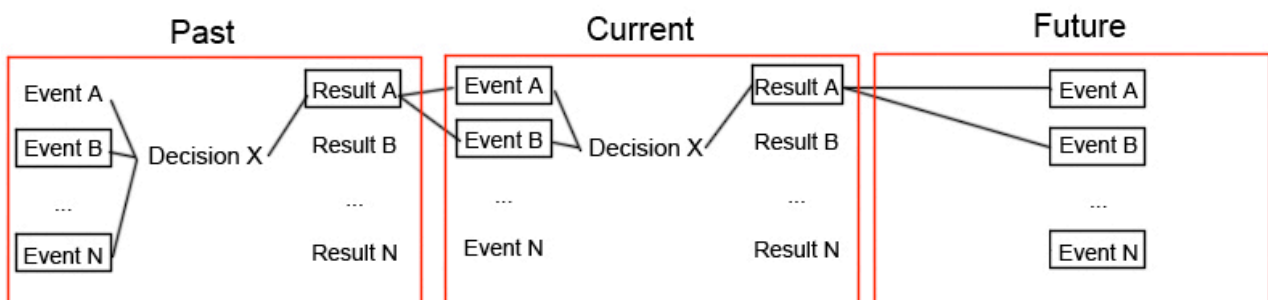
Figure 8: General Cause effect chain
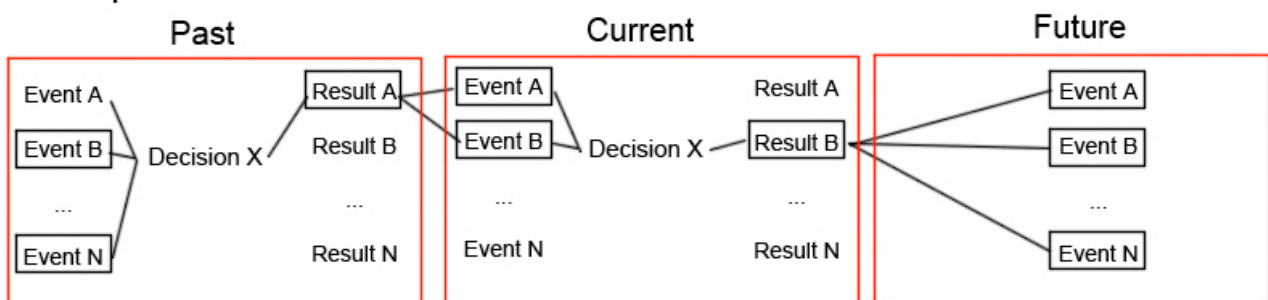
Figure 8 shows two abstract example cause effect chains from the "past" column to the "future" column. In example 1 the decision, X, is taken in both the "past" and the "current" columns, with the same result, Result A. Hence for similar future events it could be reasoned that decision X would once again have Result A. For the second example decision X in the "past" column has a

different result than decision X in the "current" column, and hence the future aspect is much more open to speculation. These cause and effect chains follow inductive reasoning, which are always open to speculation; hence the outcome should be regarded as possibilities of future outcomes rather than predictions of the future.

In the previous section, regarding data collection, a graphical representation was presented that showed in which cells different research methods had been used during the elicitation. The redundant sources helps to remove bias and political correctness that could otherwise skew the results or lead to incorrect conclusions. During the analysis of the source data an issue that must be considered is that the collected data may have been collected from several sources with the same biased views. To mitigate this risk it is good to consider which the data sources were, if they were representative for the entire organization or if they only cover on side of it, i.e. only the views of the developers and not management or vice versa. A general rule of thought, if possible, is to have three sources that support each important concept of the matrix. During the data analysis the data should then be analyzed with alignment in mind, does all the data point towards the same conclusion or are there discrepancies? If so, is it possible to draw a conclusion regarding the concept with just two of the sources? Because the answer to this latter question can be no it is valuable that the analysis be started before the data collection phase is over such that further data could be elicited to strengthen the conclusions of concepts that cannot be drawn from existing sources.

The main artefacts connected to this stage can be summarized in the following bullet-list:
1. Refined data based on the raw data collected in previous stage expressed in cause effect chains and cause matrixes for visual representation
2. Data derived for the future column of the matrix based on the past and current column of the matrix

No particular research methods were used during this stage since focus was on analysis rather than elicitation. Instead other methods, such as the cause-effect chain analysis, described above, were used, as well as other methods of analysis.

4.6 Validation Discussions

The final step in the study was to present the results, which was done in two parts. The first part was a presentation for the developers and the second a meeting with the management of CompanyA. Before the meeting with the members of management the transcript of the presentation for the developers was sent to the members of management for review. The purpose of the meeting with the members of management was to validate the findings of the study, and a few issues were found that had to be sorted out. The issues were of a mixed nature, and on different level of incorrectness. A few of the errors were based in difference of opinion between official and unofficial views within the company whilst other issues were errors that originated in erroneously elicited data. The erroneous data should have been caught by triangulation, but since the erroneous data came from several sources it was not possible for the researcher to catch it due to the researchers lack of domain-knowledge.

Once again, the analytical matrix served an important purpose, but in this case as a visual tool to present the data collected during the study. Both the initial presentation with the developers, and the transcript for the second meeting, were divided according to the matrix. The layout was chosen because it gave a good natural flow to the data presentation, as well as the ability to show an overview of all the findings at once. The overview was presented by listing bullet-points with the results in each of the cells of the matrix in a powerpoint presentation. The data during the presentation was done by going through each row of the matrix and expanding the bullet-points with more details.

After the second meeting the results were refined based on the comments and critique and added to the final report. I retrospect a better approach would have been to have had the second meeting with management first, and then present the results. This was also the initial idea, but because of miscommunication the meeting and presentation were switched.

The main artefacts produced during this stage can be summarized by the following bullets:
1. Refinement of the previous analysis artefact

2. Meeting transcript protocols containing the factual views of the organization

The specific research methods that were used during this stage are summarized in the following list:

1. Open-interviews (Validation meetings)
2. Semi-structured interviews (Validation meetings)

5. Discussion

5.1 General

This paper aimed to answer four research questions regarding exploratory case study research. The questions were defined in the introduction of the report but to simply for the reader they have once again been presented below, followed by summarized answers to each of the questions.

1. Which organizational aspects can/should be used to provide a multi-perspective view of an organization developing safety-critical software systems?
2. What research methods are applicable for an exploratory case study?
3. How can the research methods be tied together to form a study design for exploratory research?
4. What are the advantages and disadvantages of defining a research method-design around an analytical matrix?

The questions above are of a general nature, and non-trivial to answer for the general case. The following answers to these questions have therefore been given from the context of the study at CompanyA from which the data for this report was also taken.

The first question was answered to be BAPO. There are other frameworks such as PESTEL that can be used, but for the purpose of this study the BAPO aspects provided a suitable number of aspects whilst still providing good encapsulation of the organization with appropriate granularity. A clear disadvantage with using PESTEL would be that the number of cells in the matrix to consider would be several more than with BAPO. Since the number of aspects to consider were many already this would have made the project less practical. Possibly the additional aspects that can be considered from PESTEL and other related frameworks could be added as sub-aspects in our framework for companies where they have special relevance. For example, for software development companies that are heavily constrained by legal aspects such as regulations and standards this can be added as part of the Business aspect in our framework.

The second question is really hard to answer for the general case since it is dependent on what the study seeks to find, but the two most common methods are interviews and document analysis. For this study the methods watercooler discussion, surveys and structured observation was also used, because of their ability to collect a lot of data in a short timeframe.

The solution for the third research question was to define an analytical matrix that was used in all parts of the study. The methods were tied to the matrix-design through the development of concepts, derived from the original research questions, which were linked to each of the twelve cells of the matrix. Each concept was to be answered by one or several methods depending on time, budget and importance to the study. The multiple perspectives also provide additional strengths to the method, since a problem seldom affect just one aspect of an organization. By viewing the problem from different perspectives it is possible to draw further conclusions to what was the source of the problem to begin with. As an example a process change may lead to decreased architectural quality and perhaps as a cause of this lower sales. By connecting the issues over the matrix it is possible to find that the process change was the source to the lowered sales rather than just the issues with the architecture.

The answer for the forth and final question is quite extensive due to the fact that the method-design itself is quite extensive and complex. However, the main advantage of the method is its ability to aid the researcher to find how problems are connected within the BAPO perspectives chronologically for any organization dealing with architectural components. As such, it helps the researcher find not only which the problems are, but also how they affect different parts of the organization. The main disadvantage is the methods broadness. Filling the entire matrix with data

requires a huge effort and because of budget constraints it is sometimes the case that validity or data depth must be sacrificed within some area of the matrix.

The study at CompanyA showed that the analytical matrix that can be used in many areas of experimental research. It can be used as a research roadmap, to define research objectives, as a visual presentation tool and more as we have discussed earlier in the report. The matrix was used during every part of the study in different ways. One of the larger advantages with using the matrix was its ability to provide an overview of the progress of the study by displaying for which cells data had been elicited and which cells still required further elicitation. The progress visualization also helped the researcher when prioritization was required due to budget constraints. Using this method, or any other that provides a guideline, or structure, to the research is important because research will always be affected by external factors that you as a researcher cannot control. Things often do not go according to plan, but having a plan to begin with as a guideline can help you once things go wrong, if you are flexible enough to adopt to the new situation. For instance if the interviewee can only spare 30 instead of 60 minutes for an interview, with the correct preparations, you could still ask the most important questions during that time and get the most important information you require for your research. To summarize this it is important as a researcher to have a good plan as a guideline and to be flexible when executing that plan.

5.2 Pros and Cons

The first advantage of using this method is its flexibility and adoptability. The matrix-design should be applicable for all exploratory research with any company within computer science.

The methods broadness is one of its largest strengths, but as we will discuss later it is also a weakness, since it provides data on such a wide scale within one area. In the case of this study the focus was on verification and validation (V&V), and through using the BAPO perspective it was possible to identify how V&V was linked between several aspects of the organization. Hence, the relationship of customer interaction in the business aspect could be linked to the choices of processes and methods in the process aspect of the organization, aligning the two aspects with one another. The added benefit of being able to see this relationship chronologically also made it provided information about how the company has progressed within the different aspects over time, from which conclusions could also be drawn regarding the future of those same aspects. The broad data collection makes the method suitable in the initial stage of software improvement projects, since having an initial high level view of the organization makes it possible to see what affects changes have on a higher organizational level. If deeper knowledge would be required later, then the data from the initial study would help pinpoint where to go deeper. With that said, nothing stops the researcher, using this method, from going as deep as he or she wants within a specific area during the initial data elicitation. However, if the goal is to fill the entire matrix and produce a complete high-level view of the organization, the experiences from this study indicate that depth in one aspect will lead to forced sacrifice of depth in another aspect. Hence one of the advantages with the method is also a disadvantage. Because the method provides such a wide scope the elicitation period becomes quite long if depth is required for all cells within the matrix. During the study at CompanyA the data depth in a few cases caused biased data to slip through the analysis. The real source of the problem is time and cost, since the budget a company is willing to invest in a study is always limited, which also limits the amount of time that can be spent on the elicitation. Limited budgets are a normal hurdle that researchers have to face during any type of research, which makes preparation even more important, including a clear research design defined already from the beginning. As we have discussed however, it is seldom possible to follow the research design to the letter, but having a design as an initial guideline is always beneficial.

The single largest issue when using this particular method is the validity of the data for the future column of the matrix. Because it is impossible to predict the future, all results for the future aspect will be open to speculation. In order to maximize data validity during regular elicitation triangulation is normally used. However, since the future aspect has not happened yet there are no sources to elicit data from. Instead the researcher must ensure that the reasoning from which the

results are drawn is based on valid cause-effect chains.

5.3 Improvements
In order to raise validity within the future column of the matrix frameworks can be used. Examples of such frameworks are the SWOT and the Scenario planning framework traditionally used for future business analysis and planning. An unexplored possible improvement could be to modify these frameworks to use them for elicitation of data within aspects other than business.

Another possible improvement of the analytical matrix would be to analyse which research methods are the most suitable for use in the different cells within the matrix. For instance when investigating company processes it is probably more suitable with a more direct and hands-on approach, such as observation and interviews, rather than survey's with forced answer questions. Determining which methods are the most suitable for different elicitation, and develop guidelines for how to use the methods in a structured way could help reduce cost by removing redundancy.

The matrix used to provide a graphical overview of the triangulation could also be improved by showing the number of sources that were used within each cell rather then just which methods were used within each cell.

To improve upon the method even further one could also look at practices and other aspects of longitudinal research and incorporate these into the elicitation. This could be beneficial during the final analysis since the researcher would have access to more defined chronological measurement points which is the base for longitudinal research.

5.4 Validity
Since this paper only presents elicited research data for example purposes, the issue of internal validity is quite small. The main concerns are instead on reliability and external validity of the report. The reliability of this paper should be high due to the fact that the method has been described in high detail, including examples from its usage during an empirical case study. The external validity however is limited to exploratory case studies of companies within software development, since the architectural aspect of BAPO refers first and foremost to the development of software components.

6. Conclusions
This report presents the methodology that was used during the empirical case study conducted at CompanyA during the winter of 2009 and spring of 2010. The paper describes in detail how the methodology was developed, what research methods were used, and how the research methods were tied together by an analytical matrix that was developed specifically for the study. The matrix was defined with the BAPO (Business, Architecture, Process and Organization) aspects on one axis and time (Past, Current and Future) on the other. BAPO was chosen for its ability to encapsulate an organization and the matrix was used for all stages of the study. The study itself was conducted in six steps, where the first step had the purpose of providing an initial overview of the project and the study at hand. The second step included definition of research questions and development of the analytical matrix. The third step was to select specific research methods and connecting these to the matrix, as well as developing an initial overview of the studied organization. The forth step was the data collection, during which the methodology defined by the previous steps was executed. The fifth step was analysis of the elicited data and the final step included review of the results and presentation of the results.

The different steps of the method are presented, in this paper, such that the method can be replicated, including descriptions of the research methods that were used and how they were applied specifically during the case study. The methods that were used were interviews, observations, watercooler discussion, surveys and document analysis. The method description also includes examples from the empirical study, as well as guidelines for do's and don'ts that were concluded during the usage of the method. Focus in the paper is however on the analytical matrix and its advantages and disadvantages. Because of the matrix natural attributes, it can provide the researcher

with data that can be aligned both between the BAPO aspects as well as in time. This also gives the researcher the possibility to draw conclusions regarding the future of the organization through the use of inductive cause-effect chains. For instance by looking at how the company has expanded over the years correlations could be drawn from the business aspect to the organization which was forced to expand as well. The larger organization required new processes, which in turn had effects on the system architectures. These correlations show that changes in one organizational aspect has effects in all the others, as such it may be important to view the larger picture when doing organizational change. This way of analyzing the data within the matrix also adds to the internal validity by making it possible to connect the different pieces of data in a logical manner.

The method provides a very broad scope, which is good for elicitation of state-of-practice, but this is also the methods greatest disadvantage since it requires a large effort from the researcher to elicit the data for all of the cells of the matrix.

To summarize it can be concluded that the methodology described in this report, based around the analytical matrix, is a powerful tool for exploratory research that provides the researcher with multi-dimensionally aligned data.

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