Scenario-based system architecting : a systematic approach to developing future-proof system architectures

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SCENARIO-BASED SYSTEM ARCHITECTING

A Systematic Approach to Developing Future-Proof System Architectures

Mugurel Theodor Ionita

The work described in this thesis has been carried out in close cooperation with
Philips Research, Eindhoven, The Netherlands.
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Scenario-Based System Architecting
A Systematic Approach to Developing Future-Proof System Architectures

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Table of Contents

The List of Figures

Part One - Chapter 1

1 Introduction

This thesis summarizes the results of the research carried out within the AIMES (Architectural Modelling of Embedded Systems) project. This project[1] was funded by the STW (Stichting Technische Wetenschappen) foundation for technological research. The project was carried out between 2001 and 2004, and conducted at Philips Research in collaboration with the Technische Universiteit Eindhoven. The results of this work were published in six coauthored publications and ten technical reports.

1.1 Goals, Focus and Results

The overall aim of the research was to improve the architecting process for software intensive systems. For achieving this goal, the various phases of the architecting process were investigated. The research focused in particular on the early architecting phases when new system architectures are created. The reasons for considering especially the early architecting phases were twofold: (1) the quality properties of a system (such as usability, performance, or modifiability) are shaped already at the beginning of a project, and (2) architectures for professional systems, like the ones investigated in this project, are expected to last for long periods of time (typically five to ten years) and the early architectural decisions therefore strongly influence the adaptability of the architecture to the future business environment. Up to now, these issues are considered in a too ad-hoc manner. In order to improve the system architecting process, a case study was performed. The case study, provided by Philips Medical Systems, helped in focusing on real-life issues when elaborating the architecting methodology proposed in this thesis.

The work presented in this thesis is aimed at supporting the development of so-called "future proof" system architectures. This is achieved by investigating the possible variations of the future business environment before the new system architecture is fully designed. As an answer to the above mentioned research questions, a Strategic Option Design and Assessment Method (SODA) is outlined. Starting from strategic scenarios, it facilitates the development of architectural scenarios, architectural models, and the quantitative assessment of the quality properties of the proposed architectural variants. In order to support the quantitative assessment of the architectural qualities in a systematic manner, the Systematic Quantitative Assessment of Scenarios' Heuristics (SQUASH) method was developed as part of SODA.

The SODA method also provides process guidelines for creating long living system architectures. Starting from existing architecture evaluation methods (like SAAM, ATAM, CBAM, ALMA, and FAAM), a new dimension is added to the current architecting processes: the systematic treatment of the uncertainty associated with long living systems. The method helps in expressing the added value of the proposed architectural variants in various plausible future business contexts, and guides the decision-making process with respect to the most important aspects (architectural drivers) to be considered for the final design. In this way SODA supports the development of architectures that meet their quality requirements while reducing the re-architecting effort related to future changes.

[1] STW project number EWI.4877

The SODA method has been validated in a semi-industrial context by applying it in two case studies, provided by Philips Medical Systems and conducted at Philips Research, to show how the method is actually implemented. One of these case studies is presented in this thesis, for the validation of this work.

1.2 The Thesis Structure

This thesis is structured in two parts. The first part contains the motivation of the research, the related work, and a summary of the results, (Chapter 1 to Chapter 5). The second part contains the description of the cases study in which the developed methods have been actually applied and validated (Chapter 6 to Chapter 12).

1.2.1 How to Navigate this Thesis

For those interested only in parts of this thesis, this section provides some help on how to navigate through the thesis. The first two chapters, Chapter 1 and 2, provide the reader with the required information to understand the context of this research, the goals, the research questions, and the related work on the subject. Therefore they build on each other, Figure 1-1.

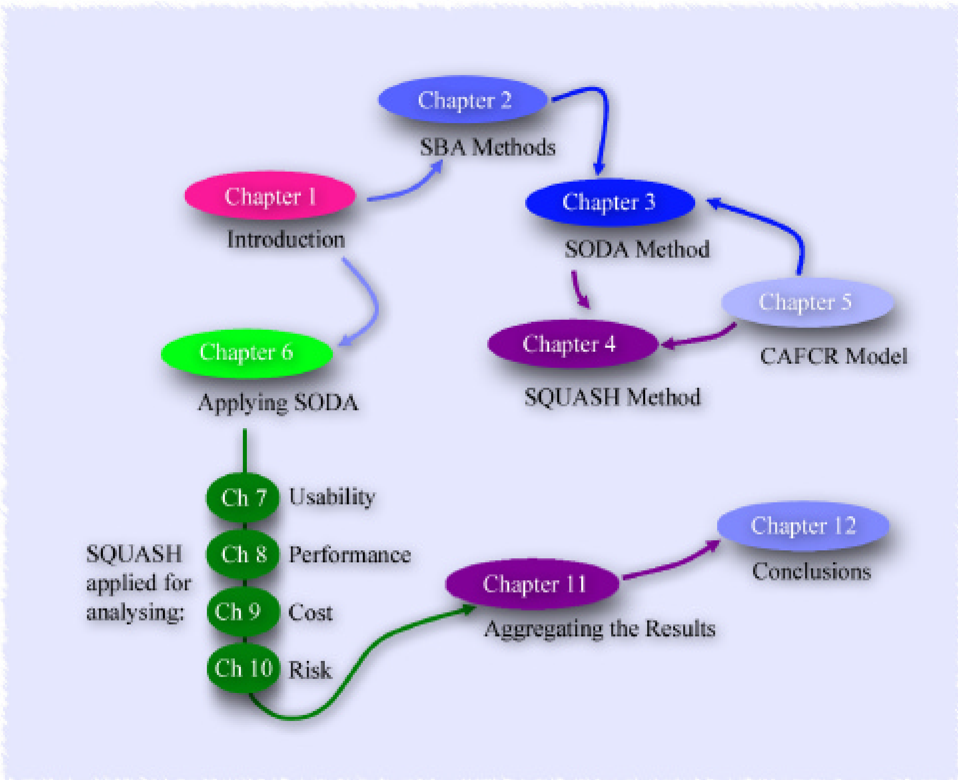

Figure 1-1: The Navigation Map of the Thesis.

Chapter 1 provides an introduction of the research, and the context. It also sets the goals of this research in the problem description section. Chapter 2 presents the related work in the area of scenario-based architecting methods and techniques to which this research contributes.

The next three chapters, Chapter 3 to 5, are dedicated to answering the research questions. These chapters present the two methods resulted from this research, as well as the architecture view model utilized by the two methods. The two methods are, the SODA method, a systematic method for developing system architectures that are more future-proof (described in Chapter 3), and respectively the SQUASH method, a systematic and quantitative method to assess the quality, cost and risks associated with the proposed architectural options, referred to as architecture scenarios (described in Chapter 4). SQUASH method has been developed to support the SODA method, namely the feasibility assessment of the architectural options activity. The two methods have been developed within Philips Research and validated in two case studies from the medical domain. The architecture view model, called CAFCR, is the result of a different research project at Philips. The model is used in this thesis to structure the architecture description and representation, as it is being introduced in the Chapter 5.

The last seven chapters, Chapter 6 to 12, present the validation of the two methods. If already familiar with the steps of the SODA and/or SQUASH methods, one could dive directly into the detailed examples provided in this part of the thesis. Chapter 6 presents the concrete examples on how the steps of the SODA method have been applied to develop and assess the feasibility of different architectural scenarios. Chapter 7 and 8 zoom into the assessment of the proposed architectural solutions with SQUASH. In these two chapters, SQUASH is applied for the analysis of two important quality attributes, which are performance and cost. Chapter 9 and 10 continue the SQUASH analysis for two other important architectural aspects, which are the cost and risks associated with the proposed architecture scenarios. The results of the analysis conducted with SQUASH are aggregated in Chapter 11. This chapter takes over where SODA left off in section 6.4, to round off the feasibility assessment initiated in Chapter 6. The last chapter, Chapter 12, finalizes the thesis with some remarks, and proposes some possible ideas for future research.

1.2.2 The Content of the Chapters

Chapter 1 presets the context of this research. It introduces the scope and the goals of the project, and it presents the context in which the research was carried out, as well as the method selected to carry out the research. It also presents the overall aim of the research presented in this thesis. First, it discusses the problems with the development of software intensive systems, and introduces the system architecting discipline as a partial answer. Second, it enumerates the problems of the current system architecting approaches, and proposes scenario-based architecting as a possible solution. Finally, it enumerates the research questions to be tackled in this thesis.

Chapter 2 discusses existing scenario-based methods for the various system architecting activities, such as strategy definition, requirements engineering, architecture design, and architecture evaluation. It emphasises the suitability of the existing scenario-based methods for dealing with the quality aspects of a system during the early development phases. Finally it presents some open issues when using scenarios for designing system architectures.

Chapter 3 introduces the SODA (Strategic Option Design and Assessment) Method as a possible solution for improving the current state of the art in system architecting. The method was developed within Philips Research and has been applied in two case studies from the medical domain. The chapter presents first the related work on scenario-based architecting and scenario-based design. Second, it positions SODA method within the RUP (Rational Unified Process) framework. Third, it explains the role of strategic and architectural scenarios within the architecting process, and enumerates various architectural models used within SODA.

When scenarios are used for architecting new systems, their relative benefits and consequences for the resulting system are usually not explicitly formulated. At best these scenarios are ranked in a subjective manner with respect to their merits. In order to differentiate among the proposed architectural scenarios during the early development phases, a quantitative approach is required.

Chapter 4 introduces such an approach, the SQUASH (Systematic Quantitative Analysis of Scenarios' Heuristics) method, developed to support the SODA method. SQUASH is a method for analysing the relative benefits of the architectural scenarios in a quantitative manner, focusing mainly on three aspects: quality, risk and cost. The method enables an informed decision-making process with respect to what are the most suitable scenarios to be considered in the design.

Chapter 5 introduces the CAFCR (Customer, Application, Functional, Conceptual, and Realization) architecture view model chosen for representing the architecture presented in the case study. Other models are discussed as well. The CAFCR model has been developed within Philips Research (America *et al.* 2000)(Muller 2003)(Muller 2004), and applied to structuring the representation of the architecture of the case study. The five architectural views the model consists of are explained, and the artifacts contained in the different views are presented. Finally, the chapter introduces the approach used in dealing with variability at a system architecture level, in terms of variation models and variation points.

The second part of the thesis describes how the proposed methods were applied in the context of a concrete case study provided by Philips Medical Systems and conducted inside Philips Research. It starts with an introduction of the context of the case study, and continues with the rest of the chapters.

Chapter 6 presents how the steps of the SODA method were actually applied for the Cathlab case study. It starts with presenting the first step of SODA, namely building the strategic scenarios. Starting from the strategic scenarios, business strategies are then derived and explained in step two of SODA. To implement the proposed business strategies, architectural scenarios are developed in step 3 of SODA. The chapter ends by presenting the beginning of the scenarios' feasibility analysis, which is then finalized in Chapter 12 after the results were collected and consolidated in Chapter 8 to 11.

Chapter 7 presents how the SQUASH method was applied for studying the quality aspects of the scenarios developed within the case study. The chapter focuses on the usability aspects of the future system, before it is fully implemented. It shows how to identify and quantify the specific factors that contribute to the final usability of the system.

Chapter 8 presents how the SQUASH method was applied to study the performance attributes for different system variants. It shows in a quantitative manner, that it is possible to come up with architectures that can meet their performance requirements.

Chapter 9 presents the scenario-based risk assessment performed with SQUASH, at a system architecture level. SQUASH is here applied for carrying out the risk assessment step for the Cathlab case study. The risk analysis is expressed here in a quantitative manner. The chapter concludes with some final remarks.

Chapter 10 introduces the cost analysis with SQUASH. The goal of this chapter is to present a systematic way to estimate the effort required for implementing the various integration scenarios. To support the decision making process, the estimates presented in this chapter are made quantitative.

Chapter 11 presents the aggregation of the results collected during the case study, to enable an informed decision making about the scenarios to be further considered in the development. It introduces the profit as an important factor on which in practice decisions are made.

Chapter 12 finalizes the thesis with some conclusions and a recapitulation of the initial research questions, and how these have been answered in this thesis.

1.3 Problem description

This section discusses the problems with developing software intensive systems, and presents the system architecting as an essential ingredient of the product creation effort. Next, the problems with the current architecting approaches are discussed. The scenario-based architecting approach is then proposed as a specific answer. In the end the research questions are presented.

1.3.1 Developing Software-Intensive Systems

A system can be defined as the assembly of resources, functions, and procedures working in interdependence, according to a priori defined rules, for accomplishing specific tasks. If the system's software *contributes essential elements to the design, construction, deployment*, *and evolution of the system as a whole,* we talk about a software intensive system (IEEE Std. 1471). Examples of software intensive systems are, automatic teller machines (ATM), mobile phones, or X-ray scanners.

Software intensive systems are built for supporting the needs of a specific group of people, or organizations. Therefore, they have to meet specific requirements – what the system should do, or look like. Requirements may regard the functionality of the system, the quality of the system, or conditions and regulations the system has to comply with. Requirements come from different sources; we call these sources the *stakeholders* of the system.

Stakeholders are persons, entities, or organizations who have a direct stake in the final system; they can be the owners, regulators, developers, users, or maintainers of the system. Due to their functional and cultural diversity, stakeholders usually have conflicting requirements. These conflicts may be at a high-level such as governmental regulations and budget limitations, or at a low-level such as implementation and operational details.

Apart from the explicitly stated requirements, stakeholders usually have unexpressed needs and objectives for the system under development. As systems are developed over long periods of time, it is often the case that throughout the development lifecycle of the system stakeholders will come up with new requirements or changes to be incorporated in the system. Some of these changes may require structural modifications of the system. They might also impact the agreements made with respect to the development costs, time-to-market, or quality of the final system. It is the task of the development organization to build systems that are in line with all their stakeholders' requirements and objectives.

In medium and large organizations the product creation effort has a structured form, called development process. Figure 1-2 summarizes some of the problems with developing software intensive systems in each phase of the development process.

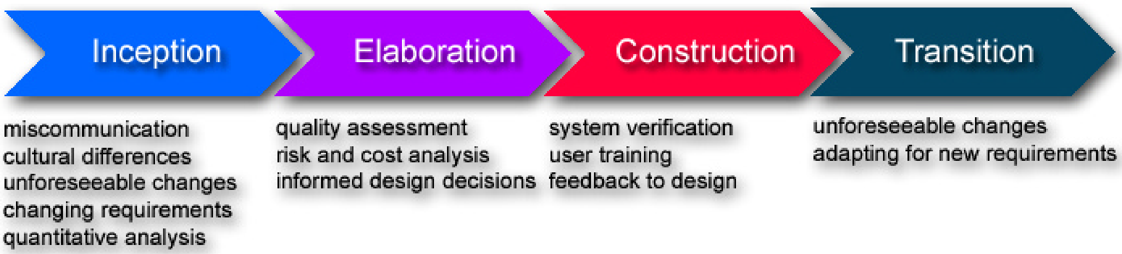

Figure 1-2: Issues with the Development of Software Systems

Looking at the development phases provided by the Rational Unified Process (RUP) (Kruchten 2000), the following associations are made between issues with the development of software systems and the various process development phases. During the early development phase, such as the inception phase, problems often appear in communication with the stakeholders – sometimes due to cultural differences between the stakeholders – which lead to change in requirements. Due to an unstable set of requirements and business context, a quantitative analysis is seldom performed, whilst changes in the external business environment are usually difficult to foresee. During the design and implementation activities, in the elaboration phase, the continuous assessment of the system quality is an issue, as well as activities like the risk and cost analysis. In this phase little support exists in guiding the decision-making activities. During the construction phase, activities like the overall system verifications or feedback to the design are time consuming activities. During the transition phase, the changes neglected in the early design phases will be hard to integrate and thus the system will not be able to easily adapt new requirements

1.4 Architecting as a General Answer

Architecting is the core activity of any system development process. It is the activity resulting into the high level design of the system, also called the system's architecture. Architecture can be defined as *the fundamental organization of a system, embodied in its components, their relationships with each other and the environment, and the principles governing its design and evolution* (IEEE Std. 1471). More recently, Bass et al. define the architecture for a software system as *the structure or structures of the system, which comprise software elements, the externally visible properties of those elements, and the relationships among them* (Bass *et al.* 2003).

When developing system architectures in a competitive market environment, apart from functionality and quality aspects, issues like competition, strategic positioning, time to market, and product branding have to be taken into account as well. Moreover, system architectures enjoy long life times, typically five to ten years, and therefore the uncertainty associated with the future business environment plays an important role when developing new system architectures (Obbink *et al.* 2003).

Developing software system architectures is not a risk free endeavour. New functions are added, architectural variants are proposed, and above all organizational and process issues are involved. All these increase the probability of something going wrong. Risk can be defined as the possibility of suffering a loss of any kind (Webster Dict.). Risks can be associated with the development of a system, as well as with its usage. Managing the risk requires that the system architecting process addresses these issues as early as the architecture is defined. Boehm et al. introduced the life-cycle architecture milestone (LCA) as a critical checkpoint when developing system architectures, (Boehm *et al.* 1998).

To deal with the various requirements, quality attributes, and risks, the architectures will have to be adapted, and trade-offs have to be made. The final decision regarding the most suitable architecture design that will be considered for the implementation is a strategic decision. To tackle systematic all the issues related to the architecting process (i.e. dealing with multiple stakeholders, unspecified or conflicting requirements, system vision, strategic architectural decision, quality assessment, or cost and risk analysis) various methods and tools have been developed. A summary of these methods is given in Section 2.4 of this thesis.

1.5 The Research Questions

The goal of this research is to investigate the contributions scenario techniques could make to the enhancement of the quality of architectures. For accomplishing this goal, the architecting process is split in four parts, namely strategy definition, business modelling, architecture design, and architecture evaluation, Figure 1-3. The requirements engineering activity is considered as going in parallel with the architecture design activities. The four development phases considered, namely *inception, elaboration, construction, and transition*, are the ones specified in RUP, (Kruchten 2000). To these four phases is added a *pre-study* phase to address those activities related to strategy definition.

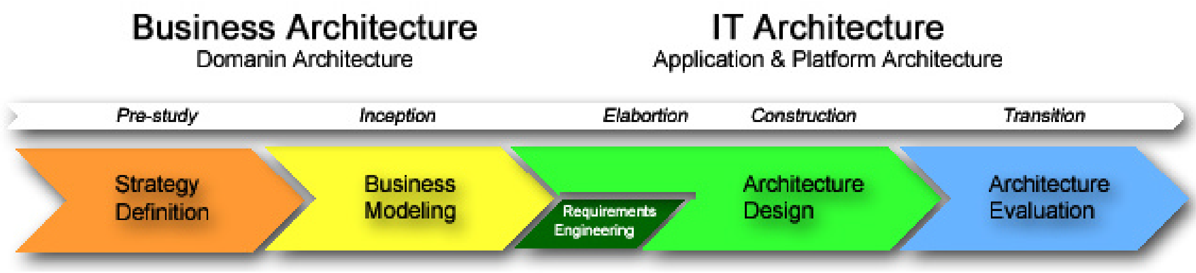

Figure 1-3: The Architecting Framework Considered

In order to accomplish the goal of this research, the following issues were studied.

- How to develop system architectures that are more future-proof?
- How to come from strategic scenarios to concrete architectural models?
- How to analyse the feasibility of the proposed architectural options?
- How to support the decision-making process when multiple architectural variants are envisaged?

An outline Strategic Option Design and Assessment method, and Systematic Quantitative Analysis of Scenarios' Heuristics method, have been developed to answer these questions.

Chapter 2

2 Scenario-Based Architecting Methods

This chapter discusses existing scenario-based methods for the various system architecting activities, such as strategy definition, requirements engineering, architecture design, and architecture evaluation. It emphasises the suitability of the existing scenario-based methods in dealing with the quality aspects of a system, early in the development phases. It presents as well some of the open issues when using scenarios for designing future system architectures.

Introduction

Companies find themselves nowadays in a complex business environment. In order to survive, they must identify new emerging markets, make use of new technologies and create products that address specific customer needs. In other words, they have to create a clear vision about the future.

Scenarios are instruments for long-term thinking and informed decision making. They can be used for envisaging different plausible futures, and thus create a vision about what the future might look like. Scenarios are powerful means to encourage innovative thinking.

Therefore scenarios have been widely adopted in many disciplines of the system development, such as strategic management and planning, requirements engineering, architecture design and architecture evaluation. The next sections present the use of scenarios in these disciplines.

2.1 Definitions of Scenarios

Here are given some definitions from literature of what scenarios represent:

- Scenarios are stories describing different plausible futures (Schwartz 1996).
- Scenarios are stories constructed to show the steps that are needed to perform a particular piece of work. When the analysts fully understand the work, they use scenarios to generate the requirements for the product that will help with that part of the work (Robertson *et al.* 1999).
- For requirements purposes, a scenario either means a small story with a vivid illustration of the work area, or a specific case of a task (Lauesen 2002).
- Scenarios can be storyboards of annotated cartoon panels, video mock-ups, scripted prototypes, narrative text, or physical situations contrived to support certain user activities. The defining property of a scenario is that it projects a concrete description of activity that the users engages in when performing a specific task, a description sufficiently detailed so that design implications can be reasoned about (Gilb 1988).
- A scenario is a specific instance, case, experience, story, or example that happens over time. A scenario contains a description of the environment, the context, the actors, and the actions. It has definite beginning and end points. The rationale supporting inclusion of the scenario is attached to the scenario description (McGraw *et al.* 1997).

Some of the authors are defining scenarios as being very much similar with use-cases (Robertson *et al.* 1999), (Lauesen 2002), (Carroll 1995), or (McGraw *et al.* 1997). This point of view is adopted in most of the existing requirements engineering methods. This type of scenarios will be further referred to as *fine grained scenarios*. Other authors define the scenarios as plausible stories about the future [SWZ96], and [VDH96]. In this case, the focus is on the future rather than the current way of working. Examples of such scenarios include technology trends and roadmaps, forecasting studies, or mission and vision type of documents. This type of scenarios will be further referred to as *coarse grained scenarios*. One can observe that different authors define scenarios in accordance with the scope and context of the analysis performed. A survey of the different type of scenarios available in literature is given below in Table 2-1. Their definitions are given in Chapter 13, in the Definitions and Abbreviation List.

Table 2-1: Scenario Types and Their Applicability per Development Phase

Category	Scenario Type	Pre-study	Inception	Elaboration	Construction	Transition
Coarse grained Scenarios	Strategic Scenarios	+ +	+	-	-	-
	Technology Scenarios	+ +	+ +	-	-	-
	Business Scenarios	+ +	+ +	+ +	-	-
	Exploratory Scenarios	-	+ +	+ +	++	-
Fine grained Scenarios	Success Scenarios	-	+ +	+ +	++	-
	Failure Scenarios	-	+ +	+ +	++	-
	Rescue Scenarios	-	+ +	+ +	++	-
	Quality Scenarios	-	+ +	+ +	++	-
	Learning Scenarios	-	-	-	+	+ +

The fine grained scenarios are used for generating requirements. In this case, they must be specific and quantifiable, focusing on particular instances of use (e.g. what happens, how it happens, and why).

The coarse grained scenarios are used in the strategic decision-making process for system development. In this case they are to keep the future use of the envisioned system in view as the system is designed and implemented. In this case, scenarios make the use concrete.

2.2 Scenarios in Strategy Definition

Corporate strategy planning is about the way the leaders fulfil the organisation's mission in the existing business environment. The business environment includes technological, societal, political, economical, and other factors, which need to be taken into account. These factors have to be considered from a future perspective, since the organization mission will be carried out over long periods of time.

The easiest way is to assume that once the business environment is identified, it will remain either unchanged or highly predictable. Based on analysis and forecasting, the strategic thinking is translated into concrete action plans covering the entire organization. This was called “corporate planning”, a practice adopted in the 1960s. This method was rigid and highly rationalistic, assuming that the envisaged future will come to pass without any question about alternative solutions.

However the reality showed that that the world we live in is characterized by large discontinuities and unpredictable changes. One can reason about the slow moving and fairly predictable events such as changes in demography, the natural division of the years in seasons, or some technology trends. However, sudden changes, such as economical up and downturns, are often triggered by unpredictable events.

This meant that a new approach to strategy and planning was required, an approach that can take into account the uncertainty associated with each of the environmental factors mentioned above.

Scenario-based planning has been identified as one possible approach able to deal with uncertainty. In this context, scenarios can be defined as stories describing plausible futures. They are instruments to educate and order the perception of the future for making strategic decisions. Scenario-based planning is about making choices today with an understanding of how they might turn out tomorrow, (Schwartz 1996).

Scenario-based approaches decisions are taken based on the consideration of different plausible futures, so called scenarios (Schnaars 1986), (vd Heijden 1996), (Hodgson *et al.* 1996), (vd Heijden 1997). In this way the decisions and their implications can be assessed before any action in implementing the decision is taken. Adopting the scenario-based approach the decision makers have the opportunity to address the “what if” questions early in the decision process and to find the alternative ways for solving eventual conflicts.

Scenarios are used in many business activities: for example in assessing the business environment and understanding its trends, in generating and evaluating strategies and options, in creating multiple visions and choosing among them, etc.

2.2.1 Scenarios Guiding Strategic Decision

In making strategic decisions, two main approaches can be defined (vd Heijden 1996). The first one is the rationalistic approach, which is based on two assumptions: any strategic question has a single correct answer, and every strategic discovery is followed by implementation. The second one is the scenario-based approach, where the assumptions are: strategic decisions must be a continuous refinement process, where scenarios are helpful in preparing for different uncertain but plausible futures.

The rationalist approach has a special pattern in dealing with uncertainty. Highly uncertain scenarios are either ignored (“there is nothing to do about the things you don’t know”), or weighted for their preference and assigned with probabilities of occurrence based on a subjective voting procedure. The scenario-based approach is more appropriate for taking strategic decisions, because scenarios are meant to carry information about possible futures (vd Heijden 1997). Although the rationalistic approach is interesting, its assumptions are highly questionable.

Working with the scenario-based approach, the decision makers may adopt one of four general types of strategies (Schnaars 1986):

- A robust strategy, which performs well over the full range of considered scenarios.

- A flexible strategy, where the idea is to keep the options open as long as possible.
- A multiple coverage strategy, in which projects with multiple resources can pursue simultaneously multiple strategies until the future becomes clearer.
- A gambling strategy, in which a strategy is simply selected.

Scenarios help to create awareness about possible futures in conditions of high uncertainty. As a consequence, scenarios are seen as powerful means in taking high-level strategic decisions.

The success of the scenario techniques at a management and corporate level is a good starting point in investigating the suitability of tailoring the same techniques at a system architecture level. This is because scenarios are tools for long-term thinking and strategic planning, activities which are also part of the architecting process itself.

2.3 Scenarios in Requirements Engineering Activities

In literature different methods for engineering requirements are proposed. Depending on many factors, for example the size of the project, its complexity, or the application domain, one can approach the requirements engineering from different viewpoints.

- One way is to derive requirements from business cases.
- Another way is to understand and refine the goals of the system.
- A third way is to use scenarios for understanding the present and future functionality of the system and for refining its mission.

Many methods and techniques have been developed for supporting the requirements engineering activity. Recently, practices such as scenario-based requirements elicitation techniques have proven their advantages (Carroll 1995)(Carroll 2000). This section discusses different approaches for deriving system requirements. Special attention is paid to scenario-based elicitation methods. In this way, various requirements elicitation methods and scenario building techniques are investigated. The expected outcome of this investigation is a better understanding of the requirements engineering domain and the supportive methods or models for eliciting requirements, together with their strengths and weaknesses.

2.3.1 Definitions of Requirements

There are different interpretations with respect to what a requirement is. By collecting different definitions of requirements, we can better understand what they represent and how to define them. Requirements for future systems, for example, can be found by observing contexts and working situations, extracting ideas, concepts and pat-terns. What requirements represent depends on what and to whom they are addressed. In literature, various definitions of requirements are proposed:

- Requirements are things that should be discovered before starting to build any system; such as what the product must do, or what quality the product must have (Robertson *et al.* 1999).
- Requirements are the conditions or capabilities needed by a user to solve a problem or achieve an objective; conditions or capabilities that must be met or possessed by a system or system components to satisfy a contract, a standard, a specification, or other formally imposed documents (IEEE Std. 610).

- Requirements are documents that describe what a system should do. They are often part of a contract between a customer and a supplier, but are used in other situations as well as in-house development where the 'customer' and 'supplier' are departments within the same company (Lauesen 2002).

Requirements can be elicited from a user, system, business, or domain perspective. Each perspective may contribute to the definition of the future system. A classification of requirements generally includes: functional requirements, operational requirements implementation requirements, interface requirements, and quality requirements such as performance requirements, usability requirements, security requirements, etc (IEEE Std. 610).

Requirements can belong to one of the three categories: functional requirements, non-functional requirements (also called quality requirements, and constraints (which are requirements specifying constraints in functionality or quality). The classification of the requirements in one of these categories is a subjective matter.

2.3.2 Scenarios-Based Requirements Methods

In eliciting requirements two main approaches can be distinguished: an exploratory approach, and a quantitative approach.

The *exploratory approach* focuses on understanding and exploring the business context, the required functionalities and qualities for the future system. For this purpose, scenario-based methods are used. In this type of approach the elicitation process extends further than the stakeholders' expressed needs and considers also the triggers of those needs. The exploratory approach provides a better understanding of the environment and the underlying models of the customer organizations. It ensures more effective requirements elicitation process.

When it comes to specifying low-level requirements or details, the key drivers for eliciting requirements are use-cases or any other similar methods. This is called the *quantitative approach*, because it focuses on specific details of system functionality and can gather requirements in very clear terms. Use-cases can be defined as simplified models of particular sub-systems behaviour, and help in understanding and managing complex systems (Jacobson *et al.* 1994). They are used to break down a system into smaller subsystems with specific participation in functionality (Cockburn 2001). However, use-cases only model a restricted part of the behaviour of their participants, referred to as the actors of the use-case, (Robertson *et al.* 1999). Because of this limitation, the understanding of the system in its total is not always possible.

A quantitative approach that is not preceded by an exploratory approach may result in unnecessary or missed requirements, (Robertson *et al.* 1999). Identifying the scenarios and the future business context of a system, together with the consequences of the various proposed scenarios, facilitates the design of architecture and complements the use of use-cases.

The quantitative approach is concerned with specifying the requirements with emphasis on project control (Gilb 1988). The exploratory approach is focused on vision and innovation. In designing new systems, the exploratory approach is recommended (Robertson *et al.* 1999).

Scenario-based methods have also become a well-established practice in the requirements engineering domain. The explicit use of scenarios in eliciting requirements has led to the development of methods and techniques, which are acknowledged by different groups as their best elicitation practices. The most-important scenario-based requirements engineering methods are presented below.

2.3.2.1 The Goal-Based Requirements Analysis (GBRA)

The GBRA method has been developed for identifying requirements based on system goals (Antón 1996)(Lamsweerde 2001). The method consists of two phases: goal analysis and goal evolution.

In the first phase, the requirements team is analysing the possible system goals based on existing documentation and interviews with the stakeholders. In the second phase, the system evolution is regarded and future goals are collected. The GBRA method specifies the use of scenarios for identifying future goals. Scenarios are used to uncover hidden goals, as well as pre- or post-conditions for each goal (Antón 1996). However, the method does not specify what a scenario is or the technique for building scenarios. The method assumes that scenario-building process is well understood and easy to implement. The focus of the GBRA method is on identifying the system's goals, and deriving requirements from them, thus can be classified as an exploratory approach. The level of applicability of the method is not specified, but we assume that the method addresses high-level requirements identification only.

2.3.2.2 The Cooperative Requirements Engineering with Scenarios (CREWS)

The CREWS approach was developed to include both goal-driven and scenario-based techniques for requirements negotiation (Rolland *et al.* 1999). In this sense, the method is not much different form the GBRA method. The only difference is that CREWS covers the derivation scenarios from system's goals and vice versa as a technique for identifying requirements. The difficulty with this method is the way it defines scenarios, as possible behaviours and interactions between systems. This is similar to what use-cases represent, and thus not of additional value. Another difficulty is that the method cannot handle groups of conflicting scenarios. Deriving goals directly from this type of scenarios may lead to situations where the system will persuade conflicting goals. The CREWS method is an exploratory approach.

2.3.2.3 The Cooperative Requirements Engineering with Scenarios – Elicitation and Validation Environment (CREWS-EVE)

CREWS-EVE was developed as a framework for requirements engineering (Haumer *et al.* 1998) and (Haumer *et al.* 1999). The CREWS-EVE framework combines three methods usually used in requirements elicitation: scenarios, goals and models of the future system. The framework is proposed as a change management model which has as outcome the identification of future requirements. The framework is an interesting combination but inherits the difficulties from CREWS. The model assumes that the stakeholders are acquainted with scenario building process as well as with the related requirements identification activities.

Table 2-2: Comparison of the three Requirements Engineering Methods

Characteristics	GBRA	CREWS	CREWS-EVE
Type of Approach	Exploratory	Exploratory	Exploratory
	Goal-driven	Goal-driven	Goal-driven
	-	-	Modeling the future system
Type of scenarios used	High-level	Low-level	Low-level
Stakeholders' participation and RE know-how level	Basic	Experienced	Experienced

2.4 Scenarios in Architecture Design

So far we have seen how scenarios are used in strategy definition and in eliciting system requirements. Both domains are nicely described in literature (vd Heijden 1996), (Carroll 1995). In the early phases of the architecting process the supportive scenario-based methods and techniques are plenty. Also in the later phases of the architecting process a considerable number of evaluation methods are known as presented in the following section. When it comes to design the system architecture, there are not so many established scenario-based methods available in the literature. This can be seen as a potential improvement point for the total architecting process, worth to investigate.

However, there are some references pointing to software architecture design practices. In (Bosch 2000) it is propose a general architecture design workflow, as shown in Figure 2-1. Here it is suggested that the software architecture should evolve from the functional requirements, to architecture design, followed by implementation, its evaluation and possible transformations, and in the end, all together contributing to the successfully deployment of the final system. The process includes re-iterations in the critical phases (e.g. architecture assessment and transformation).

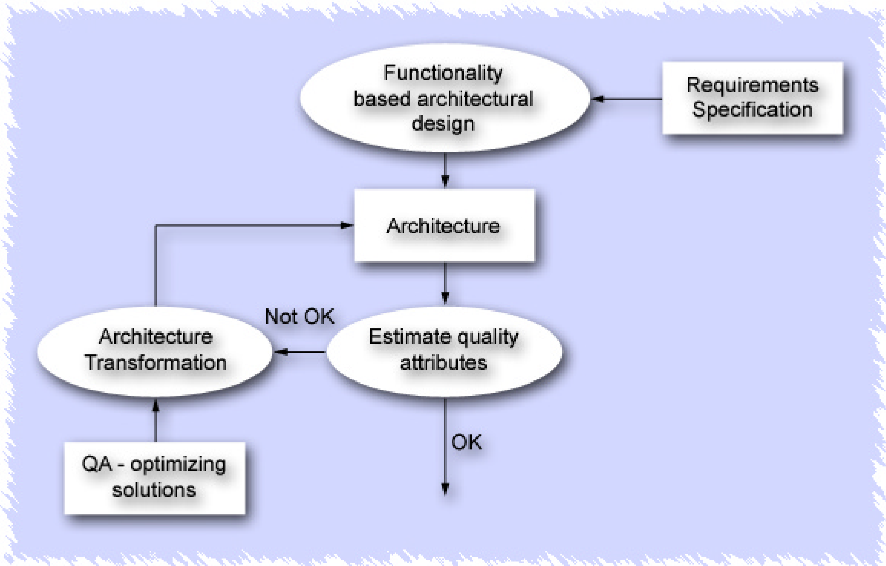

Figure 2-1: Outline of the Architecture Design Method, (Bosch 2000), pp. 32.

A few observations can be made with respect to this design approach:

1. The quality requirements are neglected in the initial architecture design phases, the architecting design process being purely functionality-based.

2. Adding quality considerations later leads to heavy redesign and an inefficient architecting process.

3. The quality attributes of the system are not explicitly considered when the architectural strategies are defined. They appear only in the evaluation of system's architecture qualities. Then it becomes more expensive to make the improvements.

4. The method does not point to any specific techniques for caring out the different steps of the method.

5. There is a vast unexplored area in the direction of consistently integrating scenario-based techniques in the architecture design process.

Bass et al. proposed a more elaborated method for architecture design called ADD (Architecture-Driven Design) (Bass *et al.* 2001). The ADD method provides the architects with a set of steps and techniques for designing system architectures based on the a priori articulated quality attributes of the system. The method uses as input the functional requirements of the system together with its quality requirements. In ADD, in a first step, the system as a whole is decomposed in sub-systems, called design elements. In a second step, for each design element the functional and quality requirements are specified. Each design element is evolved primarily from a set of use-cases, and the functional requirements, and has to satisfy as well a set of predefined quality scenarios. For managing the overall architecture, an appropriate architecture view model is used. After the instantiation of each design element, a sanity check is performed, in which the use-cases and quality scenarios are refined, for further decomposition or implementation. This second step is then repeated for each design element that needs further decomposition, (Bass *et al.* 2001).

The ADD method proposed by Bass et al. is similar to the design method proposed by Bosch, in the sense that both start the design of the architecture from the functional specifications of the system (i.e. functional requirements, and use-cases). However, the ADD method introduces the quality requirements as an important driver of the design process, and hence these types of requirements determine the initial iteration of a design.

Matinlassi et al. proposed the QADA (Quality-Driven Architecture Design and Analysis) method (Matinlassi *et al.* 2002). The QADA method consists of two main phases, the requirements engineering phase, and the architecture design and analysis phase, as shown in Figure 2-2.

The requirements engineering phase consists of two activities requirements analysis and requirements specification. In these two activities the context and the technical properties of the system are analysed and specified.

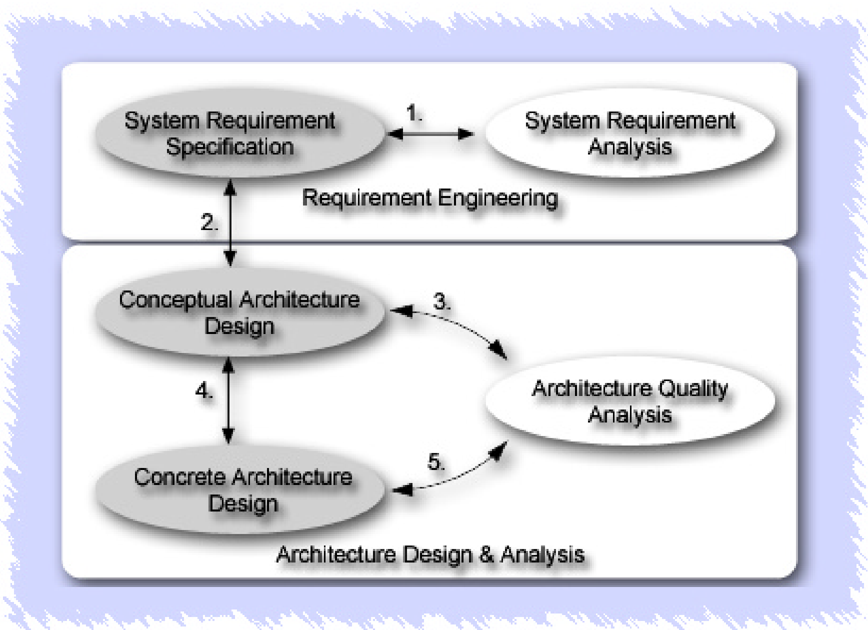

Figure 2-2: The Main Phases of the QADA Method

The architecture design and analysis phase consists of four activities, namely the conceptual architecture design, conceptual architecture analysis, concrete architecture design, and concrete architecture analysis. By means of these four activities the system architecture is evolved from concept to the actual implementation, which means form conceptual components and relations between components to concrete software components and the allocation of these components onto underlying hardware platform. These activities are similar to the activities performed in Conceptual and Realization views of the CAFCR model presented earlier in Section 1.4, Figure 5-2. In QADA the analysis of the architecture refers also to the analysis of the different quality attributes of the architecture. For this purpose the SAAM method was applied (Bass *et al.* 1998).

The design and assessment steps of QADA are well explained and supported by concrete modelling techniques and methods. However, the method is short in explaining how the early design phases are conducted, namely on how to capture and model the knowledge about the stakeholders or the business environment in which the system will operate as well as the uncertainty associated with this information. At best, in QADA it is assumed that the customer's technical specifications of the system interfaces to the external environment, namely the system requirements, are sufficient for the rest of the architecting process. In this sense, the QADA method is similar to the architecture design method proposed by Bosch.

A comparison of the three methods for architecture design is given below, Table 2-3.

Table 2-3: Architecture Design Methods - Compared

Characteristics	Design Method by Bosch	ADD Method by Bass et al.	QADA Method by Matinlassi et al.
Main Drivers	Functional requirements	Functional requirements Quality scenarios	Functional requirements
Dealing with the uncertainty of the business environment	No	To some extent	No
Iterative	Yes	Yes	Yes
Architecture description	-	Multiple view model	Standard UML Multiple view model
Techniques or tools supporting the steps are specified	Poor	Good	Poor in the early phases Good in rest

2.5 Scenarios in Architecture Evaluation

System architecture analysis and evaluation has become a well-established practice within the software systems architecting community. The development effort, the time and costs of complex systems are high enough to justify the assessment of the architectures and especially their quality attributes. In order to assess system's quality against the requirements of its customers, the architects and the developers need methods and tools to support them during the evaluation process. Different research groups have taken such initiatives and are proposing various methods for the evaluation of software architecture quality.

In the architecting community an increasing interest can be noticed towards the development of methods and tools supporting the evaluation of the software architectures' quality attributes. Popular methods include: Software Architecture Assessment Method (SAAM) (Bass *et al.* 2003), Architecture Trade-off Analysis method (ATAM) (Bass *et al.* 2003), Cost-Benefit Analysis Method (CBAM) (Bass *et al.* 2003), Architecture Level Analysis Method (ALMA) (Bengtsson 2002), (Lassing 2002), or Family Architecture Assessment Method (FAAM) (Dolan 2002). An overview of these methods is given in (Ionita *et al.* 2002). However, all these methods propose the assessment of the quality attributes of the system architecture at the end of the architecting phase, whilst the quality assessment should be an ongoing activity performed in each phase of the architecting process. Although many software architectures evaluation methods have been acknowledged as very useful during the past years, choosing a suitable approach for the early phases of the architecture definition, in line with the already existing evaluation methods, remains an unexplored domain. With an eye to the past, one can observe that evaluation of the architecture design, before any implementation is made, has been encouraged by the large number of challenged, or worse, cancelled software projects. Thus, evaluation became an usual practice, widely accepted and fully supported by managers.

How does an evaluation session work? First, there is a goal definition phase in which the assessment points are defined. Usually the most important "ilities" of the software architecture are defined (e.g. modifiability, extensibility, portability, etc). Second, the evaluation team together with the architects and representatives of the stakeholders are brainstorming over those possible scenarios that may challenge the "ilities" of the architecture (e.g. what if the billing gateway system has to support one million concurrent users instead of five hundred thousand as stated initially?). Third, the architect uses these scenarios for evaluating the architectures. Last, the results of the evaluation are presented and the follow-up activities are defined (e.g. the architecture does not support the scenario x, y, and z, so the transaction processing performance should be improved).

Below are listed a set of methods, currently available in the literature, supporting the analysis of software architecture quality attributes.

- SAAM, Software Architecture Analysis Method (Bass *et al.* 1998)
- ATAM, Architecture Trade-off Analysis Method (Bass *et al.* 2003).
- CBAM, Cost Benefit Analysis Method (Bass *et al.* 2003).
- ALMA, Architecture Level Modifiability Analysis (Lassing 2002).
- FAAM, Family Architecture Analysis Method (Dolan 2002).

Although these methods were initially developed for the assessment of the software architectures, experiences papers with ATAM and CBAM showed that they can be applied for system architectures as well (Bass *et al.* 2003).

2.5.1 A Generic Scenario-Based Architecture Evaluation Process

Scenario-based evaluation methods for software architectures usually consists of four phases: a goal definition phase, a scenario brainstorming phase, the assessment phases where the architecture is evaluated against the brainstormed scenarios, and a presentation phase, where the results of the assessment are reported and interpreted. The process is shown in Figure 2-3.

A close look to the assessment methods will reveal that there are small differences in the overall process presented. Some methods introduce reiterations and feed back loops in the assessment process workflow.

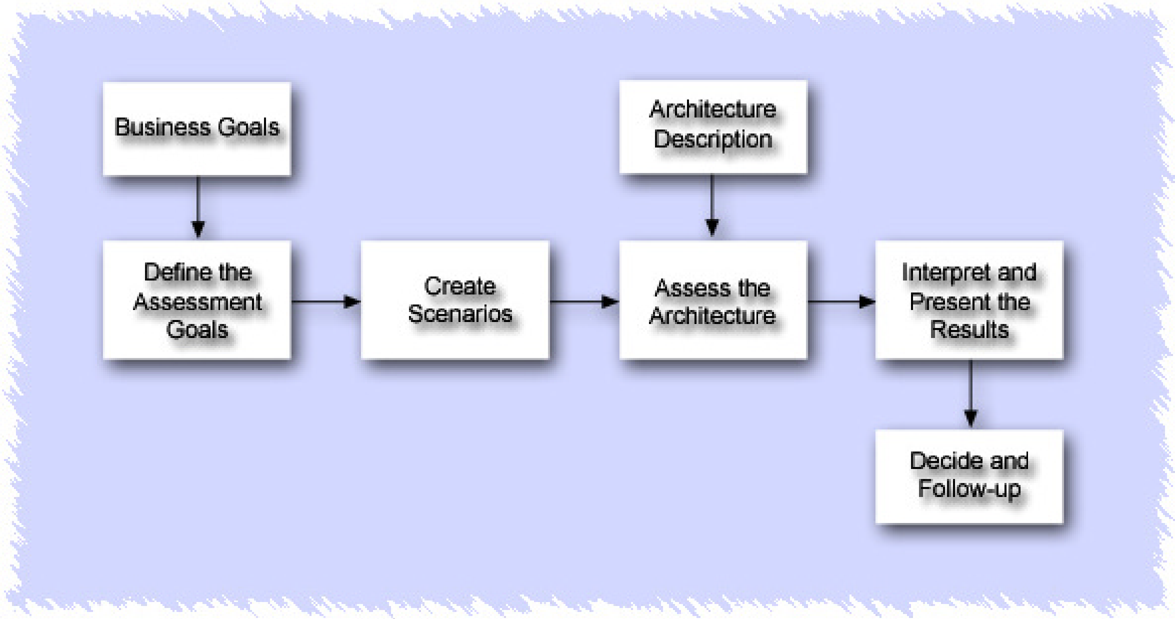

Figure 2-3: An Example of Architecture Assessment Process

An assessment session can assess different quality attributes of a given software architecture (e.g. modifiability, extensibility, interoperability, development cost, etc.). However, the phases described in Figure 2-3 may differ in terms of the types of steps to be performed, the prerequisites for the assessment session, the roles, or the outcome of the method. The duration of the different steps is determined mainly by the complexity of the architecture to be assessed and the assessment goals

2.5.2 Remarks on the Scenario-based Evaluation Methods

The classical approach in evaluating the quality of system architectures was "conformance to the requirements". The scenario-based evaluation methods are shifting the focus of the analysis towards estimating risks and uncertainty associated with the systems' requirements, architectural decisions and strategies to be adopted in case of failure. Because of this, scenario-based assessment techniques can coexist with the classical approaches. The innovation provided by these approaches rests in explicitly associating quality requirements with the architectures by means of scenarios.

Scenario-based assessment methods for system architectures are easy to comprehend. The effort in applying the methods is relatively low. Besides the outcomes of the different methods, some other benefits are:

- improved communications between stakeholders, architectural discoveries,
- improved strategic decision with respect to architecture design, and
- quickly applicable improvements if the assessment is performed early in the development phase.

2.5.3 Important Scenario-Based Evaluation Methods - Detailed

The set of methods previously mentioned, namely: SAAM, ATAM, CBAM, ALMA and FAAM, will be described briefly in this section. The goal is to provide enough information about how scenarios are used in each of the methods. For a full description of any of the methods one may directly consult their original descriptions given by the authors. A detailed overview of these methods is given in (Ionita *et al.* 2002). Table 2-4 on page 35, summarizes the main features of each method, in which the weaknesses or strengths are highlighted for each of these methods.

2.5.3.1 The Software Architecture Assessment Method (SAAM)

SAAM is the first widely promulgated scenario-based software architecture analysis method (Kazman *et al.* 1994). It was created to assess the architectures' modifiability in its various names (e.g. adaptability, portability, extensibility) (Kazman *et al.* 1996). In practice SAAM has proven useful for quickly assessing many quality attributes such as modifiability, portability, extensibility, interoperability, as well as functional coverage.

The SAAM steps are:

1) Develop the assessment scenarios,

2) Describe the architecture (architectural options),

3) Classify and prioritise scenarios,

4) Individually evaluate the indirect scenarios,

5) Assess scenario interaction, and

6) Create an overall evaluation.

The SAAM activities are shown in Figure 2-4.

In SAAM the scenarios are classified in *direct scenarios* and *indirect scenarios*, their equivalents in UML notation are use-cases, respectively change-cases. The direct scenarios are those that are supported by the architecture without any change. The indirect scenarios are those for which realization the architecture must suffer some changes.

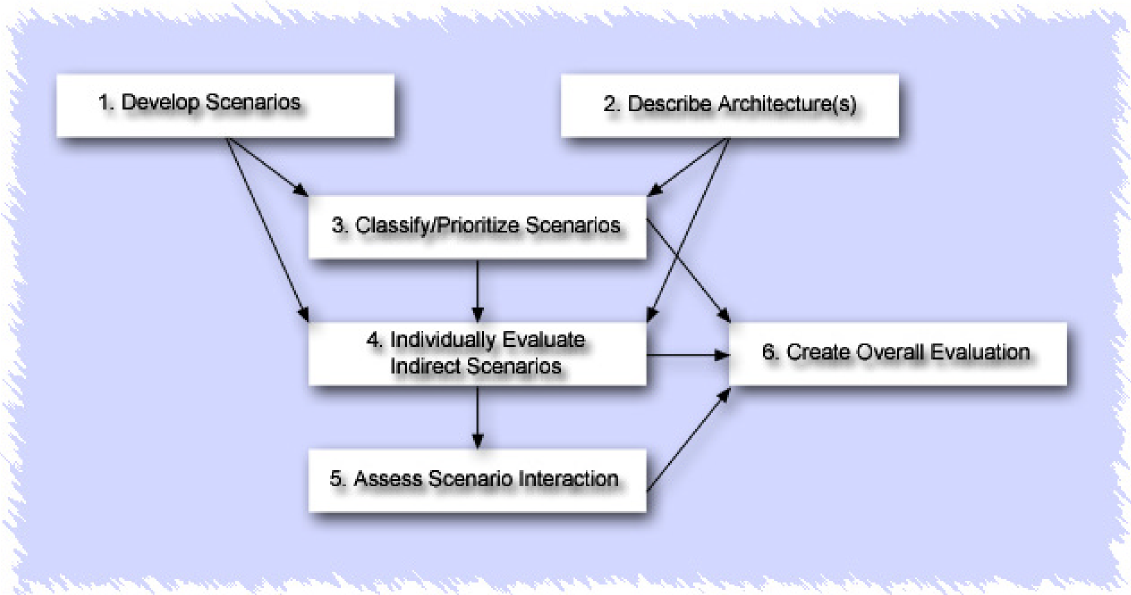

Figure 2-4: SAAM Activities and Dependencies, in (Bass *et al.* 1998), pp. 214.

A set of open questions have been identified in applying SAAM. These steps determine the success of the architecture's evaluation and address possible improvements of SAAM.

- The scenario generation process is only based on stakeholders' vision. It takes a very little effort for a stakeholder to imagine many indirect scenarios whose relevance is not clear.
- SAAM does not provide a clear metric for the architectural quality attributes being analysed.
- SAAM is a stepwise method for performing the software architecture analysis. However, it provides few techniques for performing the different steps, mainly relying on the analyst/evaluator experience.
- SAAM does not explicitly support the evaluation.

2.5.3.2 The Architecture Trade-Off Analysis Method (ATAM)

ATAM (Bass *et al.* 2003) is a scenario-based architecture method for assessing all types of quality attributes. Besides the assessment of quality attributes, ATAM also explores the quality attributes interaction and their interdependencies, highlighting trade-off mechanisms and opportunities. ATAM analyses how well software architecture satisfies particular quality goals. ATAM is based on the Software Architecture Analysis Method (SAAM).

The ATAM steps are:

1) Present ATAM.

2) Present the business drivers.

3) Present the architecture.

4) Identify architectural approaches.

5) Generate quality attribute utility tree.

6) Analyse architectural approaches.

7) Brainstorm and prioritise scenarios.

8) Reanalyse architectural approaches.

9) Present the results.

According to the Bass et al. the strengths of the ATAM method are:

- Stakeholders understand the architecture more clearly.
- Improved software architecture documentation. In some cases the architecture documentation must be recreated.
- Enhanced communication among the stakeholders.

In terms of practical outcome ATAM delivers:

- Quality scenarios produced by stakeholders based on the quality attributes requirements.
- Architecture elicitation results based on quality scenarios and use-cases.
- Quality attributes taxonomies, which provide evaluators with a catalogue of architectural parameters and appropriate stimuli for tracing different quality attributes and their interdependencies.
- Enhanced architecture
- Risks, Sensitivities, Tradeoffs

2.5.3.3 Cost-Benefit Analysis Method (CBAM)

CBAM (Bass *et al.* 2003) is an architecture-centric method for analysing the costs, benefits and schedule implications of architectural decisions (Bass *et al.* 2003). CBAM can also assess the level of uncertainty associated with these judgments, so as to provide a basis for an informed decision process with regard to architecture. Different from the former methods, CBAM is bridging two domains: software architecting process and the economics of the organization. CBAM is adding the costs (and budgets) as additional quality attributes, which need to be considered among the tradeoffs when a software system is going to be planned. So far, CBAM is the only established method to deal with the cost and benefits tradeoffs at an architecture level.

SAAM and ATAM primarily considered the design decisions with respect to architectural quality attributes like modifiability, performance, availability, usability, and so on. CBAM is adding the cost and benefit as important attributes that should to be considered when the architectural decisions are being made. An ATAM session is useful to be applied before the CBAM can be actually carried out, but this is not a pre-requisite. Sometimes steps from both methods are combined.

The steps of the CBAM are:

1) Choose scenarios of concern and their associated architectural strategies.

2) Assess quality attribute benefits.

3) Quantify the benefits of the different architectural strategies.

4) Quantify the costs of the architectural strategies and their schedule implications.

5) Calculate desirability.

6) Make decisions.

The workflow of CBAM is given in Figure 2-5.

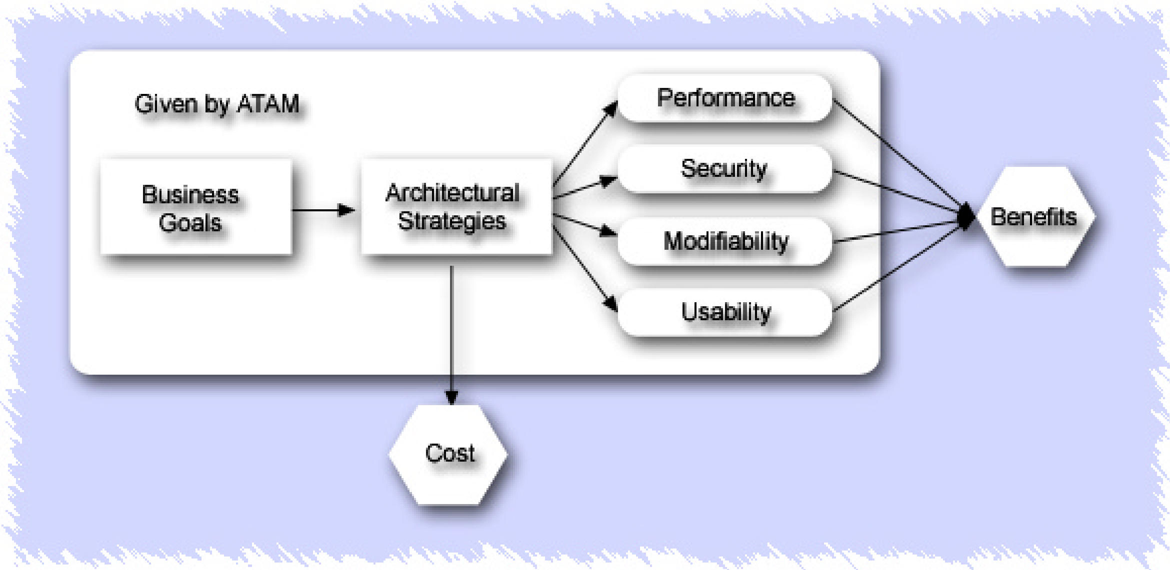

Figure 2-5: The Context of CBAM, in (Bass *et al.* 2003), pp. 308

The CBAM strengths are:

- The method provides values as a basis for a rational decision making process for applying certain architectural strategies.
- The method provides a business measure that can determine the level of return on investment of a particular change to the system.
- The method will help organizations in analysing and pre-evaluating the resource investment in different directions by adopting those architectural strategies that are maximizing the gains and minimize the risks.
- Since CBAM is built on the general architecture assessment methods like SAAM and ATAM, the method is inheriting their benefits with respect to efficiency and accuracy.

2.5.3.4 Architecture-Level Modifiability Analysis (ALMA)

Initially ALMA (Lassing 2002) has been developed and tested for Business Information Systems only, and focuses on modifiability. ALMA should also be applicable for Embedded Systems, but this assumption has not been proven yet.

Modifiability analysis usually has one of three goals:

- Prediction of future modification costs.
- Identification of system flexibility.
- Comparison of two or more alternative architectures.

ALMA is a scenario-based analysis method suitable for software architecture modifiability assessment by employing a set of indicators: maintenance cost prediction and risk assessment (Lassing 2002)(Bengtsson 2002). In case of assessing and comparing different systems, the modifiability analysis performed with ALMA supports software architecture selection as well. For this purpose ALMA uses change-scenarios, provided by stakeholders.

The modifiability analysis starts with defining a set of scenarios that might occur during the evolution of the system. Scenarios are used to verify how well the current architecture may accommodate future changes.

The ALMA steps are:

1) Set the analysis goal.

2) Describe the software architecture(s).

3) Elicit change-scenarios.

4) Evaluate the change-scenarios.

5) Interpret the results.

The strengths and weaknesses of the ALMA method are:

- The method focuses on architectural abstractions, which represent the domain functionality and the driving quality attributes.
- Similar to SAAM and ATAM, in ALMA the scenario evaluation is based on impact analysis. This consists of identifying the affected components and determining the effect on those components, together with the ripple effects.
- Stakeholders have two options in generating the change scenarios.
  - A top-down approach that identifies a set of general change scenarios categories followed by a refinement in terms of their particular instances.
  - A bottom-up approach, where the change scenarios are collected by stakeholder interviews and categorized in scenario classes.
- The possibility of assessing modifiability from different perspectives: maintenance and cost prediction, risk assessment, and/or software architecture selection.
- The method, as a general remark, lacks the means to decide upon the accuracy of the results of the analysis. ALMA cannot reason about the accuracy of the maintenance predicted numbers. Also, one cannot reason about the completeness of the risk assessment.
- ATAM is a possible substitute of ALMA with respect to modifiability. Both methods are quite similar, since they use scenarios for assessing the quality attributes and provide estimates with respect to the analysis goals.

The outcomes of the method can be summarized as follows:

- The results of the impact estimates for each scenario are expressed as (1) the size of the modification to existing components, or (2) the estimated size of the components that must be introduced.
- A modifiability prediction model based on the estimated change volume and productivity ratios. The model assumes that the change volume is the main cost driver, thus gives a productivity figure for the cost of adding new code and modifying old code
- A scenario generation stopping criterion if all categories from the classification scheme have been explicitly considered, or generation of new change scenarios does not affect the classification structure.

2.5.3.5 Family Architecture Assessment Method

FAAM (Dolan 2002) is a method for architecture assessment of information-system families, focusing on two related quality aspects: interoperability and extensibility. In FAAM, the architecture description is evaluated against the requirements with the focus on the ability and easiness to satisfy the change-cases.

FAAM focuses on the evaluation process for information system families and supports it by guidelines, metrics, and recommendations. It emphasizes the know-how techniques to enable the development teams within the organizations implementing the method.

The steps of the FAAM method are:

1) Define the assessment goal.

2) Prepare system-quality scenarios.

3) Prepare architecture

4) Review, and refine the artefacts if necessary

5) Assess architecture conformance.

6) Report results and proposals.

The strengths and outputs of FAAM are:

- The method provides how-to advice to enable development teams to conduct their own self-assessment as a means towards continuous improvement.
- The assessment process is tailored for the domain of information-systems families.
- FAAM has a well-defined process description in form of a workbench. This is useful for supporting the participants with practical techniques in generating the necessary process artefacts for evaluating the interoperability and extensibility attributes
- FAAM is based on general architecture assessment methods like SAAM and ATAM, thus inheriting their benefits with respect to efficiency.

FAAM builds on the experience of SAAM by adding a family perspective and advanced techniques for the facilitation of the assessment. ATAM can be an alternative for FAAM.

2.6 Conclusions

In strategic management, scenarios are tools for educating and ordering the perception of the different plausible futures for taking strategic decisions (Schwartz 1996), (vd Heijden 1997).

In requirements elicitation activities, scenarios are good tools for illustrating the system-user interaction for some specific tasks. The goal is to better understand the required behaviour of the system and to capture the context dependent requirements (Carroll 1995), (Carroll 2000).

In architecting software intensive systems, scenarios are excellent vehicles for communication (Bass *et al.* 2003). Their usefulness is in both scoping (e.g. preparing for different futures and taking strategic architectural decisions) and framing (e.g. understanding the functionality of the system in both its present and future business environment).

A special role of scenarios can be observed in the context of software architecture evaluation activities. Here, scenarios are used for assessing the response of the architecture to foreseeable changes, which may challenge the architecture under consideration (e.g. cases in which the modifiability, extensibility or interoperability of the system is assessed) (Bass *et al.* 2003), (Dolan 2002), (Bengtsson 2002), (Lassing 2002). Scenarios can also be used for the final evaluation of the architecture.

Although using scenarios in software architecture evaluations can prove helpful in discovering many inconsistencies with respect to design, their advantages are limited by the following factors:

- Late signalling: the discovered inconsistencies are signalled after the design, and maybe implementation, is already started.
- Limited scope: evaluating every "ility" revealed by scenarios costs usually too much time and effort, thus a restricted set of scenarios must be considered.
- Bound to the creativity of the participants: the relevance of the evaluation scenarios depends on people participating in the assessment exercise, for which adequate preparation period is often necessary.

2.6.1 Advantages of a Scenario-Based Architecting Method

Why scenario-based architecting?

Looking at the current landscape, scenario methods are widely accepted as useful tools for the early phases of the software development lifecycle. However, when they are dispersed over different phases (i.e. requirements activities, or evaluation activities), their usefulness is reduced. This promotes the need for an integral scenario-based architecting framework in which the scenario techniques, applied consistently in the different stages of the architecting process, can benefit from each other. In the sequel, the reasons in favor for a scenario-based architecting method are described per architecting phase.

For the requirements engineering phase

1. The existing requirements engineering methods are either user-centred or system-centred. We believe that the future system requirements must be elicited in accordance with a wider set of stakeholders. Users and their concerns are a good starting point. However, neglecting issues like technology trends, competition, market type and size, or economical implications of the future requirements, may lead to frequent changes in requirements and hence architecture re-design.

A scenario-based architecting method is meant to prevent this kind of problems. In the context of requirements elicitation, the main benefit of the scenario-based method is the possibility of extracting the long-term requirements as well as the short-term ones. With the existing methods the future perspective is not sufficiently supported.

2. All existing requirements engineering methods point out the fact that quality requirements are important and must be elicited early during the project inception activities. However, there are few established methods to elicit these quality requirements, such as

interviewing or brainstorming techniques (Robertson *et al.* 1999), or quality attribute frameworks (Bass *et al.* 2003).

The scenario-based architecting method can handle the specification of the quality attributes. The benefit is that quality requirements are not only stated in terms of levels, measures and metrics, but are elicited and specified in a context, with an eye to the future, and in relation with other qualities. In this way, the architects are supported to design for quality by presenting the specific quality requirements in a given context. Designing for quality is a creative process related to vision, estimation, and continuous assessment, which could profit from a scenario-based approach.

3. The existing requirements engineering methods do not deal with business aspects of the systems and with the uncertainty associated with future business contexts. The best attempt of some methods in tackling this issue is to consider the business goals as input for eliciting requirements, (Antón 1996)(McGraw *et al.* 1997).

In summary, taking a scenario-based architecting approach the improvement is twofold: (1) a feedback loop from scenarios to business models for refining the business goals, and (2) a feed-forward loop from business models to scenarios for refining their value propositions and hence smart requirements. Regarding scenarios as story lines about plausible futures, the feedback loop enables the articulation of the business goals from a future perspective. Similar, the feed-forward loop helps in eliciting future-proof architectural requirements. As a result, also the scenarios themselves can be iteratively refined and improved.

For the software architecture design phase

4. System architecting involves strategic architectural decisions. In most cases few people, usually the architects, take these decisions. Thus, there is a high risk that the decision rationales have a too small base and are not well anchored in the context. Missing the design rationales makes any re-design activity very error prone.

Introducing a scenario-based architecting approach, the state of the art can be improved in the sense that the communication between managers, architects and designers becomes more explicit. This makes it easier to coordinate the architecting activities, and anchor them in context.

5. Usually, qualities are addressed only late in the architecting process.

A scenario-based approach could prevent in many cases the re-design of the architecture - by creating the assessment scenarios in the early stages of the architecting process, and using them before the final architectural solution is proposed.

6. The implications of the architectural decisions with respect to effort, costs, risks, or achievement of the business goals are often difficult to assess and quantify.

A scenario-based approach is a suitable candidate for solving these problems. Scenarios can be used for envisaging the risks, costs, and effort associated with each architectural solution, and assessing their consequences in a specific context, (Bass *et al.* 2003) (Ionita *et al.* 2003)(Ionita *et al.* 2004).

7. Currently there are only few methods trying to bridge the gap between the requirements specification and software architecture evaluation. This gap makes the architecture evaluation unfocused and ineffective.

The evaluation methods use as input a set of scenarios envisaging changes that may impact the architecture design in the future. These scenarios are generated during the evaluation session, which usually takes place at the end of the architecture design phase. If the resulted scenarios do not take into account the initial business goals for which the system has been created, the assessment becomes an unfocused activity. In most cases these scenarios created during the assessment are not part of the initial system specifications, and therefore architectures are likely to be declared incomplete.

A scenario-based architecting method will create scenarios for guiding and assessing the design early in the architecting process, and consider these scenarios as assessment criterions for the final implementation of the system. Early specification of future envisaged changes, using scenarios, can improve the architecture and thus reduce the re-engineering effort. In this way, the scenario-based architecting approach could bridge the gap between architecture evaluation and requirements specification.

This way, any architectural design can be assessed along the development cycle and hence preventing the risk of deploying unfeasible big-bang architectural solutions.

WinCBAM, a newly developed method by Kazman et al., bridges the gap between the requirements engineering and the architecture evaluation by aligning the two processes. This is described in two papers, (Kazman *et al.* 2004) and (Kazman *et al.* 2005).

For the overall architecting process

8. In general, the architecting processes have a rigid structure that doesn't support smooth adaptation to changing business goals, requirements and technologies, (Kruchten 2000).

In the current architecting practice, the trend is to nail down the business goals and from there to derive rigid, formal, complete, and measurable requirements. Also, similar to the waterfall model, this process is treated as sequence of steps with artificial boundaries in between. The focus is on managing things that are actually constantly changing. This approach does not work because requirements, business goals, market and technology trends are unstable by nature.

A scenario-based approach enables the architecting process to be more flexible in the sense that the requirements are based on real-life situations in which uncertainty is explicitly taken into account. A scenario-based approach can provide the means to envisage alternative solution, thus making the architecting process more flexible and future-proof.

9. There are few methods and tools that support the architect (Ionita *et al.* 2002). Also these methods and tools are related to specific architecting phases and problems.

Since scenarios generate an overall picture and are usable throughout all product development phases, a scenario based architecting method could also provide a basis for tool development (Haumer *et al.* 1999).

2.7 Final Remarks

The current system architecting approaches are based on traditional software development process models, which start with requirements and finish with product testing. In the traditional development process, requirements are gathered in the inception phase of the project together with the construction of use-cases. Based on the use-cases an initial system's software architecture is proposed. The description of the architectures usually includes different views (logic, physic, code, etc). Using this input the designers build software components in an incremental and iterative manner. The working components are integrated, and the final system is tested.

In this context, many studies have been conducted for improving the support in the different phases of the software development process. Due to these efforts, various methods and tools are today well established in the requirements engineering and architecture design area. Recently, considerable attention has been paid to the software architecture evaluation area, where techniques for assessing different qualities of the software systems have been proposed. However, all established methods are limited to particular aspects of software architecture development.

Table 2-4: The relevant aspects of the different software architecture evaluation methods

Method	Quality Assessed	Metrics and Tool Support	Process Description	Strengths	Weaknesses	Systems Type Applicable for
SAAM	Modifiability	Scenario classification (direct vs. indirect scenarios)	Reasonable	Identifying the areas of high potential complexity Open for any architectural description	Not a clear quality metric Not supported by techniques for performing the steps	All
ATAM	Modifiability	Sensitivity Points, Trade-off Points Supported by ATA Tool (Kurpjuweit 2002)	Good	Scenario generation is based on requirements Applicable for static and dynamic properties	Requires detailed technical knowledge	All
CBAM	Cost, benefits and Schedule Implications	Time and Costs	Reasonable	Provides business measures for particular system changes Makes explicit the uncertainty associated with the estimates	Identifying and trading costs and benefits can be done by the participants in an open manner	All
ALMA	Modifiability	Impact Estimation Modifiability prediction model	Reasonable	Scenario generation stopping criterion	Concentrates on static properties	Information Systems
FAAM	Interoperability and Extensibility	Various specialized tables and diagrams	Very good Detailed process flow	Emphasis on empowering the teams in applying the FAAM session	Only partially proven in one particular environment Concentrates on static properties	System Families

Chapter 3

3 Strategic Options Design and Assessment

In 2000, a research group inside Philips initiated the Scenario-Based Architecting project. This group was lead by Henk Obbink and Pierre America. One of the results of this research group was the SODA (Strategic Options Design and Assessment) method (America *et al.* 2004), (Ionita *et al.* 2004). A couple of case studies have been conducted to develop and improve SODA when designing long-lived system architectures.

This chapter presents the SODA method for the use of strategic scenarios in directing the strategic and tactical decision-making process when developing long-lived system architectures.

Introduction

Organizations that develop long-lasting architectures for software-intensive systems find themselves faced with a complex situation. On the one hand, they are under increasing pressure from their competitors and, on the other hand, they are faced with a highly uncertain future business context. In order to deal with these two issues effectively, organizations have to carefully assess the future and prepare for it. It is impossible to predict the future with all relevant details. However, it is possible to construct images of a variety of plausible futures and to use these when making long-term decisions; this process is called strategic planning.

The process of strategic planning emerged as a discipline in the late 1950s (Gouillart 1995). Initially a rigid activity intended to deliver the best strategy for the one and only envisaged future. It evolved into an agile process focused on the adaptability of the organization to rapidly transform according to the changes in the business environment (Haines 2000)(Mintzberg 1994).

In the literature, scenarios are advocated as powerful tools that support the strategic planning process. For strategic planning, a scenario is defined as a story describing a plausible future (Schwartz 1996)(vd Heijden 1996), hereafter called a *strategic scenario*.

3.1 The SODA Method

The goal of the SODA method is to provide a step-by-step approach for evolving system architectures that are more future-proof, (i.e. architectures that are more resilient to future changes). In order to accomplish this goal the following issues have been studied:

1) Methods for supporting long-term strategic decision making,

2) Techniques for translating strategies into concrete architectural solutions, and

3) Methods for analysing the feasibility of the proposed architectural solutions.

The result of this research is an overall method and process description for evolving future-proof architectures.

The SODA method mainly consists of four workflows, namely: business environment analysis, opportunities and threats identification, strategic options design, and options feasibility assessment, Figure 3-1. Each of these workflows will be described later in greater detail in Section 3.2 and 3.3. At this point, to give a flavour about the four workflows of the SODA method, the following can be said. The first workflow of the method, business environment analysis, provides the context in which new systems are envisaged. However, designing the right features targeting the right group of customers is provided by the market opportunity identification workflow. These first two workflows fuel the strategic option design workflow in which the concepts about the new system, as well as the high level architectural designs, are developed. The proposed architectural designs are assessed with respect to their feasibility in the option feasibility assessment workflow.

Figure 3-1: The Main Activities in SODA

For describing the SODA method, the following template will be used for structuring the method, as in (SARA 2002):

Table 3-1: Method Description Template

Name	*A succinct name of the method*
Context	*In which circumstances is the method useful?*
Purpose	*What does the method achieve?*
Input	*What are the artefacts that the method uses?*
Output	*What are the results of applying the method/ What artefacts does it produce, and how the results can be interpreted?*
Steps	*What are the steps or the workflow of the method?*
Roles	*Who are the participants?*
Estimates	*What is the estimated effort to apply the technique?*
Reference	*Where has this technique been published?*
Tools	*What tools support this technique?*
Alternative	*What other technique could be used for a similar purpose?*

Method Name – SODA

The method is called SODA, which comes from: *strategic* **-** because it involves long-term strategic planning within organizations, *option design* **-** because it captures multiple flexible solutions as responses to possible future market changes, and *assessment* – because it helps in analysing the feasibility of the proposed design options.

SODA Context

The SODA method is a strategic scenario-based method to support the early phases of system architecture development, namely the strategic options identification. Besides the option identification, SODA includes a systematic way of quantitatively assessing the feasibility of the proposed options.

SODA Purpose

The SODA method supports the strategic and tactical decision-making process when developing long-lived system architectures.

Inputs and Outputs for SODA

The SODA method requires as input strategic scenarios for guiding the design of business strategies, and architectural options. The method provides an integral architecture showing how to respond to different futures.

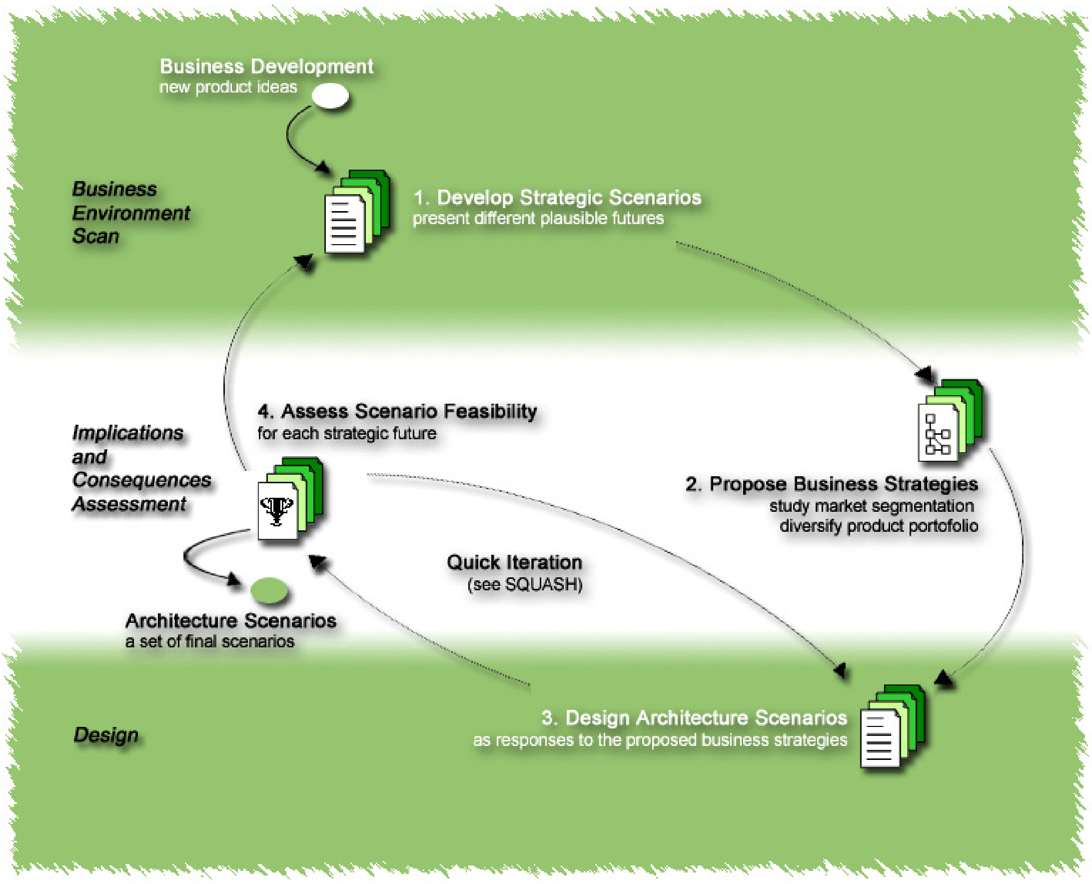

Figure 3-2: SODA Method Steps

3.2 SODA Method Steps and Workflow

The activities within the SODA method are introduced below. A concrete example, on how these activities are actually performed, is given in Chapter 6.

Activity 1 - Develop Strategic Scenarios
Activity 2 - Propose Business Strategies
Activity 3 - Design Architectural Scenarios
Activity 4 - Assess Scenario Feasibility

The relations between the different steps of the method are shown in Figure 3-2.

3.2.1 SODA Activity 1: Develop Strategic Scenarios

In this activity the future business environment is explored. The goal of this activity is to create the context for making strategic decisions with respect to: what systems to build, for what type of customers, with what features, and to what level of quality. To create the strategic scenarios the GBN (Global Business Network) model is adopted, as in (Schwartz 1996). This is because the GBN model is a well-established model, emerged from successful projects and business practices.

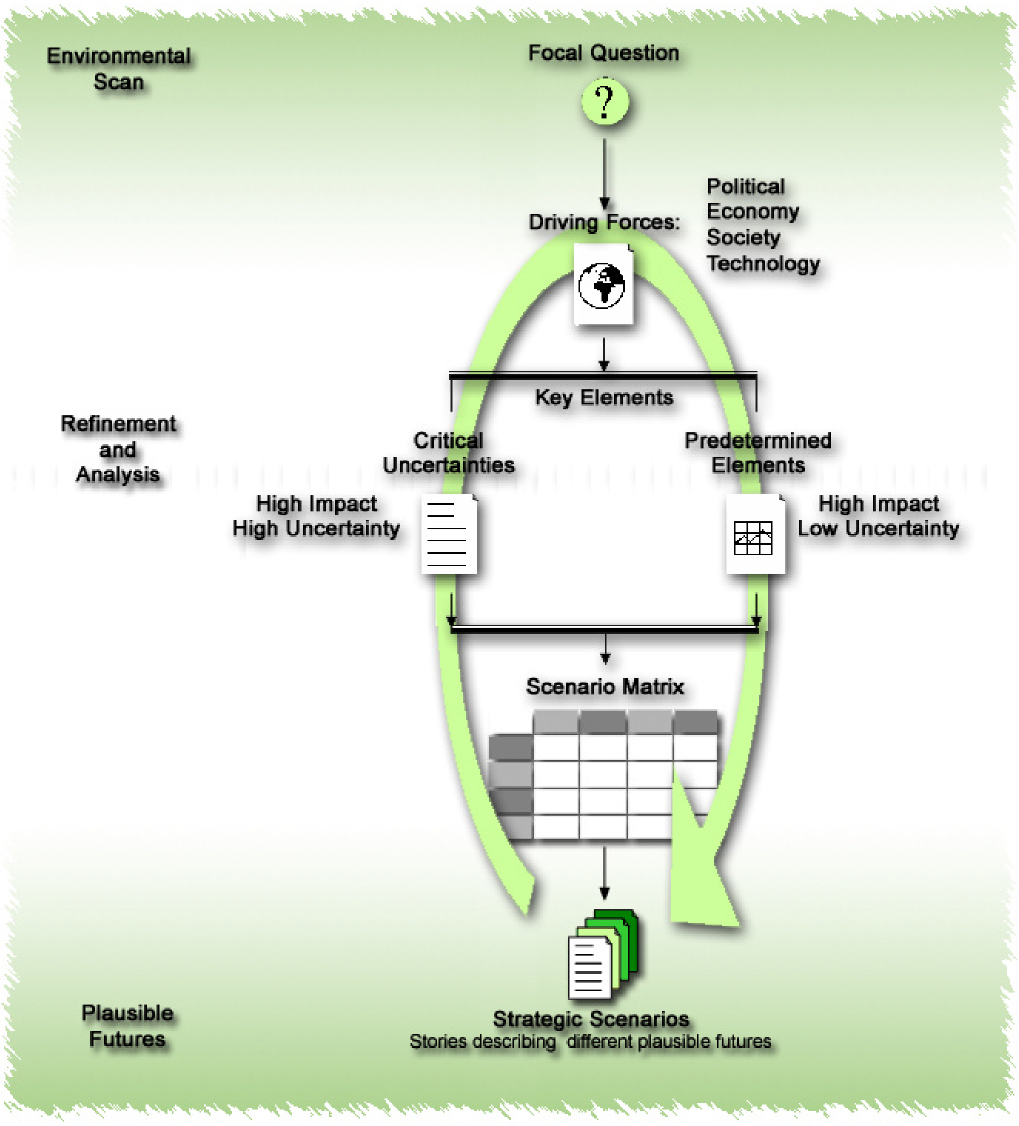

Figure 3-3: A Strategic Scenario Creation Process – The GBN Model

The GBN model proposes an iterative scenario-building process that starts by isolating the decision to be made called the *focal question*, then identifies the key elements that would affect the decision called the *driving forces*, and finishes by constructing several strategic *scenario plot lines*, analysing their implications and refining them by seeking yet more key elements, as shown in Figure 3-3. The scenario key elements can be grouped in two categories, predetermined elements and critical uncertainties. The predetermined elements are factors that are fairly predictable and we can count on, such as demographics or technology roadmaps. The critical uncertainties regard factors that have a high impact on the decision to be made, and are highly uncertain such as economy situation: recession, stable, or boom?

The driving forces, represented by the predetermined elements and the critical uncertainties, are then grouped together in the form of a table. This table is called the scenario matrix (as shown in the example from Table 3-). The table has as rows the identified driving forces, while each column of such a table contains the main ingredients for constructing a strategic scenario. The cells of each column describe the possible variations of the driving forces. For example, “Society” is a major driving force in building strategic scenarios for the medical domain. One element of the “Society” is the “Lifestyle” of the individuals. The possible variations of the “Lifestyle” element are healthy, unhealthy, or preventive. The combination of different driving forces will generate the scenario story line, Table 3-2. Scenario 2 is an example of a strategic scenario, namely a society in which individuals follow a preventive lifestyle, self choosing rather than governed by strictly rules, however aging.

The scenario creation process is described step by step in Figure 3-3. The first phase of this process is called “Environmental Scan” in which the focal question is formulated and future trends in the business environment are analyzed to answer this question. Here the PEST (Political, Environment, Society and Technology) framework is used, (Middleton 2003). In a second phase of this process, called “Refinement and Analysis” the identified trends in the business environment are split in two categories, namely predetermined elements and critical uncertainties. Also in this phase the scenario matrix is constructed. In the last phase of the scenario building process, called “Plausible Futures”, the strategic scenarios are finally assembled as a sound combination of predetermined elements and critical uncertainties. The strategic scenarios will describe different plausible futures (see Appendix B for the Strategic Scenarios used in this case study).

Business analysts typically perform this step.

Table 3-2: Scenario Matrix – Example.

Trends in:		**Strategic Scenarios**		
		Scenario 1	*Scenario 2*	*Scenario 3*
Society	Life Style	Unhealthy	Preventive	Preventive
	Demographics	Aging Population		
	Patient Type	Governed by Strict Rules	Self Choosing	Consumer

In this table, the society is a key driver with a predetermined element, which is aging population, and two critical uncertainties, which are the Life Style and the Patient Type. To identify the key elements contained in this table, the PEST framework is recommended to be used, as described in (Middleton 2003).

In order to construct relevant strategic scenarios, the different PEST factors are coupled in such a manner that they reveal different but reasonably plausible futures. If a strategic scenario includes all the PEST factors that are highly uncertain while others include most of the predetermined elements, we are in the situation of having some scenarios which are very likely, describing the near future, and some scenarios that are very futuristic, describing far and highly improbable futures, Figure 3-4.

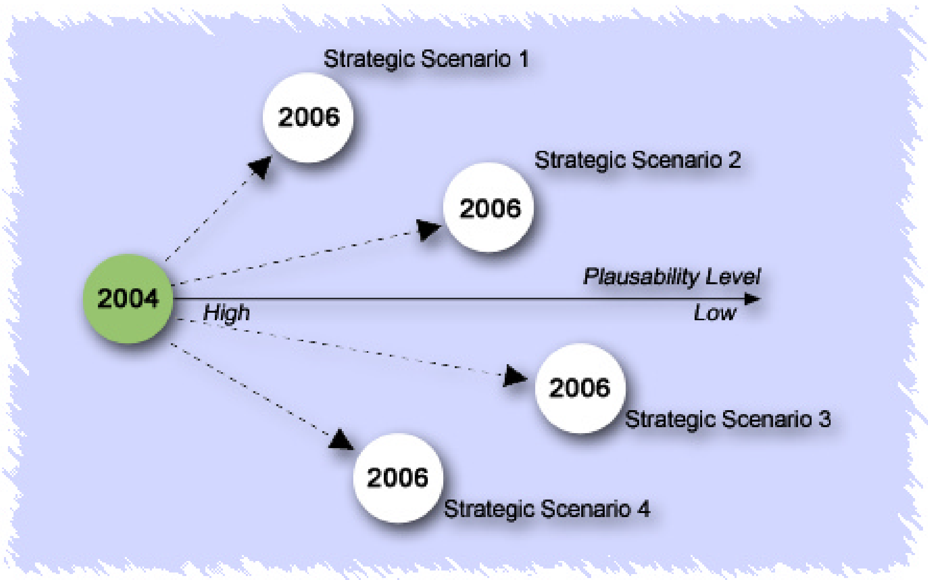

Figure 3-4: Realistic versus idealistic scenarios

Therefore, instead of highly realistic versus highly idealistic scenarios we would like to have a balanced mix of certain and uncertain factors. So, instead of scenarios having a different plausibility level as shown in Figure 3-4, we would like to have different scenarios describing equally plausible futures. These scenarios are not an accurate prediction of what is to happen in 2010, they rather describe the most likely changes that are to appear in a time interval of 5 years.

3.2.2 The Scenario Plot Lines

To have an overview of the constituting elements of the different scenarios, we use a scenario matrix. This is a table which has as rows the key elements of the different scenarios. The ordering of the key elements is done in such a way the scenarios are equally plausible. This means that one should use both uncertain key elements and predetermined ones when constructing the strategic scenarios. The columns of such a table represent the building blocks of the final strategic scenarios.

Optional Activity – Identify Scenario Highlights

An optional activity in SODA Step 1 is the identification of scenarios' highlights. This activity is only performed if the strategic scenarios are not developed within the project but come from external sources. In this step, the consequences of the strategic scenarios relevant for the architecture development process are identified. These consequences can be categorized as clues about possible opportunities and threats. The clues revealed by the strategic scenarios usually refer to trends in: society, economy, technology, markets, consumer behaviour, etc. These clues are used in the next step when the business strategies are proposed.

Business analysts usually perform this activity.

3.2.3 SODA Activity 2: Propose Business Strategies

In the second activity of SODA, different business strategies are proposed as possible responses of the organization to the external opportunities and possible threats. A *business strategy* can be defined as the actions that need to be taken to achieve the goals of the organization (Hill 2002). For example, if the objective is to improve the profitability, one can choose between a standardization strategy, which focuses on reducing the operational costs within the organization, and a customisation strategy, which focuses on improving the market value of the product. In order to come up with sound business strategies one might have to look into the current product portfolio of the organization and the type and size of the different market segments at which the new product is targeted.

Mainly business strategists are involved in this step. However, there is some participation of the architects. The business strategists will design the business strategies, while the architects will provide feedback on the actual technical feasibility of these strategies.

3.2.4 SODA Activity 3: Design Architecture Scenarios

The essence of this work is to make it easier to adapt architectures over time. Since it is impossible to adapt the architecture in all possible directions (e.g. modifiability, performance, portability, etc.) different architectural scenarios are explored, to deal with this problem.

In this activity various architectural scenarios are created as most likely implementations for the business strategies defined in step three.

Architecture descriptions typically contain different views, as explained in the Chapter 2 of this thesis. For describing architectural solutions a five view architectural model is used, namely the CAFCR model (Muller 2003)(Muller 2004)(Obbink *et al.* 2000)(America *et al.* 2003) and (Obbink *et al.* 2003). This choice is motivated by the following reason. The CAFCR model allows the modelling not only of the architecture in form of systems, subsystems, components and the mapping between them, but also it allows the modelling of large a part of the external business environment of the future system such as its users, the stakeholders and their objectives. Alternative models are the 4+1 View Model (Kruchten 1995), or the 4 views model (Soni *et al.* 1995), both focusing too much on the technical aspects of the system architecture, and therefore not completely suitable for the scope of SODA.

For dealing with the possible variations of the architecture within each view, SODA uses variation models (America *et al.* 2003)(America *et al.* 2004). The variation models map out the possible design choices within the different views of the architecture. Finally, the proposed architectures are described by means of a few architectural scenarios capturing the architectural choices made in each view. An *architectural scenario is defined as a set of specific and consistent choices across the different variation models in each architectural view*. A variation model is a description the total spectrum of possible architectural design choices within a specific architectural view, while a variation point is the indicator of the specific place in such a variation model when more than one choice exists. Here the construction of variation models can be of help in several ways, (America *et al.* 2003):

- *To structurally explore the variation space in the various views, and the relationships between them.*
- *To guide and document the choices that were made, as well as the options that were disregarded.*
- *To enhance communication and raise awareness about these choices between the architecture's stakeholders.*

This activity gives rise to a couple of architectural scenarios intended to implement the business strategies designed in the previous step. Architects and system designers carry out this step. Stakeholders are also involved in this step, especially when the scope and requirements of the system are outlined.

3.2.5 SODA Activity 4: Assess Scenario Feasibility

In this last activity the proposed architectural scenarios are analysed according to how well they help the organization achieve its strategic and business objectives.

The goal of this activity is primarily to assess the feasibility of the proposed architectural scenarios for each of the future business contexts as outlined by the strategic scenarios.

The architects and the stakeholders need to ensure that the proposed architectural scenarios are able to satisfy their customer objectives in terms of provided functionality, quality, and price. A method for systematic quantitative analysis of scenario heuristics (SQUASH) has been developed within SODA to enable this step to be carried out, as introduced next in Chapter 4. The following paragraphs will explain briefly how such a feasibility assessment is carried out. The detailed version of the assessment is actually given in Chapter 7, where a concrete case study is presented.

The proposed feasibility assessment process follows a four step pattern:

1. First, the most relevant quality attributes are specified, together with their relative importance. The architecture scenarios are then quantitatively assessed with respect to these qualities and an overview is then presented. For this purpose the SQUASH method has been developed.
2. Second, the sizes of the various market segments are estimated.
3. Third the impact of the different architecture scenarios on the current market share of the customer organization is estimated. Here an approximation is used where it is assumed that the difference in market share is proportional to the quality level of the product weighted with the importance of that specific quality. This is expressed by Formula 3-1 (see also in Section 11.1).

   Formula 3-1: $New\_Share_{i,j} = Initial\_Share_i + \sum_{k=1}^{n} w_{i,j,k} * v(a_k)$

   where $New\_Share_{i,\ j}$ is the new size of the organization's market share in segment i and future j, $Initial\_Share_i$ is the organization's current market share in segment i, $w_{i,j,k}$ is the relative importance of quality attribute a_k in segment i and future j, and $v(a_k)$ represents the value of quality attribute a_k. More precisely, $v(a_k)$ is the delta accounting for the change in the quality factor value for the architecture scenario l being analyzed, when compared to the same factor in the current product, measured in percentages. In this approach it is assumed that the most relevant quality attributes influence directly the market share. Although Formula 3-1 is a theoretical assumption, in practice this is could become a valid assumption to make, because one can measure the user preference for same type of products which differ in the quality level exhibited. However the coefficients accounting for the relative importance of the various quality attributes remain difficult to determine.

4. Last, profit figures are calculated, for each market segment *i* and architecture scenario *l*, as the difference between the system market price and its manufacturing cost, multiplied by its expected sales figure, from which is subtracted the initial development cost and the marketing cost for the new product. The different costs or profits are multiplied by a coefficient representing the future value of money (FV_k), as a correction for the delay introduced by the production duration and the time to achieve the new market share.

   This is expressed in Formula 3-2, see also in section 11.3.

   Formula 3-2:
   $$Profit_{j,l} = \left(\sum_{i=1}^{n} Sales_{i,l} \cdot \left(MarketPrice_{i,l} - FV_1 * ProductionCost_l \right) \right) - \\ - FV_2 * DevelopmentCost_l - FV_3 * MarketingCost_l$$

   where $Sales_{i,l}$ is calculated as the product between the total estimated market size and the new market share of the organization.

   The resulting figures express the cumulative profit calculated for each architecture scenario, in the context of the different strategic futures.

5. To support the visualization of the various profit figures, the data is represented on a radar graph, which has as axis the strategic scenarios and the values on these axes are the estimated profit figures yielded by each architecture scenario. Such an example is provided in section 11.4. SODA method provides the means to make a more informed decision with respect to the most suitable scenarios to be considered for implementation, based on the estimated profit figures.

3.3 Positioning the SODA Method with Respect to RUP

RUP (Rational Unified Process) is a software engineering process designed for structuring the various phases of the development process, explaining the relations between issues like activities, tasks, roles and artefacts. RUP is intended to support the organizations in optimizing their productivity and delivering higher quality software within a predictable schedule and budget. RUP is organized across nine workflows, or disciplines, namely Business modelling, Requirements, Analysis and design, Implementation, Test, Deployment, Configuration and change management, Project management, and Environment, Figure 3-5.

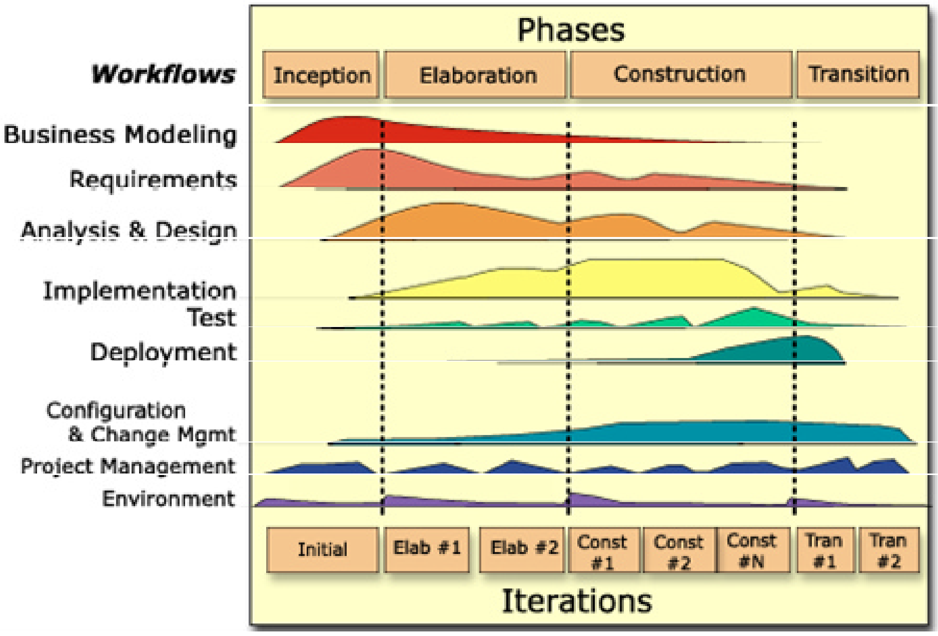

Figure 3-5: The Rational Unified Process Workflow Overview, (Kruchten 1999)

The SODA method addresses the pre-study phase of the system development process. It focuses on the exploration of different architectural options and the feasibility assessment of these options in the different future business contexts.

When comparing SODA and RUP, one could notice the following similarities. There are two workflows in SODA, namely the Strategic Option Design and the Option Feasibility Assessment workflow, which are the equivalent of the Business Modelling workflow of RUP. However, SODA focuses on supporting the strategic decision-making process when developing new system architectures, while RUP emphasises the tactical moves required for producing a specific system within predictable schedule and budget (Kruchten 1999).

The Strategic Option Design workflow is the umbrella under which the SODA Activity 3, called Create Architectural Scenarios, is actually carried out. The Option Feasibility Assessment workflow hosts the SODA Activity 4: Analyze the Scenarios Feasibility.

There are also two new workflows in SODA: firstly, the Business Environment Analysis, in which the SODA Activity 1, namely Develop Strategic Scenarios is performed, and secondly the Market Opportunity Identification workflow, in which two SODA activities are performed, namely the optional activity called Identify Scenario Highlights, and the SODA Activity 2 called Propose Business Strategies.

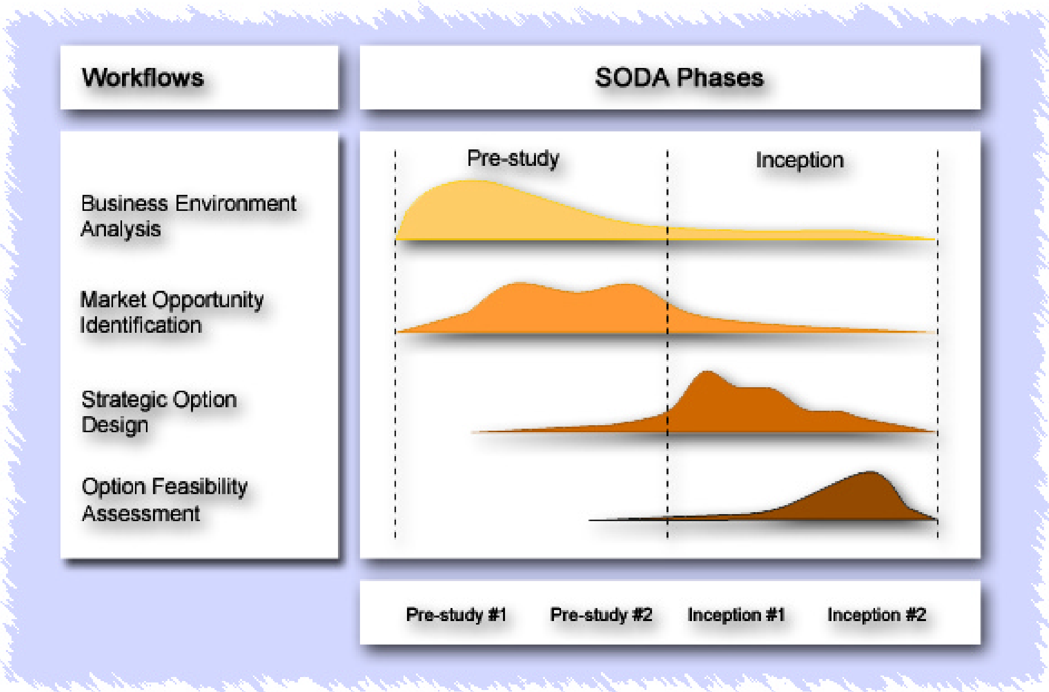

Figure 3-6: SODA Workflows and their effort distributed over time

The effort distribution of the SODA workflows is shown in Figure 3-6. The four workflows cover two phases of the system development process, the pre-study phase in which the initial ideas about the business environment and the system to be built are sketched out, and the inception phase in which are defined the end-product vision and the scope of the project. The SODA inception phase is identical to the one in RUP (Kruchten 1999).

3.4 Advantages of SODA with respect to current Design Methods

In comparison with current architecting methods (Bosch 2000)(Matinlassi *et al.* 2002), the SODA method combines forecasting techniques used for anticipating trends in technology and society, with scenario techniques used for exploring various plausible futures when developing systems architectures. The advantages of SODA method are:

- It explicitly incorporates strategic scenarios, which are useful for envisaging future requirements that are likely to be incorporated. Currently there is no method to use strategic scenarios for guiding the architecting decision-making process.

- It uses the strategic scenarios to evaluate the resulted architectural scenarios. Existing architecture evaluation methods do not take into account the possible changes to occur in the external environment.

- By involving detailed knowledge about the customer and future changes in the business environment, the SODA method provides information for making tactical decisions early in the design of the proposed architectures, also addressed in [HOF99]. It therefore provides architects with a repetitive way of developing system architectures that are more future-proof. Currently, the architecting process is very much technology focused – the customer and the business environment being often omitted from any architectural description or documentation.

Chapter 4

4 Systematic Quantitative Analysis of Scenarios' Heuristics

This chapter presents a quantitative method for scenario-driven quality, cost and risk analysis when proposing new system architectures called SQUASH (Systematic Quantitative Analysis of Scenarios' Heuristics). The method can be applied when a scenario-based design approach is adopted. It helps to articulate the relative benefits and/or disadvantages of the proposed set of architectural scenarios during the early design phases of a new system. It also provides the arguments for making informed decisions about the final scenarios on which the design can be based.

The SQUASH method focuses on the analysis of the relative benefits of the proposed scenarios in the early architecting phases of a system (Ionita *et al.* 2003) and (Ionita *et al.* 2004). It takes three main aspects of a scenario into consideration, namely its quality attributes, the risks, and the costs of implementing it.

Introduction

During the early design phases of a new system, architects are faced with a number of important questions. These questions are related to the functional, quality, and cost aspects of the system. To answer them, architects have to explore the design space of the system. One way of doing this is by investigating different scenarios and architectural design variants. The scenarios are meant to envisage the functionality and qualities of the new system, as well as its possible contexts of use; the architectural design variants are meant to explore concrete ways in which the exhibited functions and required qualities can actually be realized. Once the architect has finished exploring the design space, he or she can start to reason about the functionality and qualities that will be provided by the system.

This chapter presents a scenario-based approach for systematically analysing the quality aspects of a proposed system early during the design phases of its architecture. The approach provides the architects with the means to reason about the added value, risks and costs associated with the new system. The method implements Step 1 of the Activity 4 in the SODA method, as introduced on page 43.

4.1 SQUASH Steps

The SQUASH method consists of two phases: the information gathering phase, and the decision-making phase. Each phase consists of one or more steps, as in Figure 4-1.

The inputs of the method are the architectural and user scenarios that describe the new system architecture and the user interaction with the system, in addition to the quantifiable objectives of the stakeholders. The user scenarios complement the technical representation of the architecture by providing a short description, in natural language, of the systems, subsystems, as well as the user interaction for each of the proposed architectural options.

Concrete example of such user scenarios are given in the Appendix D. The output of the method is the quantitative assessment of all the architecture scenarios, namely how these address the quality requirements of the stakeholders, including a risk and cost assessment. The individual steps of the method are presented below in detail.

The information-gathering phase
SQUASH Step 1: Identify Stakeholders

In this step, knowledge is gathered about the different stakeholders of the system under design. The architects of the system conduct this activity. A concrete example of how this step can be carried out is given in Section 7.1 of the thesis.

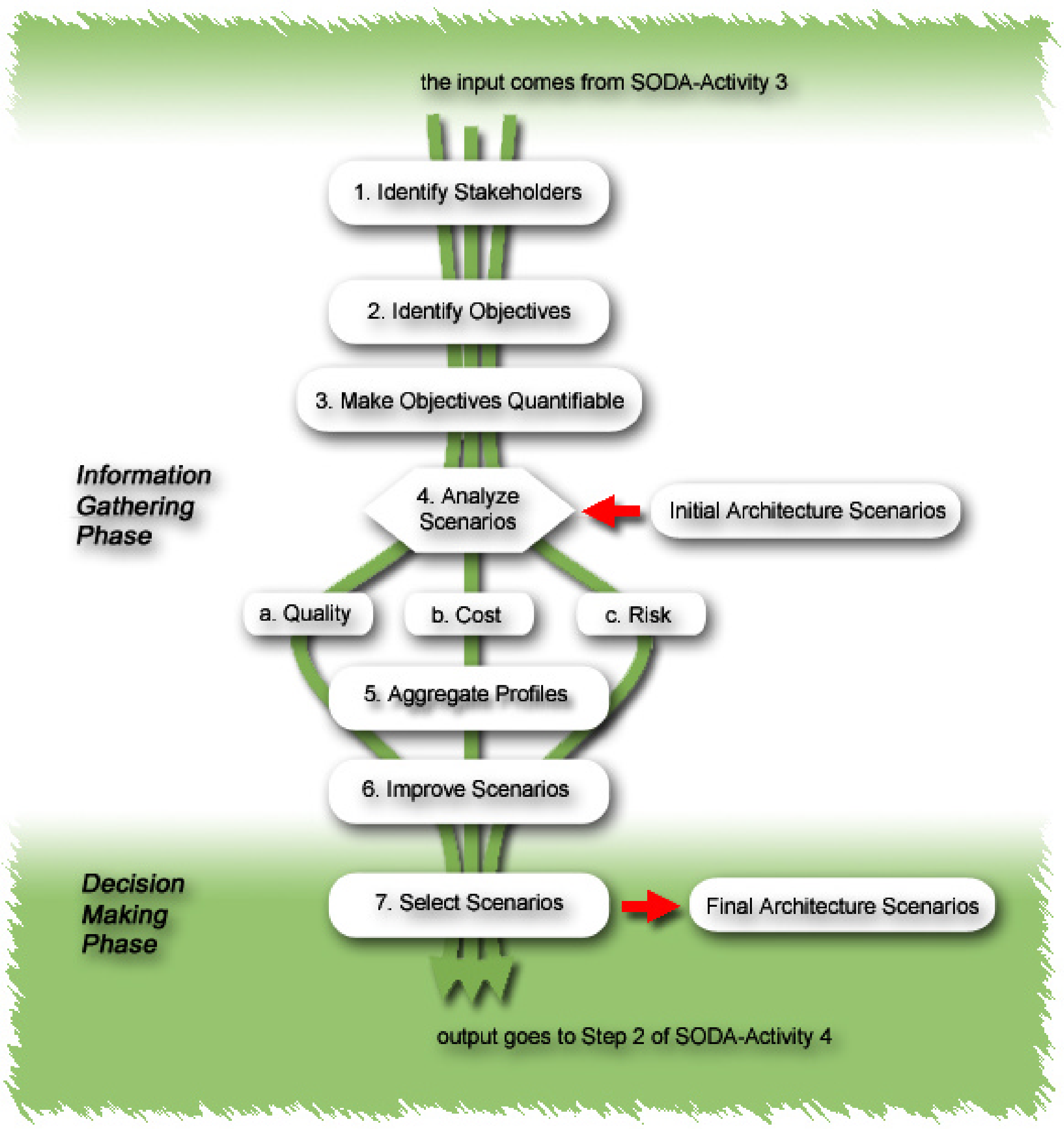

Figure 4-1: The SQUASH Method

SQUASH Step 2: Identify Objectives

In this step, the stakeholders' objectives are made explicit. The focus is particularly on their quality objectives, since these have to be considered in the early phases of the design. Neglecting the quality objectives at this stage, makes it very hard, if not impossible, to accommodate them later on when the architecture is completed. The architects identify the quality objectives by interviewing the system stakeholders. An example of how this step is carried out can be found in Section 7.2 of the thesis.

SQUASH Step 3: Make Objectives Quantifiable

In step three, the quality objectives are made quantifiable. This implies making a precise definition of each quality objective, and then associating it with a specific metric. The architects and the stakeholders perform this step together. The difficult part of this step is to get consensus on what are the relevant quality factors contributing to the achievement of a certain quality objective, and to find proper metrics for these factors. This step is usually performed in a couple of iterations: identifying quality factors and metrics, and then presenting them back to the stakeholders. This is because the stakeholders themselves have often little experience with specifying qualities, and especially in a quantitative manner. A concrete example of how this step is carried out is given in Section 7.3 of the thesis.

SQUASH Step 4: Analyse Scenarios

In step four the proposed scenarios are analysed with respect to:

a. How well they contribute to the improvement of the various quality objectives.

b. How large the costs associated with the different scenarios are, which mainly regards the development costs associated with the proposed scenarios.

c. What risks are involved, meaning looking into possible hazards that might be triggered by the different scenarios, and quantifying the magnitude of harm or loss provoked if the specific hazard occurs.

For accuracy and completeness reasons the analysis of quality factors, is performed per user scenario scene for those qualities for which the assessment view is the Application View. This means that a user scenario for example, describing the user-system interaction with the system, is split into atomic units of interaction called scenes. The quality, risk and cost analysis is performed for each of the scenes, and the obtained data is then aggregated for the whole scenario. For those factors (i.e. risks and costs) for which the assessment view is the Realisation View, the assessment is performed per sub-system, and the results are aggregated and presented per scenario.

The SQUASH method deliberately sacrifices absolute precision in order to generate estimates that are "good enough" to support the strategic decision-making process. An example of how this step is carried out is showed in Section 7.4 of the thesis.

SQUASH Step 5: Aggregate Profiles

In this step the obtained data regarding the quality attributes, risks and cost, gathered in step 4, are aggregated and presented in the form of an overview. The architects perform this step. The goal is to present this data in a way that facilitates the comparison of the benefits, disadvantages and/or consequences of the proposed scenarios. For structuring the representation of the aggregated data, and to make it easy to understand for the different stakeholders, heat maps are used. A heat map indicates by means of colours the acceptance level for a certain value. For example an unacceptable level can be indicated with red, an acceptable level can be indicated with yellow, while an excellent level can be indicated with green for the various factors being analysed. An example is given in Section 7.5 of the thesis.

SQUASH Step 6: Improve Scenarios

If the proposed scenarios envisage systems that are not be capable to meet their quality, risk and cost requirements, they are reworked in step 6. The architects perform this step.

The decision making phase

SQUASH Step 7: Select Scenarios

In the last step, possible decisions can be made based on the quantitative overview presented in step 5. These decisions regard the identification of the most suitable scenario or scenarios to be further considered in the architecture design phase. The system stakeholders perform this step.

4.2 Advantages and Difficulties of SQUASH

The advantages of the SQUASH method have been identified as follows:

- It incorporates a wide spectrum of scenario aspects in the assessment (added value, risk and cost);
- It provides quantitative analysis results, and visualizes the relative benefits of different scenarios for the decision makers;
- It creates the conditions for an informed decision-making process, to select the most suitable set of scenarios that best satisfy the stakeholders' objectives, before an elaborate architecture is designed.
- It explicitly supports the trade-off between various attributes throughout the architecting process, starting as soon as the scenarios are proposed.

The following difficulties of the method have been identified:

- Some factors (qualities, risks or costs) are hard to quantify. In this case a qualitative assessment is a possible solution.
- The method requires a considerable amount of time to collect the required data. However, once the data are collected, they can be reused in similar projects.

Chapter 5

5 The Architecture View Model

This chapter introduces the most important architecture view models, and explains in detail the model chosen for representing the architecture in our case study. It details the architectural views the model consists of, and it presents the artifacts contained in the different views. Finally, the chapter introduces the approach used in dealing with the variation, in terms of variation models and variation points.

Introduction

The architecture of a software intensive system can be also viewed as comprising the most important technical decisions about the system, where “most important” means “most difficult or costly to change”. However, the representation and documentation of these decisions is rendered by means of different architectural views. A view is the *representation or description of the entire system from a single perspective* (IEEE Std. 1471).

5.1 Existing Architecture View Models

Many authors advocate the need for multiple views. Kruchten for example, proposes a *4+1 View Model* of the architecture consisting of the following views (Kruchten 1995), (Kruchten 2000), as shown in Figure 5-1.

- the *logical* view being an abstraction of the design model of the system, describing the main subsystems, or design packages of the system,
- the *process* view capturing the concurrency and synchronization aspects of the system at run-time,
- the *implementation* view describing the organization of the software modules in the development environment,
- the *deployment* view describing how the executables and run time components are mapped to the underlying platforms, and
- the *use-case* view - illustrating the relation between the first four views by means of a few selected use-cases; the architecture being in fact discovered and designed from these use-cases.

Soni et al. proposed a similar model with the 4+1 View model, (Hofmeister *et al.* 1995). This model contains four different viewpoints of an architecture:

- the *conceptual architecture* viewpoint, describing the high-level structure of the system independent from the actual implementation details of the system (i.e. components, interfaces and connections between the components)
- the *module interconnection* architecture view point, describing the ideal implementation structure of the software into layers, independent from the programming language
- the *execution architecture* viewpoint, describing the dynamic structure of the system such as run-time elements and resource allocation issues.

- the *code architecture* viewpoint, describing the organization of the code in the development environment, such as the allocation binaries, code, libraries and executables.

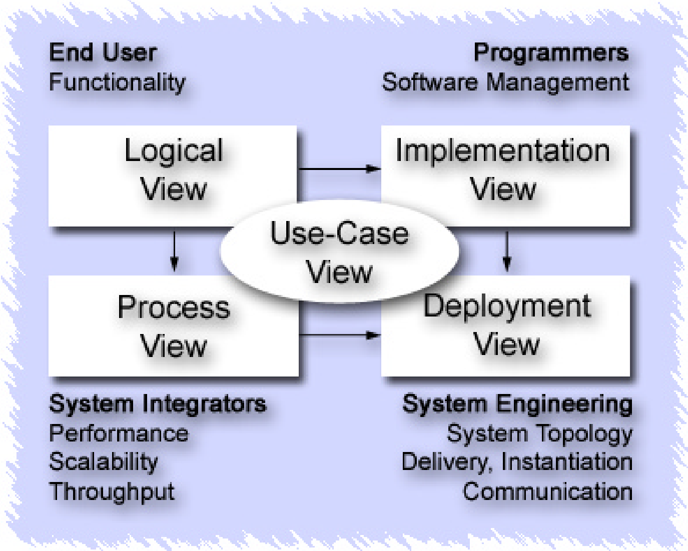

Figure 5-1: The 4+1 View Model of Software Architecture, (Kruchten 1995).

A much wider framework developed within Philips consists of five architectural views, namely Customer, Application, Functional, Conceptual, and Realization (CAFCR) (Muller 2003), (Muller 2004), (Obbink *et al.* 2000), (Obbink *et al.* 2003). Figure 5-2 shows the five views and gives some short descriptions for each of them.

The CAFCR model describes the system architecture from five different viewpoints. The Customer view presents the different stakeholders of the system, and the relation between them – focusing on the customer goals, and what the customer wants to achieve. The Application view describes how the system will help the customer accomplish his goals. The Functional view describes the externally visible properties of the system, such as features or quality attributes. The Conceptual view describes how the system works, in terms of the concepts governing the system, the different components of the system and the relation between them. The Realization view describes how the available technology is used for implementing the components of the system, and documents also the “make or buy” type of decisions.

In addition to the system structure and functionality rendered by the various architectural views, a system can be characterized also by the degree of excellence in its quality aspects, such as performance, usability, security, etc, also so-called the quality attributes of the system. According to many authors, the quality attributes of a system are enabled or constrained by its architecture (Bosch 2000), (Bosch *et al.* 2003), (Bass *et al.* 2003).

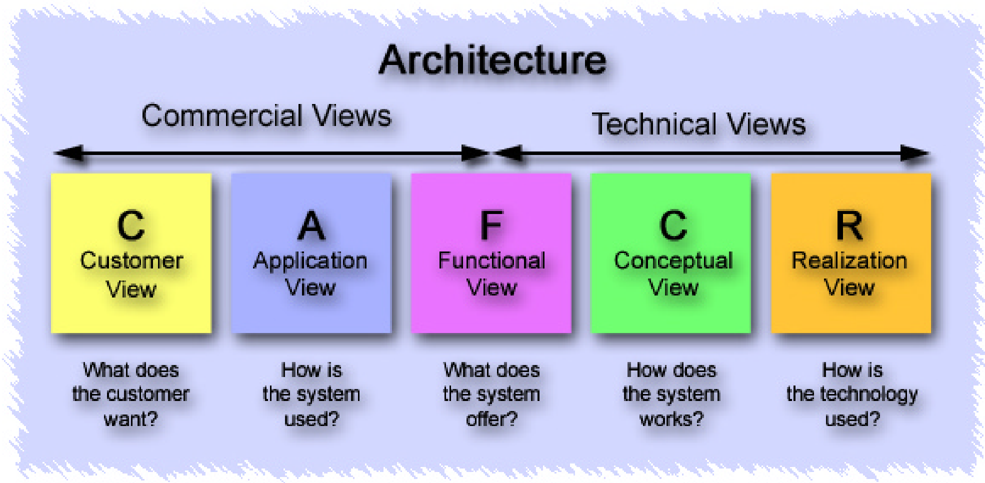

Figure 5-2: The CAFCR Architectural Views

Table 5-1 shows a comparison of the three architectural view models presented above.

Therefore, qualities should be addressed as early as possible in the architecting process because they cannot be added in a later stage. However, dealing with the quality attributes of a system is not an easy task. The modification of one quality attribute usually affects one or more other attributes. For example, improving the performance of a software system may affect its modifiability, extensibility, portability, or cost in a negative way. Therefore, dealing with quality attributes of a system sometimes involves trade-offs and compromises.

Table 5-1: Architectural View Models Compared

	4+1 View Model	Soni et al. Model	CAFCR Model
Similarity between the views	Logical View	Conceptual Architecture Module Architecture	Functional View Conceptual View
	Process View	Execution Architecture	Conceptual View
	Implementation View Deployment View	Code Architecture	Conceptual View Realization View
	Use-case View	-	Application View Functional View
	-	-	Customer View
Domain coverage	Technical	Strongly Technical	Business and Technical

Systems are developed to support specific (business or private) goals of the customers. Therefore the system architecture should be developed with a deep understanding of the customers' culture, habits, and drivers, and of the future environment in which the system has to function.

5.2 The CAFCR Architecture View Model – Explained

The Customer, Application, Functional, Conceptual and Realization framework (CAFCR) is used to evolve, describe and document the different views of system architectures. This framework has been developed within Philips. Initially introduced in (America *et al.* 2000), it is taught in architectural courses inside and outside Philips, (Muller 2003)(Muller 2004)(Obbink *et al.* 2000)(America *et al.* 2004). Each of the CAFCR views presents the system architecture from a different perspective, Figure 5-2.

The CAFCR view model was chosen to represent the architecture in our case study, because it incorporates both technical and business views to describe the architecture, as initially explained in the second paragraph of the section 3.2.4 of this thesis.

5.2.1 The Customer View

The Customer view contains knowledge about the various stakeholders of the system, such as the buyers or the users of the system. In short, this view presents by means of documents, models and/or scenarios various knowledge such as: Who are the customers? What is their business context? Who are the competitors and what are their strengths and weaknesses? What are the customers' objectives (i.e. functions, qualities and constraints), whether in business or in private life, as much as possible unrelated to a concrete system. The reason to make the customer view as independent as possible of the concrete systems is to get stimulated to think of completely different approach to meet the customer's objectives (e.g., a drug instead of a cathlab to fix heart problems). This knowledge is essential for building the right systems for the right customers. In gathering it we use expert knowledge, feasibility studies, different techniques for market research, trend analysis, customers profiling, customer segmentation, and customer scenarios.

5.2.2 The Application View

The Application view mainly contains knowledge about how the system is used. This means detailed information about the system users and their context of use, stakeholders, workflows, domain models, system requirements, etc.

5.2.3 The Functional View

The Functional view describes what the system offers in terms of functionality and quality. The various functions offered to the user by the system are referred to as external features. Qualities are also mentioned in this view but the specific knowledge to reason about them, as we will see later on, comes from other views as well.

5.2.4 The Conceptual View

The Conceptual view contains knowledge about the construction and working of a system. This is in expressed in terms of UML class diagrams, components and their relations, collaboration models, the mapping between components and the underlying platforms, decomposition models, etc.

5.2.5 The Realization View

The Realization view contains knowledge about the available technology (e.g. self-made or commercial of the shelf components), and how this technology is used to implement the system.

5.3 The CAFCR Artifacts

The CAFCR views consist of artifacts (this is a generic term for documents, models, code, etc., used among others in the Unified Process (Jacobson *et al.* 1998)). A way to do that is proposed by America et al. (America *et al.* 2004), as shown in Table 5-2. The rows on functionality, qualities, and supporting artifacts have been largely adapted from various existing architecting approaches, such as Bredemeyer Malan *et al.* 2002, Siemens (Hofmeister *et al.* 1999), RUP (Kruchten 1999), and COPA (America *et al.* 2000).

Table 5-1: Table 5-2: Artifacts in the CAFCR View Model

	Customer	Application	Functional	Conceptual	Realization
Variation	Variation models Scenarios	Variation models Scenarios	Variation models Scenarios	Variation models Scenarios	Variation models Scenarios
Functionality	Value proposition	User scenarios	Feature dictionary	System de-composition	Technology mapping
Qualities	Customer drivers	Quality requirements	Quality properties	Principles Mechanisms	Mechanisms Conventions
Supporting Artifacts	Context diagram Trend analysis PESTLE analysis Complementers-competitors analysis Market-customer segmentation and scenarios	System context Workflow context Domain model Architectural scenarios User scenarios	Feature – value matrix Feature – impact estimates	Collaboration models Information models	Collaboration estimations Supplier roadmaps

5.4 Variation Modeling

It is usual for a new system to be described by a number of scenarios. To understand the business context for which the system has to be suited, strategic scenarios are used. To explain the user-system interaction, provided functionality and quality aspects, user scenarios are used. To explain the architectural choices across the various CAFCR views, architecture scenarios are used.

When considering various possible scenarios it is important to get an overview of the commonalities and differences not only among the scenarios, but also among the various architectural responses to the scenarios. For this purpose variation models are used. A variation model is a representation of the possible options within a model. This representation can appear in form of a decision tree, workflow diagram, or activity diagram. The points representing multiple choices in such a variation model are called variation points.

An example here could be a variation model of a user interface. The user interface has a graphical part consisting of buttons and menus displayed on a screen, and a non-graphical part consisting of devices for interaction such as a keyboard, joysticks, trackball, and/or mouse. The variation model for this example can be represented as follows, Figure 5-3.

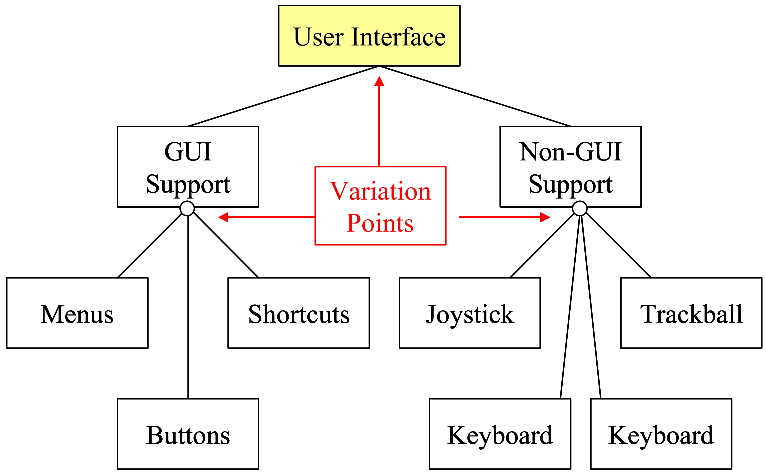

Figure 5-3: An Example of User Interface Variation Model

The approach to variation was proposed by Pierre et al. (America *et al.* 2003) and is new and specific for the SODA approach. As explained in (America *et al.* 2003), the construction of variation models is useful for:

1. "To structurally explore the variation space in the various views, and the relationships between them.

By modelling the variation space, one can quickly get a feeling of the complexity and main issues of the domain. It is relatively easy to spot gaps in a model, and to ensure that the variation space is explored thoroughly. The disadvantage is that models tend to get very large. It is essential to be practical in this respect and not to try to include everything in the domain. By using recurring elements in the models across the views, it is possible to show relationships between choices in different views.

2. To guide and document the choices that were made, as well as the options that were disregarded.

The resulting models can be used to guide decisions like, which features will the system have? What kinds of application will it support? etc. These choices can be made visible in the models, e.g. by using color/grayscales or by restructuring the models, and thus serve as documentation for the decisions taken. Because the (original) models contain the full range of possibilities considered, they also show the options that were not chosen. This can help to avoid endless reconsidering of the same options. The models do not include every detail necessary to make a decision. They are a useful tool to explore options and document decisions, but the final decision should not be based on the models alone.

3. To enhance communication and raise awareness about these choices between the architecture's stakeholders.

The notations chosen for these variation models are simple enough to be understood by anyone, regardless of their professional background. This allows stakeholders other than the architect to review or even co-create the models. For the customer view, for example, marketers or sales people could cooperate".

Techniques for modelling variation have been under development in the field of product families or product lines (vd Linden, ed. 2001), (Ferber *et al.* 2002), (Beuche et al. 2004). A product family represents the set of products which have been derived from a single architecture. However, the diversity that this variation modelling approach deals with is larger, in two ways:

- Product family development takes into account only the products that are intended to be developed. By contrast, this approach takes into account various alternatives from which only one or a few will be chosen, depending on future circumstances.

- Most existing product family development approaches concentrate on the explicit modelling of diversity in the features of the products, corresponding to the functional view in CAFCR. The above described approach, proposes the construction of variation models for the other views as well, to get a good overview of the diversity in those views and the relationships between them. Since such an overview is useful for product families as well, is proposed to follow a similar multi-view variation modelling approach for product families even without considering multiple scenarios.

The use of variation modelling for creating the architecture scenarios is described in section 6.3.1 of the thesis, (Step 3 of the SODA method).

5.5 Cross-view Relationships

Together, the CAFCR views and their artifacts sketch a more or less complete picture of the problem and solution domains. Each artifact shows the system under development from a slightly different viewpoint. The artifacts do not stand alone, but form a whole, strongly connected both across and within the views. This connection is best visible in the repeating elements across artefacts of the same and different views. Examples of such repeating elements are:

- The customer drivers are reused in the quality requirements, quality properties and feature/key-drivers matrix.
- The application variation model serves as a basis for the user scenario episodes.
- The user scenarios are a source of features for the functional variation model.

Concrete examples of cross-view relationships in the variation models are presented in the case study, starting with the next chapter.

Part Two - The Cathlab Case Study

This chapter presents the validation of the SODA and SQUASH methods in a concrete case study from the medical domain.

Introduction

The Catheterisation Laboratory, hereafter *Cathlab*, is used for the minimally invasive treatment of patients with coronary artery diseases. The coronary arteries are the blood vessels that irrigate the heart muscle. In time, they can become narrower or become totally obstructed by plaque; this can provoke a stroke or heart attack. The cardiologist uses X-rays and special contrast fluid to examine the state of a patient's coronary arteries. The contrast fluid is delivered locally using a catheter, which is navigated to the spot through a major blood artery. The catheter is positioned using *fluoroscopy*. This is done using low dose contrast fluid and low intensity X-rays to watch the progress, as shown in Figure 5-4.

Figure 5-4: The Catheterization Laboratory – The Intervention Room[2]

When the catheter reaches the heart area, the cardiologist performs an *exposure*, by inserting a high dose of contrast fluid and exposing the relevant region of the patient's body to high intensity X-rays. The exposure provides accurate images of the heart blood vessels. The accuracy is important to localize the stenosis. The X-ray images acquired are displayed on a monitor. Next, a stent is deployed via the catheter's guide

[2] Image provided courtesy of Philips Medical Systems

wire. The stent is a special thin aluminium cylinder that can be enlarged with a special balloon inside the blood vessel in order to correct the stenosis, as shown in Figure 5-5.

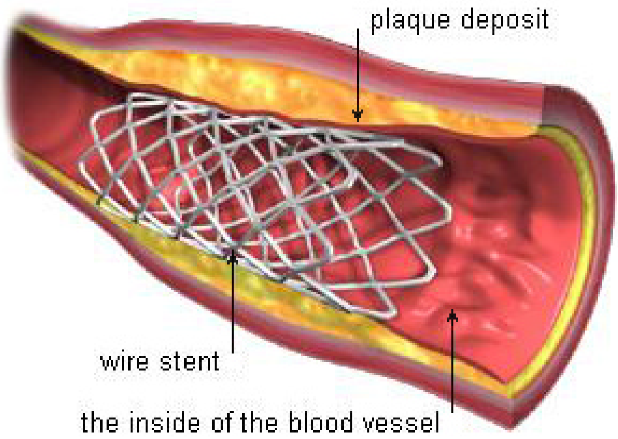

Figure 5-5: Illustration of an inflated stent as deployed inside a blood vessel[3]

During the intervention, the cardiologist uses different systems situated in the two rooms of the Cathlab. The intervention room houses the X-ray system and the patient monitoring system (Figure 5-4) while the control room houses the patient data logging system, and reviewing workstations for patient studies (e.g. magnetic resonance studies, or X-ray studies), (see Figure 5-6).

Figure 5-6: The Catheterization Laboratory – The Control Room[4]

In our case study, we examined the possibilities of integrating in the current Cathlab new features, such as:

- 3D capabilities for the existing Cathlab, in particular 3D rotational angiography (3DRA). This is a technique to construct a 3D model of the coronary arteries from a large number of X-ray images taken from different angles (3DRA 2002). Such a model can help the cardiologist to better diagnose and treat coronary artery diseases.

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[3] Image provided courtesy of Endovasc Inc.
[4] Image provided courtesy of Philips Medical Systems

Chapter 6

6 Applying the SODA Method

This chapter describes the SODA method applied to the Cathlab case study conducted within Philips Research.

Disclaimer

Although this chapter presents a case study from the medical domain in which many people from Philips Medical Systems were involved, the data presented in this study is based on information public available and is completely unrelated to any past, current, or future products of Philips Medical Systems.

6.1 SODA Step 1: Develop Strategic Scenarios

Cathlabs have a typical lifetime of ten to fifteen years. The development time for such systems can vary from one to three years. This suggests that any architecture development activity in the medical domain, which is initiated in 2004, should target a market that is two to four years ahead. Therefore, the year 2006 has been chosen as a likely time-to-market target for this case study.

For building strategic scenarios, the GBN model proposed by Schwartz et al (Schwartz 1996) is used. This model, as explained in detail in the Appendix A, starts by isolating the *focal question* which represents the key decision to be made, identifying the *driving forces* which are the key elements that would affect the decision, constructing the *scenario plot lines* and analysing their implications, and refining the scenarios by seeking yet more key elements.

6.1.1 The Focal Question

The key decision to be made regards the selection of the new features which the new Cathlab should incorporate. From this, the focal question for this case study can be formulated as: *What is the future of cardiology and how the organization should respond in order to maintain its competitive advantage?*

6.1.2 The Driving Forces

To study the future of cardiology, different types of plausible changes and trends in society, economy, and healthcare technology have to be investigated. The idea is to plot the key elements likely to impact the cardiology domain in the future, and learn from these, Figure 6-2. Based on these characteristics, strategic scenarios will be created.

In the Cathlab case study a number of elements have been identified as having an impact on the future of cardiology. These include,

- Aging of the population – a predetermined element, at least in Europe, and therefore it will appear in all strategic scenarios

- Drug eluting stents[5] – the appearance of drug eluting stents could reduce the risk of frequent re-interventions
- Drop in number of cardiac specialists worldwide – this can have a high impact on the way hospitals do business in the future (e.g. long working hours, and stress)
- Stent deployment for very small arteries – this could impact current level of accuracy of the catheterizations. Being able to deliver stents on smaller arteries will increase the number of persons requiring a catheterizations, and possible the duration of the catheterization process. rug placement in small arteries – to enable this factor, systems with higher image accuracy and higher precision mechanisms for catheter navigation are required. Current systems do not facilitate small arteries navigation. Having such an option in the future, the treatment of heart related problems will be made much easier.
- New materials reduce restenosis – this element might reduce the current rate of catheterizations, and thus the need for larger institutions.
- Cardiovascular disease is Europe's larger killer – this can be seen also as a predetermined element when building the strategic scenarios.

A method to identify key elements (e.g. predetermined elements and critical uncertainties) is the PEST method (Middleton 2003). PEST is an analysis framework used for scanning the relevant factors in the external macro-environment in which a company operates; where PEST stands for Political, Economical, Societal, and Technological. Political factors include formal and informal, legal and governmental issues under which the company should operate. Some examples of political factors are: environmental regulations, tax policies, safety regulations, competition regulations, and so on. Economical factors affect purchasing power of the company's potential customers, and the company's cost of capital. Examples of economical factors include inflation rates, economic rates, consumers' confidence, or unemployment policies. Societal factors describe the demographic and cultural aspects of the business environment that might affect the characteristics and the size of the different customer segments. Some examples of societal factors include income distribution, population growth rates, age distribution, changes in lifestyle, education, living conditions and locations, fashion hypes, and so on. Technological factors characterize the business environment in terms of expected technological progress and speed of innovation. Some examples of technological factors include technology roadmaps, rate of technological change, new inventions and developments, governmental research spending rates, etc. The PEST framework is summarized in Table 6-1.

The results of a PEST analysis are a set of factors that describe possible changes in the business environment of a company. Based on their uncertainty and estimated impact, these factors are then categorized either as predetermined elements or as critical uncertainties.

The PEST analysis conducted for cardiology domain resulted in a number of factors, which are the driving forces in building the strategic scenarios. A summary of the process of identifying the key element with PEST approach is given in Figure 6-1.

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[5] Drug-eluting stents are stents that contain drugs that potentially reduce the chance the arteries will become blocked again

Table 6-1: PEST Framework

Political	Economical	Societal	Technological
Environmental regulations Tax policies Safety regulations Competition regulations	Inflation rates Economic rates Consumers' confidence Unemployment policies	Income distribution Population growth Age distribution Lifestyle changes Education level Living conditions Fashion hypes	Technology Roadmaps Rate of technological change New inventions and developments Governmental research spending rates

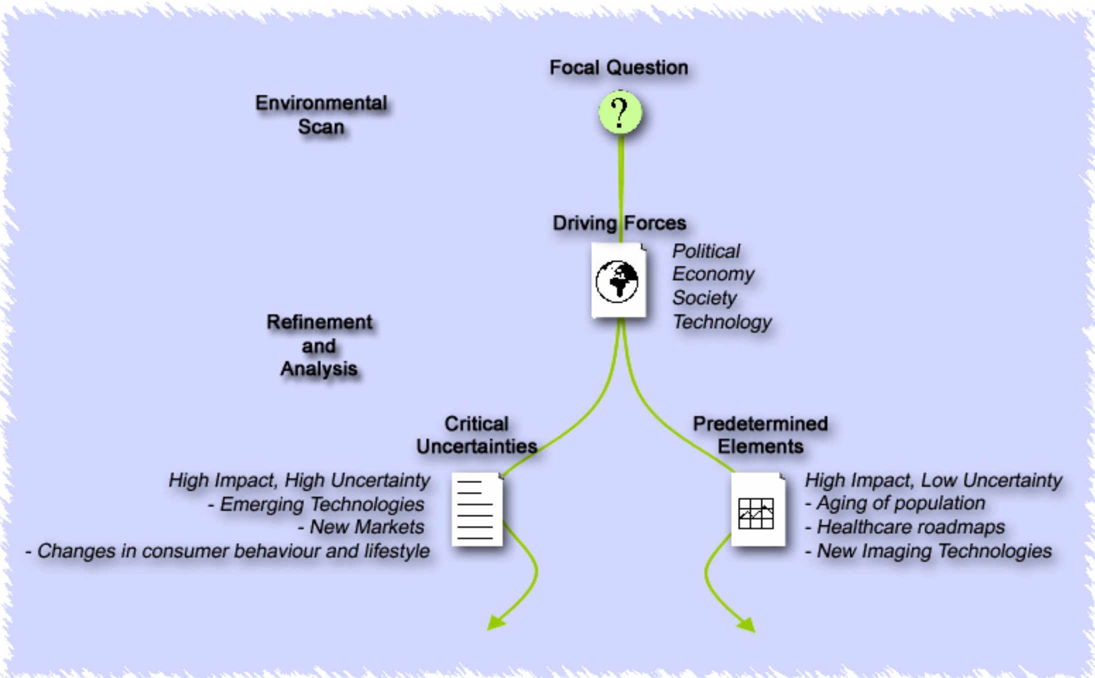


Figure 6-1: From Focal Question to Key Elements for Cardiology

Political

- Diagnostic MR, CT, or US modalities become preferred
- Drug eluting stents become the de facto standard
- Strict tobacco regulations and control policies

Economy

- Growth in cardiovascular procedures
- Hospitals provide differentiated "boutique" services
- Decline in the annual healthcare expenditure

Society

- Aging of the population
- Cardiovascular disease is Europe's biggest killer
- Drop in the number of cardiac specialists worldwide

Technology

- Patient information across different modalities (X-ray, MR) available
- Diagnosis and 3D coronary tree models with X-ray available in real time
- Stent deployment for very small arteries
- People at risk for cardiovascular diseases identified early
- Direct drug placement in small vessels
- New materials reduce the chance of restenosis

Next, the PEST factors are ranked in terms of their impact on the cardiology domain in general and their uncertainty level in terms of how likely these factors are to occur. The result of this activity is shown in Figure 6-2.

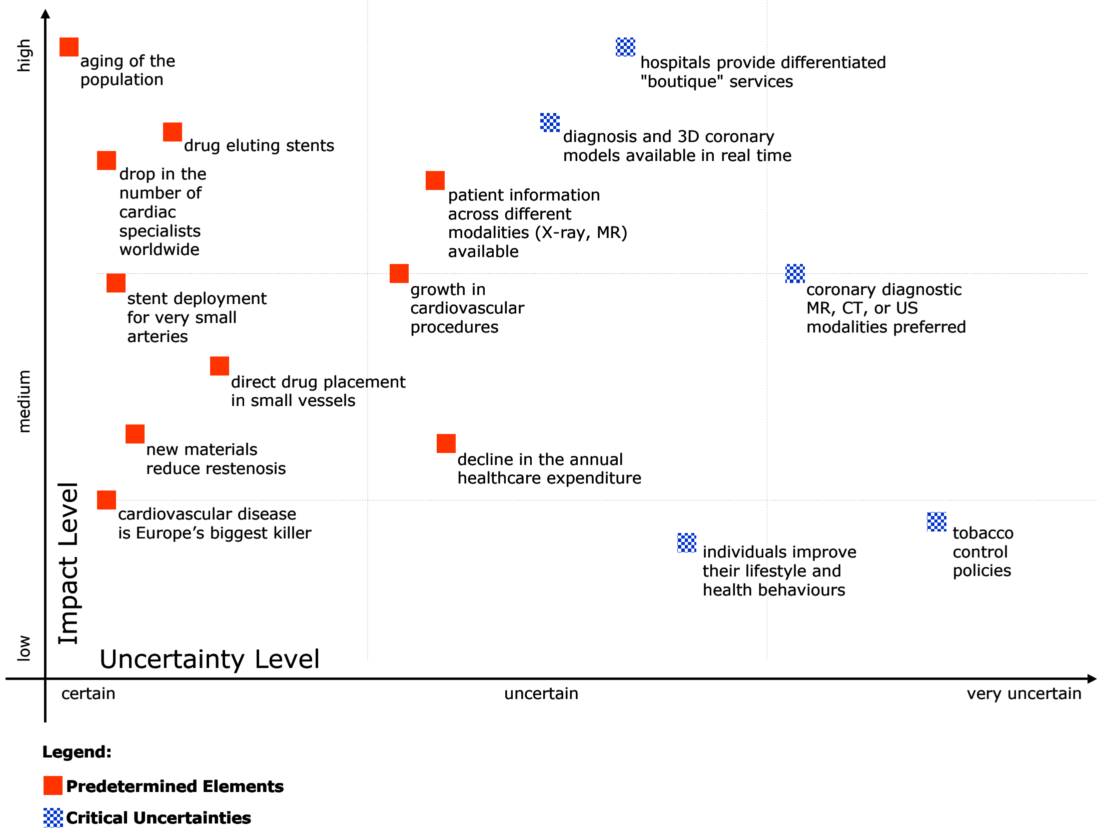


Figure 6-2: Key Elements - ranked by importance and likelyhood of occurrence

6.1.3 The Scenario Plot Lines

From here full scenario story lines are constructed, describing different futures. The strategic scenarios are intended to describe different and equally plausible futures, Figure 6-3. Therefore, each of these consists of a balanced mix of predetermined elements and critical uncertainties, Table 6-2. Within the Cathlab case study four strategic scenarios were built. Below there a short description of these scenarios is given. The full strategic scenarios appear in Appendix B, on page 145 of the thesis.

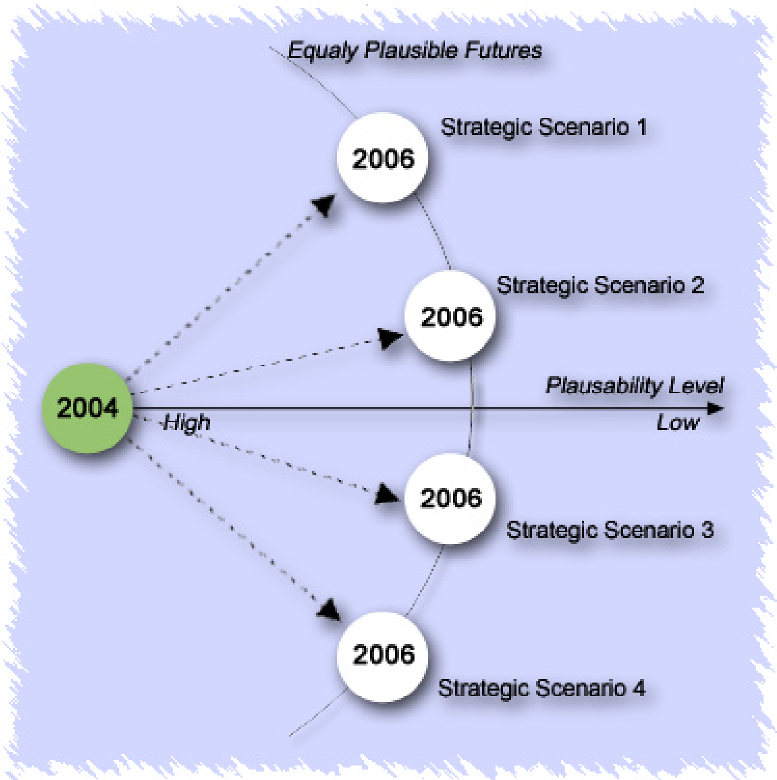


Figure 6-3: Equally Plausible Futures

- *McHealth* (S1), describing a future characterized by an aging population, slow technological advance in medicine, economic recession, and tight governmental regulations; in this type of future small clinics appear which offer standard services at low prices.

- *Clinique de Luxe* (S2), describing another future in which the economic situation is one of stable growth, but is still characterized by slow technological advance and an aging population; this type of future enables clinics to offer a larger range of services at differentiated prices.

- *See Treat Cure* (S3), describing a future in which technological advance gives rise to hospitals with better and faster imaging modalities in combination with a stable economic situation, thus enabling patients to afford more specialized and customized types of treatment.

- *Brave New Pharma World* (S4), describing a booming economic situation which fuels genomic research and technological advance; in this scenario there are clinics that offer a personalized type of treatment.

Some of the scenario titles were inspired by a similar project within Philips. The four strategic scenarios are fully described in the Appendix B.

6.1.4 SODA *Optional Step* – Identify Scenario Highlights

When strategic scenarios come from external sources, such as marketers or corporate planners, they have to be analysed by the architects in order to extract architectural relevant information. The results of such an analysis, performed for the four strategic scenarios presented in Section 3.2.2, are summarized in, Table 6-3 to Table 6-6 for strategic scenario.

Table 6-2: Scenario Matrix – building strategic scenarios with key elements

Trends in:	Scenarios:	McHealth	Clinique de Luxe	Brave New Pharma World	See-Treat-Cure
Society	Life Style	Unhealthy	Preventive	Preventive	Unhealthy
	Demographics		Aging Population		
	Patient	Governed by Strict Rules	Self Choosing	Consumer	Passive
Economy	Economy	Recession	Stable	Boom	Stable
	New Markets	Success China East Europe	Moderate West Europe US	Promising Global	Moderate West Europe US
Health Care	Pharmaceutics	Some Advance	Differentiated Prices	Drug Revolution	High Prices
	Cardiology	Tight Regulations	Patient & Doctors	Pharma World	Imaging Industry
	Insurance	Strictly Regulated	Solidarity Principle	Individualized	Individualized
Technology	Medical Technology	Low Tech	Evolution	Drug Revolution	High End Imaging
	Genomics	Slow Advance	Slow Advance	Personalized Medicine	Disease Prediction

There are a couple of reasons for which the information extracted from the strategic scenarios is important. First of all, the architecting team can get a quick and accurate overview of the highlights of a scenario. Second, these highlights can become requirements, or decision criterions, when architectural decisions are made. For example *people save money* highlight in the Society section of the McHealth scenario, creates awareness about the fact that interventions should be affordable, which means that Cathlab systems should contribute to achievement of this goal. The *only most efficient hospitals can afford to stay open* highlight in the HealthCare section of the McHealth scenario, creates awareness about the fact that efficiency (low cost per procedure and low intervention durations) are critical decision factor when hospitals acquire new Cathlab equipment. Therefore improving the efficiency of the current medical systems could become a quality requirement for the architecting team when developing new Cathlab systems.

Table 6-3: Architecture Relevant Information in the McHealth Scenario

<table>
<tr><th colspan="2">McHealth Scenario: Architectural Relevant Factors</th></tr>
<tr><td>Society:
▪ People save money.
▪ Baby boomers retire.
▪ Fewer computer scientists.
▪ Fewer cardiologists.</td><td>Economy:
▪ Fewer tax payers.
▪ Lower subsidies.
▪ Economic Recession.</td></tr>
<tr><td colspan="2">HealthCare:
▪ Hospitals prefer to maintain existing Cathlab systems.
▪ Increasing demand for healthcare services.
▪ Better drug treatment available only for the rich.
▪ Only most efficient hospitals can afford to stay open.
▪ Fast treatment clinics offer boutique services.
▪ Interventional cardiac MRI and CT only for the rich.
▪ Success assured by reducing the costs.
▪ Poorly insured CAD patients receive standard treatment.
▪ Fast clinics successful in Asia and Eastern Europe.
▪ Investments in information management systems.
▪ Accuracy less important.
▪ People react to diseases, no preventive behaviour yet.
▪ For premium customers Siemens and GE introduce, MRI.</td></tr>
<tr><td colspan="2">Technology:
▪ Microsoft is still dominant.
▪ 10GHz processor is usual.
▪ Sufficient computing power for real time MRI. - Microsoft OS is dominant.</td></tr>
</table>

Table 6-4: Architecture Relevant Information in the Clinique de Luxe Scenario

<table>
<tr><th colspan="2">Clinique de Luxe Scenario: Architectural Relevant Factors</th></tr>
<tr><td>Society:
▪ Around 40% of the people earn more than €50.000 per year.
▪ People use the Internet to learn about the best clinics, insurance services, and reimbursement options.
▪ People demand the best from the health care clinics.
▪ The poorly uninsured patients benefit from solidarity principle.</td><td>Economy:
▪ Stable economical situation.
▪ Profits are made from offering expensive and sophisticated services, ranging from simple screenings to multi-modality diagnosis and CAD treatments.
▪ “De Luxe” clinics have low acceptance in the former Eastern Europe; the standard services are preferred.</td></tr>
<tr><td colspan="2">HealthCare:
▪ Possible personalized treatments are years away form large-scale deployment.
▪ Better drug treatment available for CADs but only for richest.
▪ Hospitals opened “de Luxe” cardiology clinics and equipped them with the latest technologies for diagnosing the CAD.
▪ Web-based forums and health care focus groups for a second opinion.
▪ Drug eluting stents are the de facto standard.
▪ Fierce competition among the top medical systems manufacturers.</td></tr>
</table>

Technology: ▪ The success of the multi-modality high-end medical equipment in these countries was limited to the few rich. ▪ Real time video communications on affordable devices between cardiologists. ▪ Microsoft still dominant on the consumer market of operating systems. ▪ Large companies and medical applications use Linux. ▪ India and China move away from the Microsoft dominance, going Linux. ▪ 3D model reconstruction and navigation of the heart performed in real time.

Table 6-5: Architecture Relevant Information in the Brave New Pharma World Scenario

Brave New Pharma World Scenario: Architectural Relevant Factors	
Society: ▪ Educated patients. ▪ More and more can afford expensive treatment.	**Economy:** ▪ Booming economical situation. ▪ Profit made from molecular imaging services, ranging from simple screenings to personalized drug therapies for dealing with CAD. High impact in Asia and Eastern Europe.
HealthCare: ▪ Era personalized treatments. ▪ Hospitals acquire the latest technologies for molecular diagnosis. ▪ Cardiologists monitor the health state of their patients remotely. ▪ Patients have once in a while a blood test. The results are sent to their cardiologist ▪ Drugs can be delivered locally to the heart by means of minimally invasive techniques. ▪ Catheter implantation became obsolete. ▪ Healthcare evolved from treatment to prevention. ▪ Internet used to learn about the best clinics, insurance services and government compensation schemas.	
Technology: ▪ Real time video communications on affordable devices. ▪ Clusters of supercomputers are used for molecular diagnosis. ▪ Linux more preferred than Microsoft OS.	

Table 6-6: Architecture Relevant Information in the Brave New Pharma World Scenario

Brave New Pharma World Scenario: Architectural Relevant Factors	
Society: ▪ US signalled over 100.000 cases of paediatric CAD. ▪ Baby boomers retire, and less cardiologists.	**Economy:** ▪ Stable economical situation brings confidence and comfort. ▪ Expensive CAD drug treatment. ▪ Molecular imaging has some impact in Asia and the Eastern Europe.

HealthCare: ▪ Molecular imaging provides functional and anatomical information about the different types of CADs. ▪ Screenings and diagnosis for CAD on single multi-modality machine. ▪ Web-based forums for cardiology. ▪ Poorly insured patients get X-ray.
Technology: ▪ Clusters of supercomputers for computing the data resulted from molecular imaging and diagnosis. ▪ GE and Siemens go Linux. ▪ China and India move to Linux, away from Microsoft dominance.

6.2 SODA Step 2: Propose Business Strategies

After scouting the different futures to understand their possible consequences and impact on the current Cathlab systems, specific business strategies need to be developed. In order to come up with reasonable strategies, a more detailed understanding is required of the possible changes within the Cathlab market segments. This regards both the Cathlab customers (i.e. hospitals and clinics), and their customers (i.e. the patients).

6.2.1 Patient Segmentation

Statistics showed that in 2001 about 2.365.000 cardiac catheterisations and angioplasty procedures were performed in the Unites States alone, with an average growth of about 5% per year, (AHA Report 2004). By extrapolating this information, one could learn that in 2006 the number of CAD (Coronary Artery Disease) interventions is expected to increase to 3.000.000 procedures per year.

The CAD growth is considered for two reasons, first to anticipate the future patient load for our customers, and second to anticipate its possible implications. Moreover, the preferences and objectives of the different types of CAD patients are studied, so that appropriate type of treatments could be proposed for each patient segment. To structure this analysis a patient segmentation is performed. The characteristics of each segment are described with so-called patient scenarios.

Four such patient segments are identified. These are described by means of a couple of scenarios, as follows. For a detailed version of these scenarios see the Appendix C.

- *The Minimalist Segment* – this type of patients are interested in fast and standard CAD treatment, with high accuracy, good treatment outcome, at a low price.

- *The BioMed Segment* – this type of patients are also interested in standard, accurate and low price CAD treatment, but unlike the Minimalists, the BioMeds like to have all kinds of gadgets at home, such as devices for measuring blood pressure, cholesterol level, sugar level, stress level, weight, etc. They have a more preventive attitude towards the CAD disease.

- *The Modernist Segment* – this type of patients can afford a higher quality of treatment. Modernists require more advanced diagnosis technologies. However, they do not pay much attention to CAD prevention.

- *The Premium Segment* – this type of patients are the top customers of the Cathlab. Premiums are interested in accurate and personalized CAD diagnosis and treatment.

Based on market studies, the size of the different patient segments is quantified for each strategic scenario. The idea is to have an approximate value for the size of the different segments in each strategic scenario. For the Cathlab case study such estimates are presented in Table 6-7. It was not easy to come up with these judgements. Therefore it took a couple of iterations and domain experts' involvement before the final figures could be agreed upon. The estimates will be used when the relative benefits of the proposed systems in the different strategic futures is calculated.

Table 6-7: Estimates of the Size of the Different Patient Segments

Strategic Scenario (s_m)	Patient Segment (p_k)			
	Minimalist	**BioMed**	**Modernist**	**Premium**
Mc Health	🧍🧍🧍🧍🧍	🧍🧍🧒	🧍🧒	🧍
Clinique de Luxe	🧍🧍	🧍🧍🧍🧍🧍	🧍🧒	🧍🧒
See Treat Cure	🧍🧍	🧍🧍	🧍🧍🧍🧍🧒	🧍🧒
Brave New Pharma World	🧍	🧍🧍🧍🧒	🧍🧍🧍	🧍🧍🧒

where, 🧍 = 300,000 patients, and 🧒 = ½🧍.

6.2.2 Customer Segmentation

According to the American Heart Association (AHA Report 2004), in the United States there are currently 1,774 healthcare institutions offering angioplasty and catheterisation services.

Looking at the landscape offered by the strategic scenarios, and the patient scenarios, one could observe over time the following phenomena. Economic recession or slow growth, combined with slow or modest technological advance, impose the need for two types of healthcare institutions:

- *mass treatment hospitals*, offering standard CAD treatment services, and thus requiring efficient Cathlab systems for supporting high patient throughput.
- *specialized clinics*, offering higher quality of treatment and comfort for the CAD patients. In this type of clinics high patient throughput is not a big issue.

The distribution of the patient types per healthcare institution type is estimated based on the market studies and information provided by large healthcare institutions. For the Cathlab case study the following estimates will be used, Table 6-8. It is important to remind the reader that these estimates should not be interpreted as hard figures, therefore the standard deviation for these estimates was not considered. It was already difficult enough to gather all these estimates, let apart their deviation. These estimates were good enough to illustrate how to this step of the method is carried out.

Table 6-8: The Distribution of Patients per Healthcare Institution

(p_k)	Mass Treatment Hospitals (h)	Specialized Clinics (c)
Minimalist	97%	3%
BioMed	79%	21%
Modernist	55%	45%
Premium	25%	75%

Based on the data from Table 6-7 and Table 6-8, the number of patients h and c is calculated per type of institution, for all customer segments (p_k) by Formula 6-1 and Formula 6-2 in all strategic scenarios s_m (m = 1 to 4).

Formula 6-1: $$h(s_m) = \sum_{k=1}^{4} h(p_k) * p_k(s_m)$$

Formula 6-2: $$c(s_m) = \sum_{k=1}^{4} c(p_k) * p_k(s_m)$$

The resulted data is shown in Table 6-9.

Table 6-9: Estimated Number of Patients per Year

Strategic Scenario (s_m)	**Mass Treatment Hospitals (h)**	**Specialized Clinics (c)**
Mc Health	2.370.000	630.000
Clinique de Luxe	2.127.000	873.000
See Treat Cure	1.911.000	1.089.000
Brave New Pharma World	1.803.000	1.197.000

To calculate the number of Cathlab systems required per institution, in each strategic scenario, the following assumptions are made. For the mass treatment hospitals, the Cathlab throughput is in average as much as 500 patients per year, while for the specialized clinics the throughput is 250 patients per year.

Based on Table 6-9, the Cathlab expected Cathlab market size is calculated for each strategic scenario by Formula 6-3 and Formula 6-4.

Formula 6-3: $$LCL(s_m) = \frac{h(s_m)}{500}$$

Formula 6-4: $$HCL(s_m) = \frac{c(s_m)}{250}$$

The results of these calculations are summarized in Table 6-10.

Table 6-10: The Expected Cathlab Market Size [systems per year] per Strategic Scenario

Strategic Scenario (s_m)	Low-end Cathlabs (LCL)	High-end Cathlabs (HCL)
Mc Health	4.740	2.520
Clinique de Luxe	4.254	3.492
See Treat Cure	3.822	4.356
Brave New Pharma World	3.606	4.788

The replacement rates rr_{LCL} for the low-end and rr_{HCL} for the high-end Cathlabs is different in each strategic scenario. Here the following replacement rates are considered, Table 6-11.

Table 6-11: Yearly Cathlab Replacement Rates

Strategic Scenario (s_m)	For the LCLs (rr_{LCL})	For the HCLs (rr_{HCL})
Mc Health	10%	15%
Clinique de Luxe	15%	20%
See Treat Cure	15%	20%
Brave New Pharma World	20%	25%

The number of existing Cathlabs on the market is currently estimated at 3200, in a constant growth of 5% per year. Out of these $^2\!/_3$ are Low-end Cathlabs (LCLs) for mass treatment hospitals, and $^1\!/_3$ are High-end Cathlabs (HCLs) for specialized clinics, we can calculate with Formula 6-5 and Formula 6-6 the total market size for the new low-end Cathlabs (TM_{LCL}), and new high-end Cathlabs (TM_{HCL}) required for 2006 as the difference between the total number of required Cathlabs, and the existing number of Cathlabs – corrected with the growth and replacement rate coefficients.

The resulted data is shown in Table 6-12, and visually plotted in Figure 6-4.

Formula 6-5:

$$TM_{LCL}(s_m) = LCL(s_m) - \frac{2}{3} * 3200 * (1+0,05)^{(2006-2004)} * [1 - rr_{LCL}(s_m)];$$

Formula 6-6:

$$TM_{HCL}(s_m) = HCL(s_m) - \frac{1}{3} * 3200 * (1+0,05)^{(2006-2004)} * [1 - rr_{HCL}(s_m)];$$

Table 6-12: The Estimated Total Cathlab Market Size for 2006, expressed in number of Cathlabs

Strategic Scenario (s_m)	Total low-end Cathlab market size **TM_{LCL}**	total market size for the high-end Cathlabs **TM_{HCL}**
S1	2.623	1.520
S2	2.255	2.551
S3	1.823	3.415
S4	1.724	3.906

6.2.3 The Business Strategies

In order to be able to formulate sound business strategies, the data obtained so far with respect to market trends, customer needs, and projected demand for Cathlabs, should be interpreted. This was done as follows.

In the McHealth strategic scenario (S1) there is a high demand of low-end Cathlabs focusing on the throughput optimization and the reduction of the cost of intervention, Table 6-12. The key drivers in such a strategic scenario are efficiency and low cost of intervention, for both the healthcare providers (i.e. hospitals, or clinics) and the healthcare consumers (i.e. patient). These conclusions are partly valid also for the Clinique de Luxe strategic scenario (S2), where one can observe still a high demand of efficient Cathlabs, complemented however by more specialized type of Cathlabs to suit the needs of the high-end customers. In the See Treat Cure scenario (S3), and the Brave New Pharma scenario (S4), one can observe a drop in the need for standard Cathlabs, and a huge increase in the number of specialized Cathlabs offering personalized treatment, better imaging techniques at a higher cost per intervention, Table 6-12. Based on these observations, a couple of conclusions can be drawn

- First, a *standardization strategy,* which focuses on producing efficient low-end Cathlabs with standard functionality, improved workflow, and low intervention costs.
- Second, a *customisation strategy,* which focuses on producing specialized high-end Cathlabs that support personalized treatment, higher quality of care, and higher imaging accuracy.

These two strategies are used to guide the architectural options creation process.

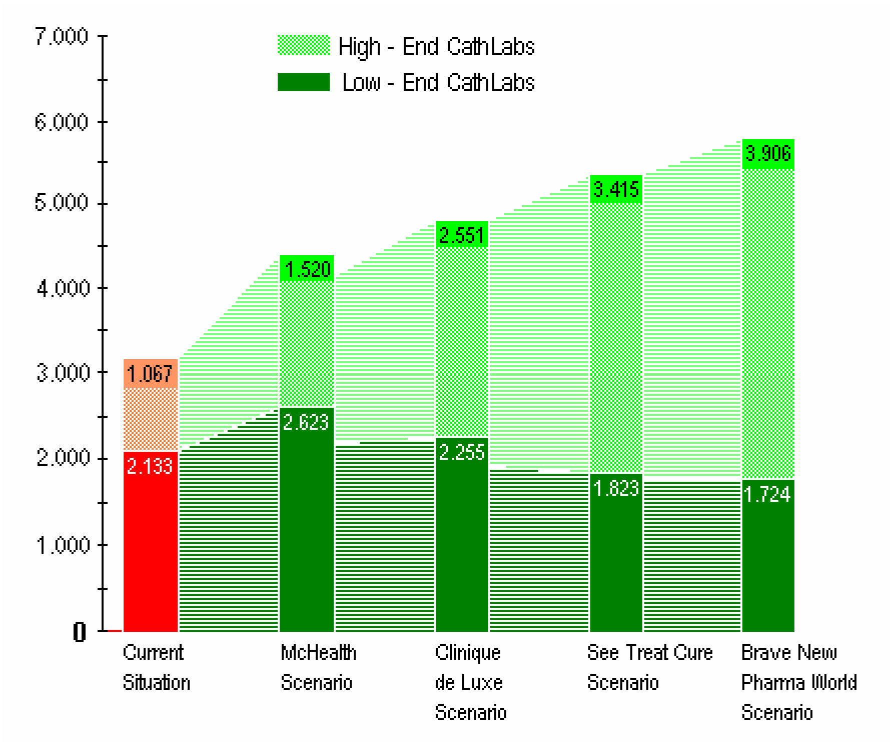


Figure 6-4: Estimated Cathlab Total Market Size in 2006

6.3 SODA Step 3: Design Architecture Scenarios

In this step, possible architecture options are investigated. These are intended to help in successfully implementing the two business strategies proposed in step three.

To implement the standardization strategy, a first architectural option would be to focus on optimising the workflow of the current Cathlab with respect to issues like intervention duration, intervention cost, personnel involved, and image reconstruction duration. This option aims at satisfying the requirements of the mass treatment type of hospitals. A second option is to focus on improving the intervention accuracy offered by the existing Cathlab, however cost efficient. These options target mainly the lower customer classes, such as the Minimalists and BioMeds.

To implement the customisation strategy, which targets the higher classes of customers, such as the Modernists and Premiums, an architectural option is to focus on the improvement of softer quality attributes of the Cathlab, namely the quality of care, and the accuracy of CAD treatment. The aim is to integrate in the current Cathlab interventional technologies, which do not necessarily improve on workflow optimization, or keep the interventional costs at a low level, but which can help the cardiologists to offer specialized services for each type of cardiac disease, and especially more personalized treatment for different types of patients, age groups, or stages of the disease. For this purpose, the availability of magnetic resonance imaging (MRI) data is considered.

6.3.1 Variation Modeling

The architectural viewpoint model considered in this case study is the CAFCR model, see Chapter 5.2. This model was chosen for a couple of reasons, namely:

- it allows the presentation of both technical and business information relevant for representing and documenting the architecture,
- CAFCR builds on top the knowledge contained in the previous models such as 4+1 View Model, Soni, or Bredemeyer,
- the people involved in this case study were already very familiar with the model, and therefore easier to use CAFCR than other model.

In this step are described the possible set of choices for each of the identified architectural options. For representing these options from different viewpoints, variation models are used, as proposed by America et al. (America *et al.* 2004) and explained in Chapter 5.2. The variation models are built for each of the CAFCR views. Within each variation model the possible architecture scenarios are then presented. The reasons for using variation models were are as follows.

- To structurally explore the variation space in the various architectural views, and the relations between them,
- To guide and document the choices that were made, as well as the disregarded choices,
- To enhance communication and raise awareness about these choices among the architecture's stakeholders.

6.3.1.1 The Customer Variation Model

The customer view is intended to capture knowledge about the customer. Such knowledge is initially gathered by means of scenarios, marketing studies, or expert knowledge. The customer variation model presents the customer of the Cathlab, here after identified as the Cardiology Department and the variation points around it. For this purpose UML stereotypes are used, specifying the choices that can be made at each point, Figure 6-5.

For the Cathlab case study, the following variation points have been identified:

- Organization Type, which can be either the large hospitals or small private clinics.
- Complexity, which can be standard – representing routine procedures for high volume treatment, or specialized – representing procedures more academic in nature.
- Purpose, which can be CAD diagnosis, CAD general treatment based on standard procedures, or CAD personalized treatment based on specific procedures using expensive but more accurate cardiac care technologies.
- Procedure Type, covering the different cardiac procedures, such as angiography, or electro-physiology.
- Modalities, describing the different technologies available for the cardiology department, such as X-ray, magnetic resonance imaging (MRI), or ultrasound (US).

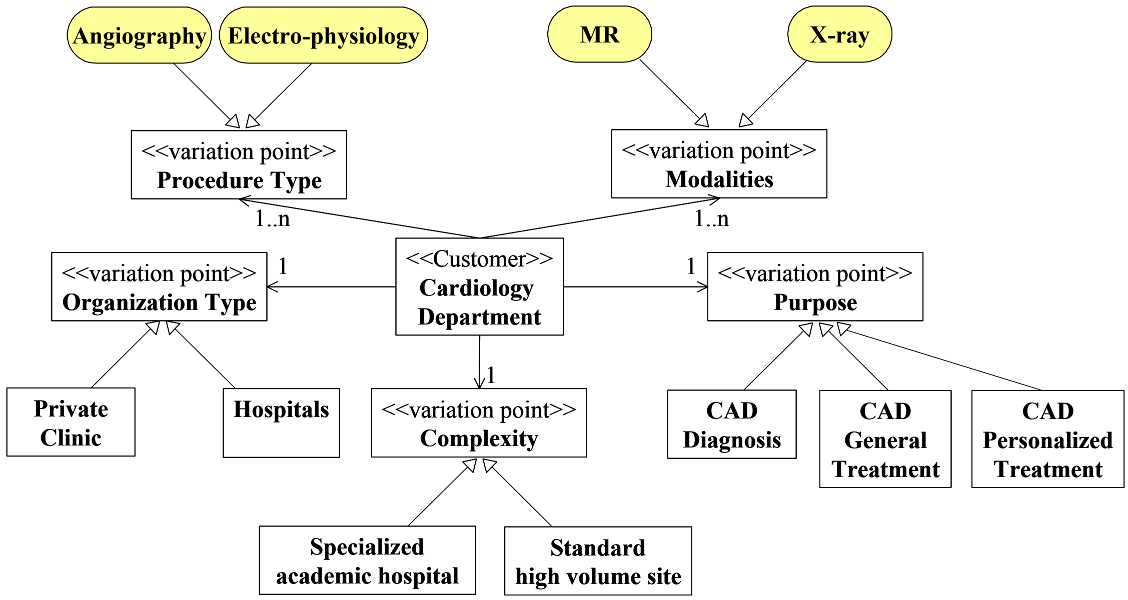
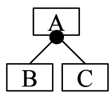


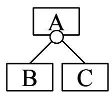
Figure 6-5: The Variation Model in the Customer View

6.3.1.2 The Functional Variation Model

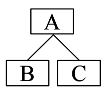
The variation modelling activity continues with the functional view, because it is closely related to feature modelling approaches for product families. The functional variation model gives an overview of the features relevant for the new Cathlab. As graphical representation, a tree model is used. The notation used in this model is as follows:



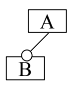
Represents the multiplicity relation (if feature “A” is chosen, at least one of the sub-features “B” or “C” must be chosen as well).



Represents the alternation relation (exactly one of sub-features “B” or “C” must be chosen).



Represents the obligatory relation (all sub-features “B” and “C” must be chosen).



Represents the optional relation (the sub-feature B is optional).

The variation model for the functional view charts the possible features, which the existing Cathlab can be enhanced with. The features to go in the functional view variation model are extracted directly from knowledge about previous systems and the new features introduced by the new user scenarios of the system.

For this case study, the new features introduced by the user scenarios are:

- An invisible *picture archiving and communication system* PACS, which is a caching mechanism of the data available in the external PACS onto the X-ray machine prior the intervention. Optional 3D controls for manipulating the images can be made available.

- The capability to display 3D models onto the *reference monitor* (RM), previously stored in the PACS.
- The capability to display on the reference monitor in the *intervention room* (IR) magnetic resonance (MR), images, which have been previously acquired with the respective modality and stored on the PACS. The MR can be reviewed in two ways: slices, or *maximum intensity projections* (MIP).
- The capability to synchronize the hemodynamic information with the heart beat, display the hemodynamic waves on the *live monitor* (LM), and/or offer the capability of performing the hemodynamic measurements from the *intervention room* (IR).
- The diagnostic MRI as a safer way of conducting the diagnostic operations. For the diagnostic MRI, the 3D rendering feature, and motion, stain and blood flow visualization would be a plus. The diagnostic MRI would offer image sequencing features, monitoring features for the cardiac functional parameters, and morphological information.
- The 3DRA feature incorporated in the existing Cathlab, and using for this purpose a faster reconstructor. The 3D reconstruction could be generated automatically, progressing with the same speed as the cross sections are acquired, and the results could be made available in the intervention room as well as in the control room of the Cathlab.

To chart the possible choices, a variation model is created for the functional view. This model is shown in Figure 6-6. About the notation used in this figure, the boxes represent software components implementing new features.

6.3.1.3 The Application Variation Model

The application variation model contains instead of features, the actions to be taken in order to accomplish the different tasks in the Cathlab. For this model the following notation is used: rounded rectangles corresponding to the UML notation for activities. The model shows the relation between the different activities, using for this purpose the same notation as in the previous section, and not the sequence in which these are performed.

The application variation model captures only the main activities performed in the Cathlab. This is because a complete model covering all the activities would become too large, and not completely useful for the purpose of the case study.

The Cathlab is used for two main purposes: diagnosis of the CAD related diseases, and interventions in case of sever CAD cases. In case of diagnosis, the cardiologist is interested in assessing the existence, or evolution of the CAD. This can be done using X-rays, or MR technology. In case of intervention, this can follow a standard procedure type using X-ray technology and standard drug treatment, or it can be improved by introducing more personalized type of treatment using MR.

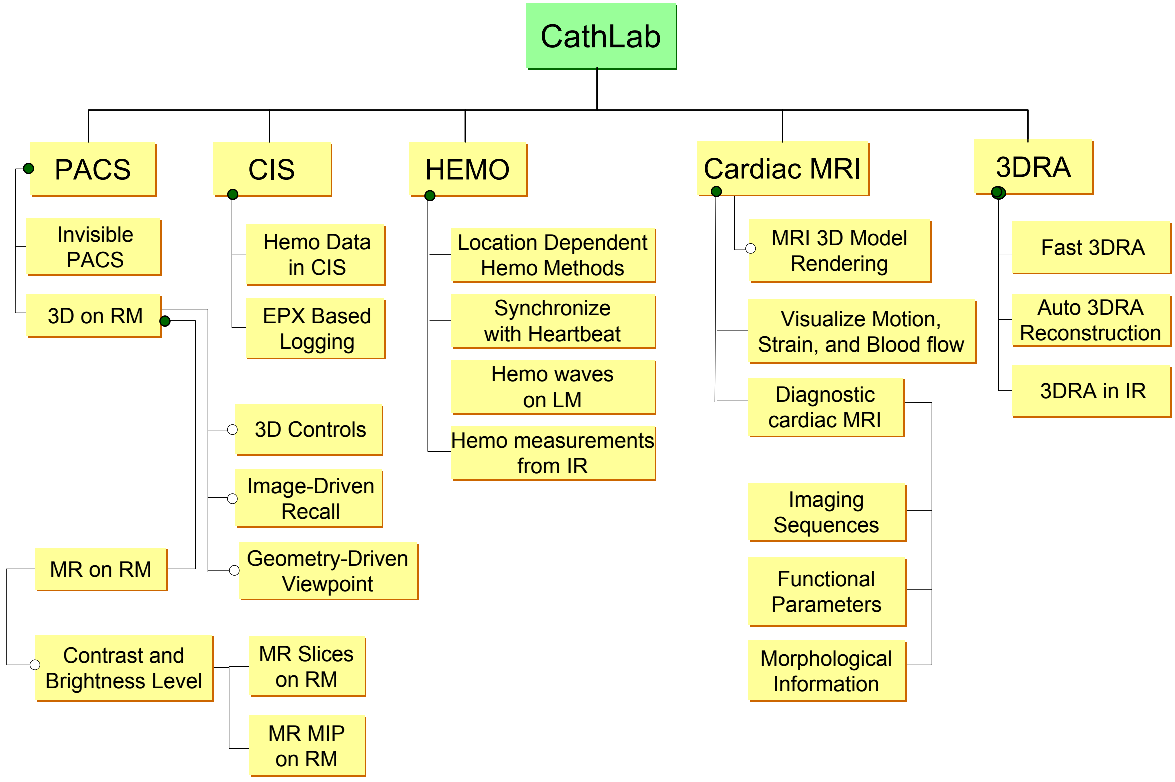


Figure 6-6: The Variation Model for the Functional View

The choices in the application view are charted in Figure 6-7. Having represented these choices, it is now possible to link the elements of the application variation model to the ones of the functional variation model.

For example the Electro-physiology or the Angioplasty activity (Figure 6-7) would require a Cathlab equipped minimally with an X-ray workstation connected to the CIS and PACS. However, if the goal is to improve the efficiency of the Cathlab, it would be highly recommended to implement the invisible PACS feature, with fast 3DRA, and 3DRA in the intervention room.

The activities Assess Stenosis, and Assess CAD Evolution (Figure 6-7), can be usually performed using the X-ray system. For more specialized and personalized treatment, the MRI technology could be used. Features such as 3D Model Rendering, Motion, Strain, and Blood Flow Visualization, or displaying the Morphological Information and monitoring the Functional Parameters, can be implemented.

As one can notice there are many ways of choosing and respectively mapping the envisaged features onto the activities performed in the Cathlab. These choices in the various views have to be: (1) reasonable, in the sense that a very complex activity shouldn't be assigned to a standard treatment Cathlab systems, and (2) consistent with the choices made in the other views – for example the private clinics will look for Cathlabs with an improved accuracy, while the mass treatment hospitals will focus on efficiency and cost reduction thus preferring the standard technologies and better workflows.

These consistent sets of choices across the various architectural views are called *architectural scenarios*, (America *et al.* 2004).

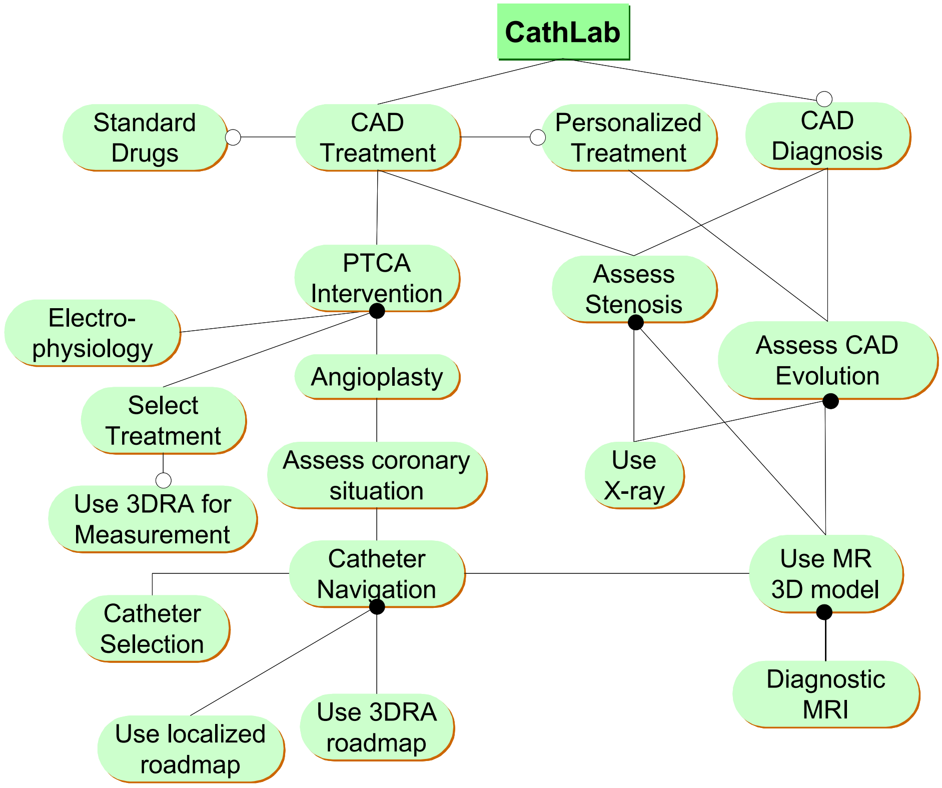


Figure 6-7: The Variation Model in the Application View

6.3.1.4 The Conceptual Variation Model

The conceptual variation model describes the internal features of the system, which are not observable from the system's behaviour alone but have to do with the way the system is designed. Sometimes a single variation model may become too complex to chart all the possible choices in one diagram. In practice it was noticed that is easier to construct a couple of these models per view, where necessary.

Figure 6-8 shows the conceptual variation model for the Workflow Optimisation Scenario. The letter "F" is used to depict the relation between this model and the one in the functional view. For example the Invisible PACS feature (from Figure 6-7) will require an internal synchronization mechanism between the PACS and the X-ray system, which in turn will require access to 3D volumes via network or locally stored.

For designing the Fast 3DRA feature, a real time image reconstructor is required. Currently the 3D model is reconstructed after all the 2D images have been received. The real time reconstructor could be implemented in software or hardware, and would be responsible for the construction of 3D models as soon as the first 2D image is received. Such a 3D reconstruction could save the cardiologist time, by cutting off the unnecessary exposures in case a wrong acquisition has been initiated. For having the 3DRA model available in the intervention room, a portable or real time reconstructor is required, having the capability of displaying 3D volumes on the reference monitor.

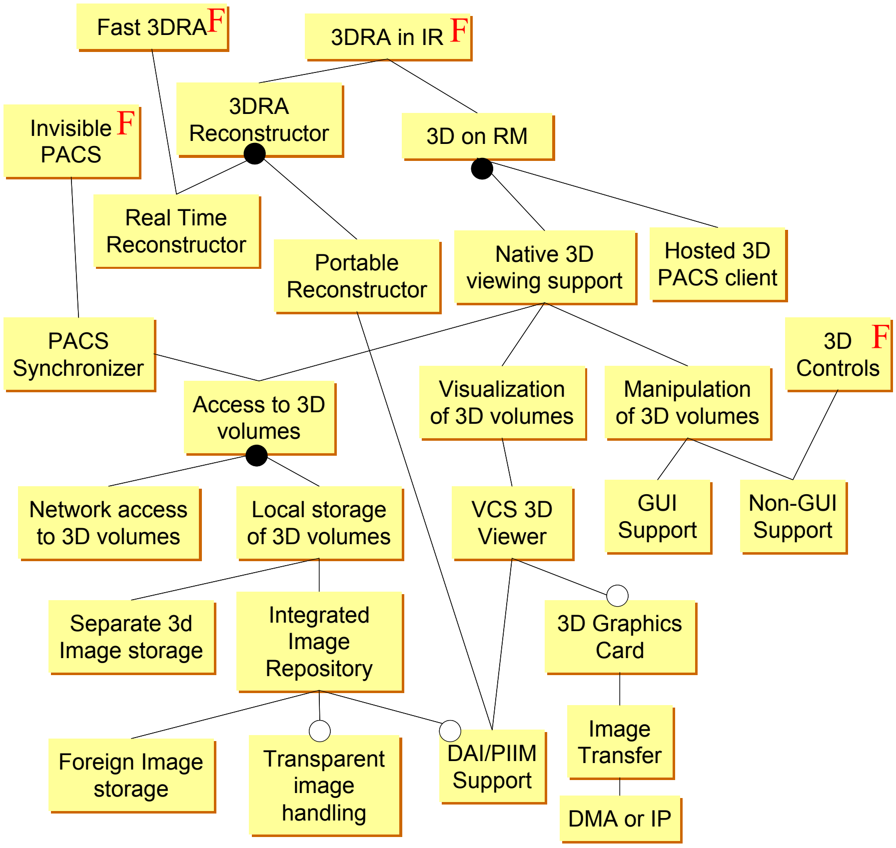


Figure 6-8: The Variation Model in the Conceptual View Workflow Integration Scenario

6.3.1.5 The Realization Variation Model

The realization view shows how the different architectural concepts can be mapped onto the existing technology. Figure 6-9 presents such a variation model for the Realization View. The Local 3DRA, and the 3D Controls features coming from the Functional View require (1) a conceptual feature called 3DRA Reconstructor, which can be implemented using the workstation's existing processor or a dedicated one, and (2) the Non-GUI support for image and 3D model manipulation, which can be implemented using a joystick, a trackball, or some proprietary hardware.

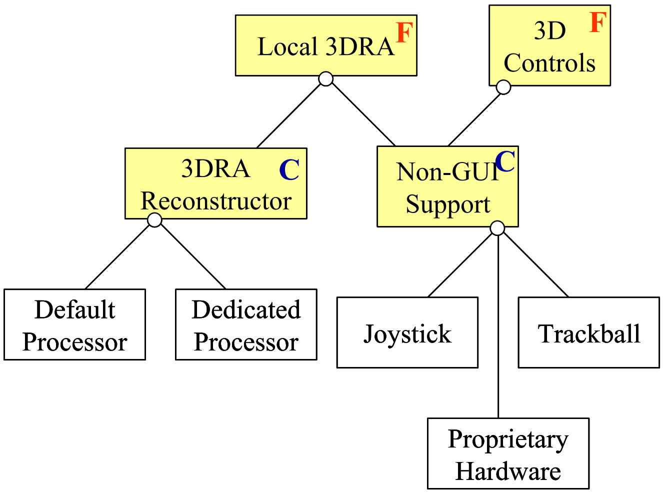


Figure 6-9: One of the Variation Models in the Realization View

Due to confidentiality reasons, a fully-fledged realization view for the Cathlab scenarios shall not be provided in this thesis.

6.3.2 The Cathlab Architecture Scenarios

Finally, four architecture scenarios were created to describe the various Cathlab integrations that will help implementing the two business strategies (i.e. Standard and Efficient Cathlabs, and High-Tech Cathlabs with improved accuracy – as introduced Step 3 of SODA). The architecture scenarios considered in this case study were constructed follows. We started by looking at the variation model in the Customer view. Here the following decision was made: *to design the architecture scenarios of the Cathlab in such a way that they are suitable for two types of customers, the academia and interventional facilities,* first column in Table 6-13.

The academic hospitals focus on improved communication within the different modalities in the Cathlab, where the various systems are able to exchange information with each other. The production clinics and hospitals focus on both: fast treatment with low intervention costs, and/or high quality of treatment and tidy Cathlabs. To deal with these requirements, from left to right, choices were made in the rest of the CAFCR views. The choices had to be consistent across the various views, in the sense that the features contained in the functional scenarios have to contribute to the realization of the customer requirements formulated before. For each set of customer scenarios, a number of application scenarios were constructed. The application scenarios describe the user interaction with the system, in literature known also as user scenarios. For each application scenario a functional scenario was built, describing the set of features contained in each application scenario. After this one or more conceptual scenarios were assigned, and respectively a correspondent realization scenario to show how the available technology will be used to implement them.

Table 6-13 shows the resulted set of architecture scenarios in the Cathlab case study. For example, the for the production hospitals we designed three application scenarios, namely Presentation & Control, Workflow and Full Integration scenarios. As it is explained below, these scenarios address different usability, performance and cost objectives in the Cathlab.

With each of the application scenarios, a functional scenario was proposed, followed by a conceptual scenario and a concrete realization scenario, namely Cohost for the Presentation & Control and Workflow scenarios, describing the type of integration envisaged here, respectively Flat screen for the luxurious integration proposed by the application Full scenario.

Table 6-13: Building the Cathlab Architecture Scenarios

<table>
<tr><th>Customer</th><th>Application</th><th>Functional</th><th>Conceptual</th><th>Realization</th></tr>
<tr><td rowspan="3">Academic</td><td>Minimal</td><td>Minimal</td><td>-</td><td>-</td></tr>
<tr><td>Data</td><td>Data</td><td>DM Integration</td><td rowspan="2">Multihost</td></tr>
<tr><td rowspan="2">Presentation & Control</td><td rowspan="2">Presentation & Control</td><td>HW Switch</td></tr>
<tr><td rowspan="3">Production</td><td>Alt-Tab</td><td rowspan="2">Cohost</td></tr>
<tr><td>Workflow</td><td>Workflow</td><td>Coordinator</td></tr>
<tr><td>Full</td><td>Full</td><td>Luxury</td><td>Flat screen</td></tr>
</table>

A short description of the five application scenarios is given below.

- **Minimal integration** means a situation in which only standardized mechanisms for integration (e.g., DICOM) are used for integrating the Cathlab systems.
- **Data integration** focuses on the sharing of data. If data is produced by one system, a second system can read, understand, and change it whenever applicable.
- **Presentation and control integration** are two sides of the same coin. Presentation integration is accomplished when two or more systems can present their results in a similar way. Control integration on the other hand, means that two or more systems can be controlled in similar ways. In practice, these types of integration are usually joined to create a common look and feel.
- **Workflow integration** means that systems work together to support the workflow of their users. It is important that this behavior is flexible and can be adjusted to meet specific workflow needs and habits.
- **Full integration** represents a fully integrated Cathlab system. Besides the above mentioned integration levels, new features that are enabled by this high level of integration are described.

The user scenarios have been proposed to explore the design variants of an integrated Cathlab. The scenarios start with a minimal integrated Cathlab in which the systems are still distributed within the Cathlab, being operated by a cardiologist or technician, and gradually build towards a fully integrated Cathlab in which the systems are translated into individual applications, running on a single workstation, and are controlled only by the cardiologist. The full version of the different user scenarios is given in Appendix D. These scenarios have been created by architects within Philips Research. They appear in this thesis only for the illustration purpose of the method and for experimentation. As one will observe, each user scenario is structured in a number of scenes. A scenario scene describing a task or a combination of tasks (also called atomic actions), the user will perform in order to achieve a certain result. The result of a scene is usually used as input for the next scene along in the scenario story line.

6.4 SODA Step 4: Analyze Scenarios' Feasibility

In the last step the feasibility of the proposed architectural scenarios in the different future contexts is analysed. The goal is to understand which scenario suits best what type of future, and the size of the targeted market segment in each scenario. Ultimately, the feasibility of the different architectural scenarios is quantified by an estimate figure of the expected profit of the organization.

Carrying out this step starts by quantifying the change in the market share due to acceptance or rejection of the quality attributes of the product offered. For this task, architects' expert judgment was used. For example, what if an expensive and highly accurate Cathlab treatment is proposed for the mass treatment hospitals? Although the clinical advantage of such a solution is unquestionable, the majority of patients reaching these hospitals will not be able to financially afford such a solution, if considering it at all. If the solution offered does not comply with the stakeholder objectives, the customers will opt for solutions offered by competitors. Therefore an estimate of the magnitude of change in the customer segment size, and hence profit, triggered by the different architectural scenarios is calculated. In these calculations however, it is considered the change in size of the various market segments due to the quality aspects exhibited by the various architectural scenarios. This change is expected to differ for each strategic scenario. Consider for example, a booming economic situation – or the Brave New Pharma World scenario in our case. In such a scenario the Minimalists might be able to afford more expensive and accurate Cathlab treatment. However, if economic recession occurs, the Minimalists can afford only basic treatment services. The Premiums however, will decide their treatment based on accuracy rather than costs.

For assessing the different quality attributes of the proposed architectural scenarios the SQUASH (Systematic Quantitative Analysis of Scenarios Heuristics) method is used, as introduced in Chapter 4. The next chapters (i.e. Chapter 7 to Chapter 10) present the data gathered with SQUASH for the finalization of last step of SODA. The finalization of the feasibility analysis for decision making is described in Chapter 11 of this thesis, after all the data is available.

Chapter 7

7 Usability Analysis with SQUASH

Introduction

The SQUASH method (see Chapter 4) has been developed in particular for analysing the quality attributes of a future system as early as the architecture is proposed. In this chapter, the SQUASH method is applied for studying the usability aspects of the Cathlab scenarios. The method provides the means to reason about the usability of a future system, before it is fully implemented, by quantifying the specific factors that contribute to the final usability of the system.

The SQUASH method consists of two phases: the information gathering phase, and the decision-making phase. Each phase contains one or more steps, as introduced earlier in Chapter 4 of this thesis. This chapter describes only the usability analysis. The performance, risk and cost analysis is presented in the subsequent chapters.

7.1 SQUASH Step 1: Identify Stakeholders

The first step in SQUASH is to identify the system's stakeholders. The stakeholders are important in providing the initial information about the different qualities that are expected from the future system. The identified stakeholders of the Cathlab are shown in Figure 7-1. In this figure, the arrows indicate dependency relations between the various stakeholders.

The interpretation of Figure 7-1 is as follows. The hospital administration requests new innovative systems for its Cathlabs. The new systems will be used directly by the cardiology departments for treating patients with coronary artery diseases. These new systems have to be in line with the government regulations and policies with respect to patient safety and privacy, as well as with the constraints imposed by the insurance companies with respect to intervention costs. Finally Philips Medical Systems proposes new Cathlab systems that will meet the stakeholder quality and functionality objectives. All relations are bidirectional, because the different stakeholders can influence each other.

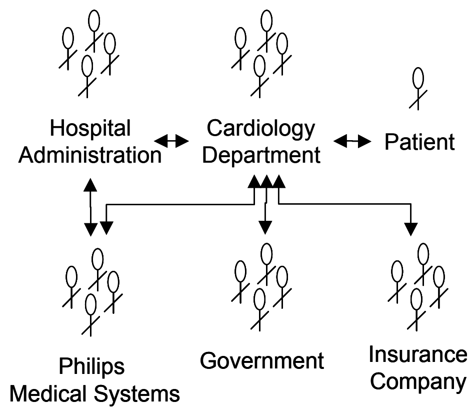


Figure 7-1: Stakeholder Identification and Relations

7.2 SQUASH Step 2: Identify Usability Objectives

In step two we identify the stakeholders' primary usability objectives. This can be done directly by asking the stakeholders about their usability requirements, or indirectly by studying the users' tasks, existing system specifications, or models of the future system (Jordan *et al.* 1996)(Rosson *et al.* 2002). For describing the tasks the users perform with systems, same expert knowledge and/or user task analysis is indicated in the literature as a successful way of gathering this information. A generic approach for performing this type of analysis is the Hierarchical Task Analysis (HTA). A comprehensive overview of the HTA approach and its benefits can be found in (Rosson *et al.* 2002) pp. 207.

The result of this step is a set of usability attributes, which have to be taken into account when the system architecture of the new system is developed. Using HTA and interviews with domain experts, the following objectives were identified.

- The hospital administration is interested in the efficiency of the Cathlab, such as the number of personnel involved in the Cathlab.
- The cardiologist wants a Cathlab that is easy to use and has a lower X-ray activity during the intervention (i.e. effectiveness and satisfaction).
- The nurse assists the cardiologist in the intervention room. The nurse's main usability objective is a sterile and tidy Cathlab environment, a comfortable physical means of support for the patient during the intervention, and as low dose as possible of X-ray radiation received during the intervention (i.e. effectiveness and satisfaction). However, the comfort attribute is not part of this case study.
- The technician also assists the cardiologist, but from the control room, where he or she operates the patient monitoring systems. The technician's usability objectives are a Cathlab with fewer user actions per task, and with functions that are easy to learn (i.e. efficiency).

This information was used for translating the usability objectives into more concrete usability factors, as shown in Table 7-1.

Table 7-1: Usability Objectives

Usability Objective	Usability Factor for the Cathlab
Efficiency	Personnel involved
	Number of atomic actions
	Learning duration
Effectiveness	Intervention success rate
Satisfaction	Intervention average duration

7.3 SQUASH Step 3: Make the Usability Objectives Quantifiable

In this step, the usability factors identified in the previous step are made quantitative. This means associating each usability factor with a specific proper metric, and specific acceptance levels. These metrics are described below as summarized in Table 7-2. The acceptance levels are given in Table 7-3.

- *Personnel involved* measures the number and type of persons involved to complete a certain activity, such as cardiologists, nurses and technicians.
- *Number of atomic actions* accounts for the number of indivisible operations the involved personnel has to do to complete a task. The metrics used for this factor are: the number of walks between the two rooms of the Cathlab – the intervention room and the control room, the number of resterilizations due to an interaction with a non-sterile item, and the number of operated controls (e.g. buttons pressed, or menus navigated).
- *Learning duration* refers to the time that needs to be spent by the medical personnel in becoming familiar with the new systems and learning how to operate them correctly. The metric in this case is the number of training hours.
- *Intervention success rate* refers to the intervention outcome in terms of percentage of successful interventions for a given number of interventions. The outcome of an intervention is mainly influenced by the image quality provided by the different imaging modalities that could be used (e.g. X-ray, ultrasound, or magnetic resonance), or/and the intervention duration. Longer interventions increase the chance of something to go wrong. For brevity reasons the success rate is measured in this case study by the probability of success of the individual scenario scenes.
- *Intervention average duration* is a usability factor related to the satisfaction level for both the medical personnel and the patient – a metric in this case is units of time – more concrete, minutes. Lengthy interventions are exhausting for both the cardiologist and the patient. Sometimes factors such as the ergonomics aspects of the medical systems, or accessibility to the patient, can provide a more detailed measure of the satisfaction level for the new Cathlab.

Table 7-2: Usability Factors and their associated Metrics

Usability Objective	Usability Factor for the Cathlab	Metric
Efficiency	Personnel involved	Number of persons
	Number of atomic actions	Number of walks
		Number of resterilizations
		Number of buttons pressed
	Learning duration	Hours of training
Effectiveness	Intervention success rate	Percentage of success
Satisfaction	Intervention average duration	Minutes

7.4 SQUASH Step 4: Analyze Scenarios

In step four the usability factors are assessed at a scenario level. The assessment of the usability attributes is an elaborate process involving scenario walkthrough sessions with architects and/or stakeholders. The assessment is based on the user scenarios, in which each usability factor is analyzed quantitatively per scenario scene. The user scenarios considered are the ones described in Appendix D. This type of assessment is also called bottleneck analysis because it reveals the particular scenes where the values of certain usability factors may be outside the acceptable boundaries. Because each usability factor is studied per scenario scene, reasoning about the entire scenario becomes more easy and accurate (e.g. by summing up, or taking the maximum, of the individual usability estimates obtained per scene). The hard data obtained in this way is used in the decision making process (i.e. Step 7 in SQUASH) when is to select the final scenarios to be considered for the implementation.

Sometimes the data provided by the scenarios was insufficient to estimate or measure the value of certain usability factors. To overcome this problem, other information sources have to be consulted, such as specifications of existing systems, or interviews with domain experts. However, if there are significantly differences in the provided estimates, joint meetings with all domain experts should be organized in order to achieve agreement. Alternatively, all data should be reconsidered in order to explain the differences. The second suggestion is more likely to be adopted, because joint meetings are usually hard to organize, require a lot of preparation time, and rarely result in single values being agreed upon by all participants.

In order to assess the quality factors of the Cathlab scenarios in a quantitative manner, acceptance levels for the different factors are defined, which are specific for each market segment. Table 7-3 presents the usability factors of interest and their associated acceptance levels. To visually indicate the acceptance level of a certain quality factor in a scenario scene, a five level colour scale is used ranging from excellent (dark green shading), to good (light green shading), acceptable (yellow shading), poor (orange shading), and unacceptable (red shading), as shown in Table 7-3 for the usability factors. For grouping the usability factors by category reasons, the order is a bit changed from the one presented in Table 7-2. Although very important, the *number of buttons pressed* factor could not be accounted for at this stage of the design, thus is neglected in the present case study.

Table 7-3: The Usability Factors and Their Acceptance Levels

Usability Factor	**Acceptance Level**				
	Unacceptable	Poor	Acceptable	Good	Excellent
Number of walks	= 3	2	1	0	0
Number of persons	> 4	3	2	1	0
Number of resterilizations	= 1	1	0	0	0
Learning duration	>30 hours	[20-30] hours	[10-20) hours	[5-10) hours	<5 hours
Intervention avg. duration	>60 min	[45-60] min	(35-45) min	[30-35] min	<30 min
Intervention success ratio	= 0,7	(0,7-0,8)	[0,8-0,9)	[0,9-0,94)	[0,94-1]

7.5 SQUASH Step 5: Aggregate Scenarios Usability Profile

In this step we analyzed the usability factors defined above, and quantified them in each of the five proposed user scenarios. For accuracy and completeness, we divided the scenarios into scenes. A scene is defined as a unit of continuous, related action (e.g. preparing the patient, performing an X-ray study, comparing two studies, etc). Each factor was then analyzed per scene, with the end results being aggregated to give an overview of the whole scenario.

For the aggregation three types of functions are used, such as the *Sum* function for the factors that have a cumulative effect (e.g. number of walks, number of resterilizations, learning duration or intervention average duration), the *Maximum* function for those factors that do not have a cumulative effect (e.g. personnel involved), and *Product* function for those factors that measure the probability of individual events per scenario scene (e.g. intervention success ratio).

The results of the usability analysis per scenario scene are presented in the Appendix E, in Table 13-1 for the Minimal Integration Scenario, in Table 13-2 for the Data Integration Scenario, in Table 13-3 for the Presentation and Control Scenario, in Table 13-4 for the Workflow Integration Scenario and in Table 13-5 for the Full Integration Scenario.

The final data obtained for each usability factor is referred to as the scenarios usability profile. For the five user scenarios, the obtained usability profile is presented below in Table 7-4.

Table 7-4: The Usability Profile for the Five Cathlab User Scenarios

Usability Factors	Scenarios				
	Min	Data	PC	Wf	Full
Number of walks	4	3	0	0	0
Personnel involved	3	3	2	2	2
Number of resterilizations	0	0	0	0	0
Learning duration	6h	6h	10h	10h	11h
Intervention average duration	43 min	38 min	31 min	29 min	25 min
Intervention success ratio	0,80	0,82	0,90	0,91	0,94

7.6 SQUASH Step 6: Improve the Scenarios

In this step the scenarios that fail to accommodate all the usability factors at an acceptable level will have to be modified. In our case the *number of walks* attribute in the Minimal Integration scenario is at an unacceptable level, which triggers two actions – either improve on those scenes that introduce an unnecessary number of walks, or drop out completely this scenario from being considered further in the design of the architecture.

In the Cathlab case study the scenarios were given for experimentation, therefore they were left unchanged.

7.7 Conclusions

7.7.1 Assessing the usability at a scenario level - Limitations

Identifying and defining the usability factors was a relatively easy task. However, when it came to perform the actual analysis, a number of difficulties appeared. These difficulties and their possible remedies are described below.

- Insufficient information at a scenario level for estimate realistically some of the usability factors, e.g. the duration of completing an atomic action, when assessing the intervention total duration.

Suggested Remedies:

- o Analyze of those use-cases in which the atomic actions are described.
- o Use rough estimates based on domain experts' knowledge.
- o Postpone the analysis of these attributes until working prototypes are available, because estimating them at this level is anyways premature and unrealistic.

- No single value for those usability attributes that measure the duration of a specific action or activity per scene (e.g. duration of the X-ray exposures).

Suggested Remedies:

- o Work with average estimates (e.g. the exposure time is approx. 200 seconds)
- o Live with the uncertainty of these estimates, thus considering the minimum, average (or most likely case), and maximum values of the attributes and explain the variation reasons.

- Differences in the data provided when interviewing different domain experts.

Suggested Remedies:

- o Work with the most acknowledged domain experts available
- o Organize joint meetings with all the domain experts and bargain the assessment values when disagreement occurs.
- o Consider all differences in the various data provided by the domain experts and explain these differences. This is because joint workshops are usually hard to be organized, require a large amount of preparation time, and rarely finalize with single values agreed by all participants.

- Unattainable estimates for some usability attributes (e.g. patient comfort)

Suggested Remedies:

- o Specify these attributes as contributing to the usability level but flag them as uncontained during the assessment process.
- o Find alternative attributes that are more accessible to be measured.

7.7.2 Assessing the usability at a scenario level - Benefits

Although some difficulties were encountered while gathering the usability data, a number of positive contributions of this activity can be named:

- A fine-grained classification and quantification of the factors that contribute to the achievement of a specific usability attribute.
- A systematic quantitative way of analyzing user scenarios of a system before committing effort and budget into designing the system's architecture.
- The accuracy of the analysis improves by assessing the various qualities per scenario scene. The scenes that may hinder the usability of the final system can be explicitly identified.
- Working with scenarios in form of stories has been an efficient method of communication for the architects and the stakeholders of the system. The analysis of the usability at a user scenario level means that real system prototypes do not have to be built.
- The system's stakeholders are given a clear overview of the relative benefits of the different scenarios in the form of written user scenarios annotated with quantitative information about their various quality levels. With this quantitative information at hand, the decision makers are better able to decide which scenarios should be considered for the design.
- The usability levels specified in the user scenarios can be used later to measure and validate the implemented systems.
- Some of the unattainable estimates can be actually gathered if different design cases are considered and performance issues are studied (e.g. duration of an atomic action, duration of 3DRA reconstruction)

Using SQUASH for gathering information about the various quality aspects is intended to help in taking informed decisions with respect to which are the relevant scenarios that should be considered in the follow-up design phases of a project.

Chapter 8

8 Performance Analysis with SQUASH

Introduction

In building complex medical systems various functional aspects as well as quality aspects need to be taken into account. The SQUASH method has been developed in particular for analysing the quality attributes of a future system as early as the architecture is proposed. The objective of this chapter is to assess the performance attributes for the new integrated Cathlab systems using the SQUASH method.

Analysing the performance attributes in different design cases showed that it is possible to come up with real architectures that meet their performance requirements. The estimated values for each of the performance attribute were presented. Based on such estimates the decision-makers (architects) could make architectural trade-offs if more quality attributes are taken into account (e.g. usability, cost, etc). The performance estimates to be presented in this chapter have been calculated theoretically based on the technical specifications of the various hardware/software components involved. This chapter describes only the performance analysis. The risk and cost analysis is presented in the subsequent chapters

The steps of the SQUASH method have been introduced initially in Chapter 4 of this thesis. This chapter shows how steps 2 to 5 of SQUASH are carried out for assessing the performance of the Cathlab scenarios proposed in Chapter 6.3.2.

8.1 SQUASH Step 1: Identify Stakeholders

The main stakeholders of the Cathlab have been identified in the previous chapter. In short, these were the hospital administration, the cardiology department including the patient, the government, the insurance companies, and Philips Medical Systems. All these stakeholders have a vested interest on the performance factors of the Cathlab. The hospital administration for example is interested in quick review of patient medical records and image archives, the cardiology department is interested in reducing the intervention duration by using more efficient Cathlab systems, the government and insurance companies is interested in reducing the waiting lists and price per intervention in the Cathlab, and Philips Medical Systems is interested in creating better products and thus product portfolio optimization.

In the next step we are going to investigate which are the performance relevant factors that contribute to the overall performance of the Cathlab.

8.2 SQUASH Step 2: Identify Performance Objectives

8.2.1 The Context of the Cathlab

The modalities used for diagnosis and interventions are presented below in the conceptual view - Figure 8-1, using UML notations. The interventional modality is mainly the Cathlab (X-ray based, with 3D image reconstruction capabilities), and a possible future modality called XMR – this is X-ray combined with MR. For diagnosis, both interventional modalities make use of diagnostic modalities like magnetic resonance (MR), computed tomography (CT), or ultrasound (US).

The main resources for both intervention and diagnosis modalities are two databases called Picture Archiving and Communication System (PACS), and Cardiology Information System (CIS).

The PACS contains an archive with all patient images taken for various diagnosis or intervention purposes. The CIS stores all medical records and personal data of a patient. During diagnosis, the medical record and the clinical images of a patient are retrieved from the CIS and PACS, analysed, updated with new data or new acquired images and stored back in one or both of the databases. The Image Generator component is responsible for image acquisition, presentation and storage from the diagnostic modalities to the PACS. The Workflow component is responsible for patient data and medical records updates in the CIS. The manipulation of the patient data and images is possible via networked workstations (e.g. imaging workstations, office or administrative workstations).

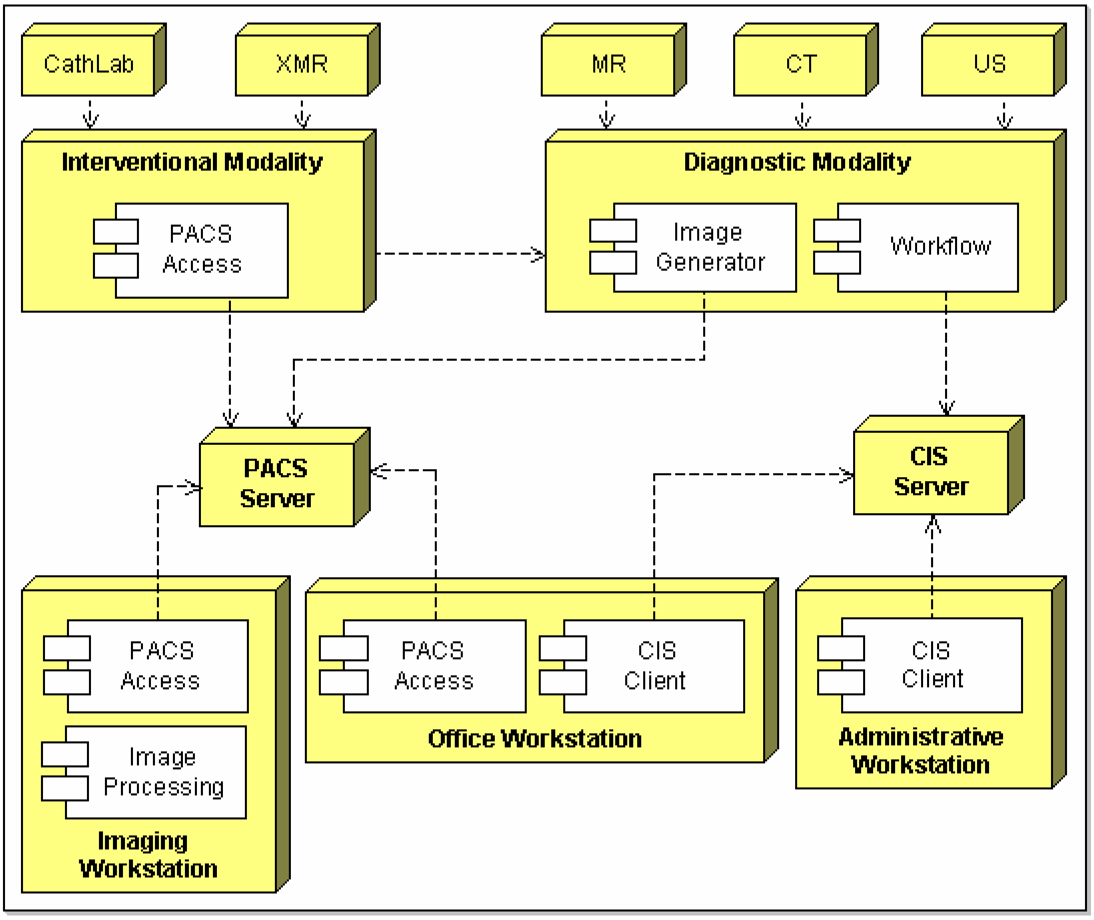


Figure 8-1: The Context of the Cathlab – Conceptual View

Other resources available for either diagnosis or intervention are the three types of workstations presented in Figure 8-1.

- The imaging workstation is used especially during the intervention for image processing or navigation. The main components of the imaging workstation are the PACS access and the imaging processing components.
- The office workstation is mostly used for diagnosis purposes. From this workstation the doctor can access patient medical records stored in the CIS and clinical studies stored in the PACS.
- The administrative workstation is used before and after diagnosis or intervention for patient rescheduling or billing activities. For this purpose the administrative workstation makes use of the patient data available in the CIS.

8.2.2 Cathlab Performance Dependencies

The main goal of the integration effort is the improvement of the Cathlab clinical performance. Shortening the catheterisation duration per patient is expected to result in a higher number of patients treated per day in the Cathlab. The duration of the intervention depends on two main factors: (1) the performance of the Cathlab users (e.g. cardiologists or technicians), and (2) the performance of the Cathlab systems.

The Cathlab users' performance depends first on the degree of experience the users have with the catheterisation process, and second on the usability of the Cathlab systems. The Cathlab systems' performance also depends on some other factors that are the latency of the Cathlab systems, and the throughputs of these systems. Although the systems' and users' performance factors are technically separated, in practice any performance problems (e.g. high latency or low throughput) will be perceived as a usability issue. These dependencies are presented in Figure 8-2.

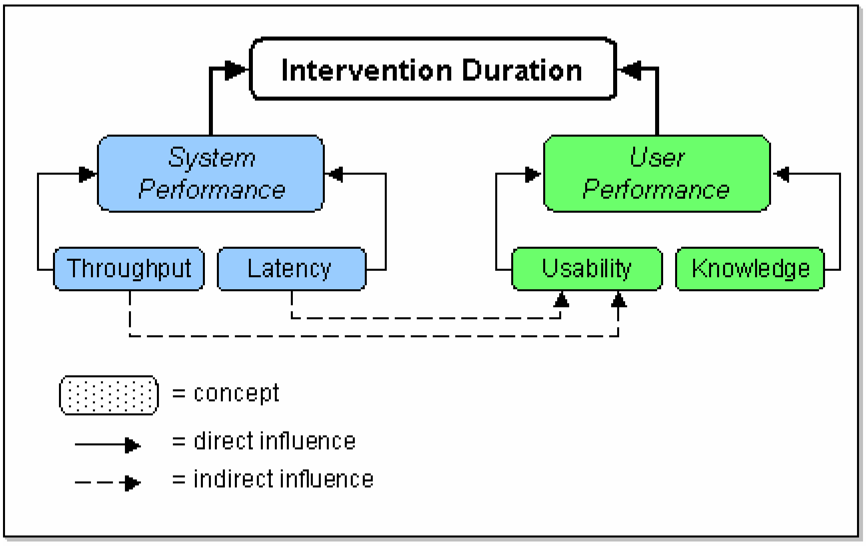


Figure 8-2: The Cathlab performance factors and their dependencies.

In this figure, the strength of the dependencies is shown by the thickness of the arrows as resulted from the analysis of the interactions within the Cathlab case study.

8.2.3 The Performance Factors

The factors that contribute to the performance of the Cathlab are described in this section. For each performance factor, a quantitative definition is proposed. These definitions will be used when analysing the performance expressed at a scenario scene level. The focus will be on the clinical performance of the Cathlab systems, namely on those performance factors that are system dependent and can be adjusted in such a way that the Cathlab throughput is increased.

As explained already, the performance of the Cathlab is partly determined by the medical personnel and partly by the Cathlab systems. However, the performance of the medical personnel will not be considered in our analysis. We assume that that the medical personnel's clinical performance is excellent. Therefore, we focus on the performance of the Cathlab, namely *the response time* of the various systems (t_r), measured from the point in time the user initiates a system task until he gets the response from the system for completing his task, Figure 8-3. The task initialisation time (t_i) and the task finalization time (t_f) are not relevant for our purpose because they depend on the performance of the user.

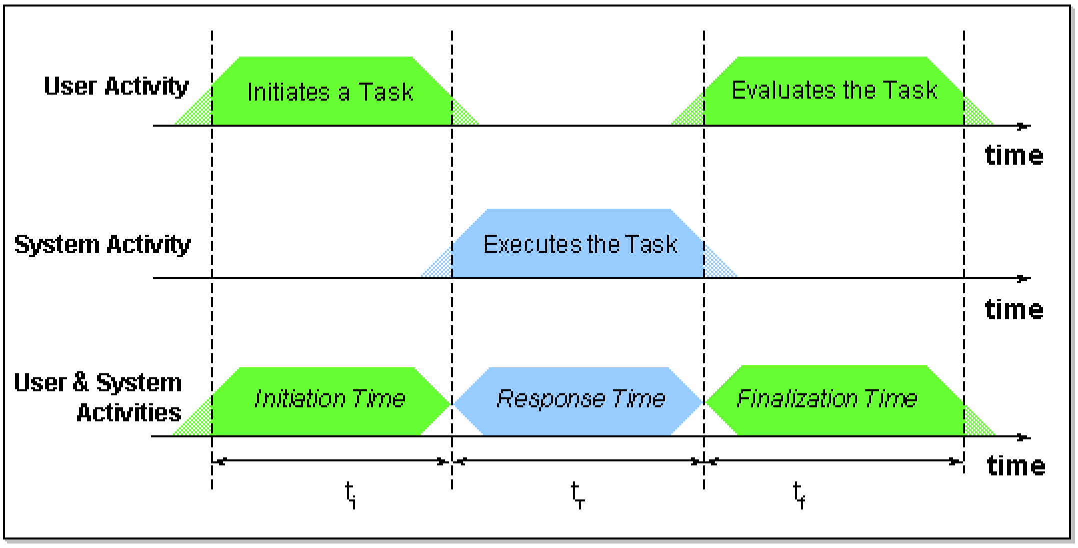


Figure 8-3: The basic components of a task for showing the performance variables

8.2.3.1 Identifying the most time consuming activities using Sequence Diagrams

In order to identify the most time consuming activities in the Cathlab, and hence possible performance bottlenecks, sequence diagrams are used to model the interactions between the users and the systems in the Cathlab. The graphical representation of the sequence diagrams is intuitive, easy to learn and to understand for both architects and designers. The goal of this activity is to translate the scenarios scenes from a textual form into a representation that will ease the identification of the possible performance bottlenecks, Appendix F.

8.2.3.2 The Identification Process

For each scenario scene in Appendix D the systems, the users, and their interactions are identified. Next, a sequence diagram is created, as presented in the Appendix F, out of which the factors that influence the Cathlab overall performance are extracted Table 13-6. Although the analysis of the scenarios with sequence diagrams may reveal a large amount of performance relevant factors, this type of analysis should be combined with similar findings based on interviews with domain experts. This is because scenarios may omit certain performance relevant details.

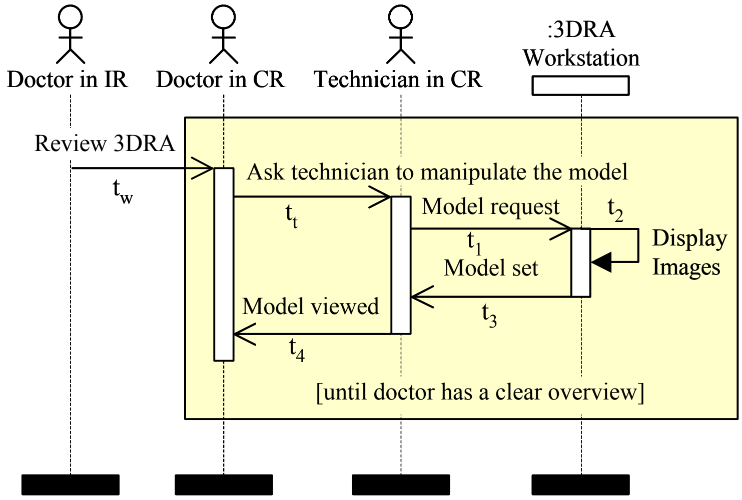


Figure 8-4: An Example of Sequence Diagram for Scene 9 in Minimal Scenario

Figure 8-4 present such an example of identifying the most time consuming activities in a specific scenario scene. By associating with each activity an estimate of the time required for its accomplishment (t_1 to t_4), one could subsequently point out the performance bottlenecks for the various activities in the Cathlab.

8.2.3.3 The Findings

The scenarios' analysis with sequence diagrams revealed the following findings:

- Most of the performance relevant factors presented in Table 13-6 refer to user actions in which, although a significant amount of time is spent (i.e. the order of magnitude is minutes), the system's response time is not an issue. Examples: data logging, clinical steps logging, table repositioning, contrast fluid insertion, catheter navigation. Because these factors account for the time spent in activities of which duration depends mostly on the user's skills, they will not be further analysed.
- There are also scenes in which the user has to wait for the system's response before being able to continue his task. These systems' response times are the ones in which we are most interested, because they are considered to be potential performance bottlenecks. Examples: MR study retrieval duration from the PACS, X-ray images sending duration to the PACS, display duration for the catheter's tip position, X-ray image acquisition and display duration, X-ray image storage duration, rotational angiography process duration, 3D image reconstruction duration, display stenosis size duration, and blood pressure and stenosis values display duration, Table 8-1.
- The domain experts interviewed with respect to the utility of the performance factors extracted with sequence diagrams acknowledged that the attributes are significant and sufficient. More over, they pointed out the following remarks: (1) A large part of the performance factors mentioned in Table 8-1 (indicated by the

rows which are not shaded) are very well handled in the current Cathlab. However, in the current Cathlab there are also some serious performance related bottlenecks such as: the 3DRA reconstruction duration, the MR study retrieval duration, and the 3DRA model display frame rate (indicated by the shadowed rows). (2) Although some performance factors have large values (in order of seconds) this is due to the characteristics of the human body (e.g. the heart rate beat per second, thus a few seconds of X-ray exposure are needed in order to get a clear view of the heart movement over several beat cycles).

8.3 SQUASH Step 3: Make Objectives Quantifiable

We define the performance for the Cathlab in the following way:

"*The extent to which the Cathlab systems contribute to the reduction of the catheterisation duration time, by reducing the systems response time when acquiring or presenting X-ray or MR images, and increasing the frame rate when presenting or navigating volumes".*

In order to make this definition quantitative, a number of performance factors and metrics are identified, Table 8-1.

Based on this input, the user scenarios for the Cathlab integration and concrete design cases for each of these scenarios, we analyse to what extent the performance attributes presented above can be satisfied.

Table 8-1: The important performance factors in Cathlab

Performance Attribute	Performance Factor	Measuring Method	Poor Level	Planned Level	Best Case
Response Time	Duration for the retrieval of the MR pictures from the PACS, Scene 2.	The time it takes since user requests a MR study until he gets the picture displayed on the screen, measured in fractions of a second.	>5sec	[1, 5]sec	<1sec
	X-ray exposure image acquisition and display, Scene 5.	The time it takes to acquire an X-ray exposure since the cardiologist presses the pedal of the X-ray machine, until he gets the 2D picture displayed on the monitor, measured in seconds.	>2sec	[1,2]sec	<1sec
	X-ray image storage duration, Scene 5.	The duration of the X-ray images storing process, measured in seconds.	>5sec	[1, 5]sec	<1sec
	Rotational angiography process duration, Scene7.	The duration of the X-ray rotational angiography process, measured in seconds.	>20sec	[10,20] sec	<10sec
	3D image reconstruction duration, Scene 7	The duration of the 3D reconstruction process, out of the X-ray images, measured in seconds.			
	Display stenosis size duration, Scene 10	The duration of the stenosis size and percentage calculation and display, measured in fraction of a second.	> 1sec	1sec	<1sec
	Blood pressure and stenosis values display duration. Scene 11	The time it takes to calculate and display the blood pressure and stenosis values using fluoroscopy, measured in fraction of a second.			
	Sending time for the MR slices to the X-ray machine, Scene 2	The duration of transferring MR slices form the imaging workstation in the control room to the X-ray systems in the intervention room, measured in seconds	>5sec	[1, 5]sec	<1sec
Frame Rate	3D model display rate, Scene 8	The refresh rate in displaying the 3D model on a monitor or to update the model if the 3D coordinates of viewing change, measured in image frames per second, for a 5122 and 10242	<8fps	[8-20] fps	>20fps
	Frame rate when displaying the position of the catheter, Scene 4.	The refresh rate in displaying the catheter's tip location using fluoroscopy, measured in image frames per second.	<30fps	[30-60] fps	>60fps

8.4 SQUASH Step 4: Analyze Scenarios

In order to reason about the various performance attributes, we will present first a couple of concrete design cases for the Cathlab systems (i.e. servers, workstations, network connections, etc), and second, the constituent components of these systems that play a role with respect to performance.

8.4.1 Cathlab System Views

The layout of the Cathlab systems is studied per scenario. Each scenario results in a different configuration of these systems, as presented below. Here the focus is on the application view, which carries the most relevant performance information.

8.4.2 The Application View for the Minimal Integration Scenario

The proposed configuration of the Cathlab systems in the minimal integration scenario is presented in Figure 8-5.

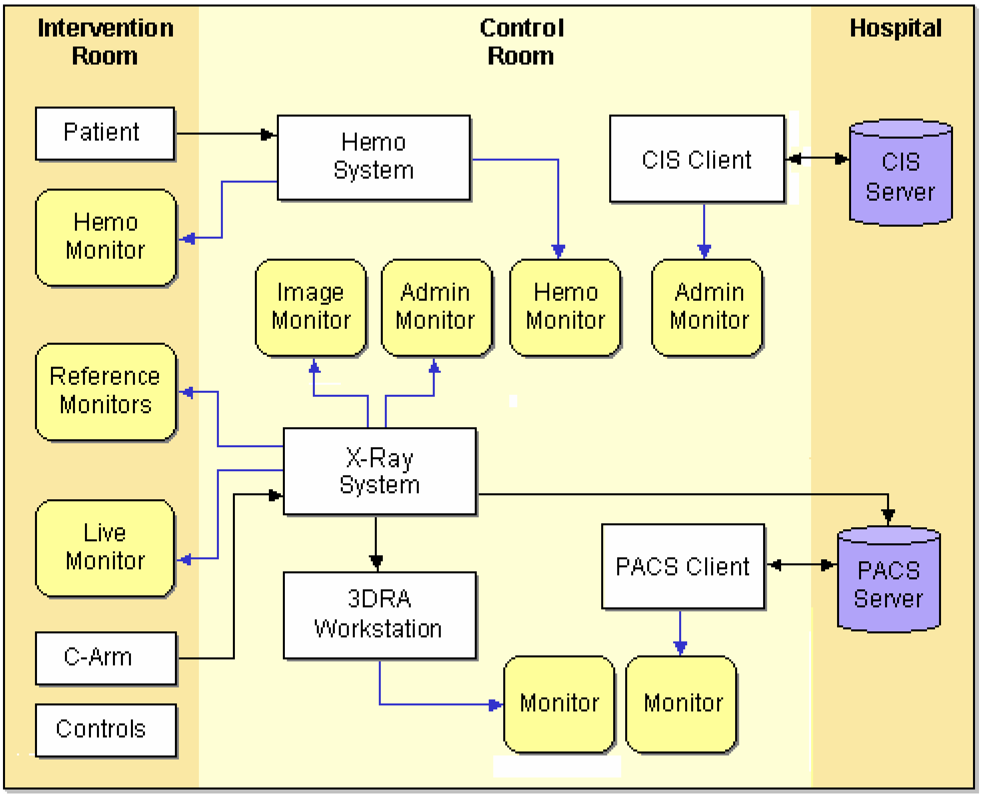


Figure 8-5: The Application View for the Minimal Integration Scenario

Outside the Cathlab, in another location within the hospital, will be placed the Picture Archiving and Communication System (PACS) and Clinical Information System (CIS).

Inside the Cathlab, in the control room there will be placed the Hemodynamics Workstation, a CIS client, the X-ray system, the 3DRA Workstation, and the PACS client, each of them having their own display monitors and control panels. In the intervention room there'll be a hemo monitor, two X-ray reference monitors, the X-ray live monitor, the X-ray arm and its control panel, and a patient table.

The communication between the Cathlab systems is as follows:

- The PACS client is connected to the PACS server. Any stored study of a patient can be retrieved from the PACS using this client;

- The X-ray system is also connected to the PACS server. All X-ray images acquired during the intervention with the X-ray system are archived and sent to the PACS server to be stored for later use;

- The 3DRA workstation is connected to the X-ray system. The images acquired with the X-ray system during the rotational angiography process are sent to the 3DRA workstation for reconstructing the 3D model out of the 2D X-ray captures;

- The CIS client is connected to the CIS server. The logs of the interventional procedure steps and all information about the patient are stored/retrieved in/from the CIS via the client.

- The Hemo system is a patient monitoring system which collects the patient's ECG and blood pressure information all during the intervention;

In the minimal integration scenario the "Controls" refer to the X-ray system control panel, which is used for X-ray images acquisition and manipulation from the intervention room. The minimal integration scenario intended to be mainly a starting point from which the rest of the user scenarios will be evolved, rather than a real integration of some of the Cathlab systems. In this respect, the minimal scenario offers less functionality than the current Cathlab.

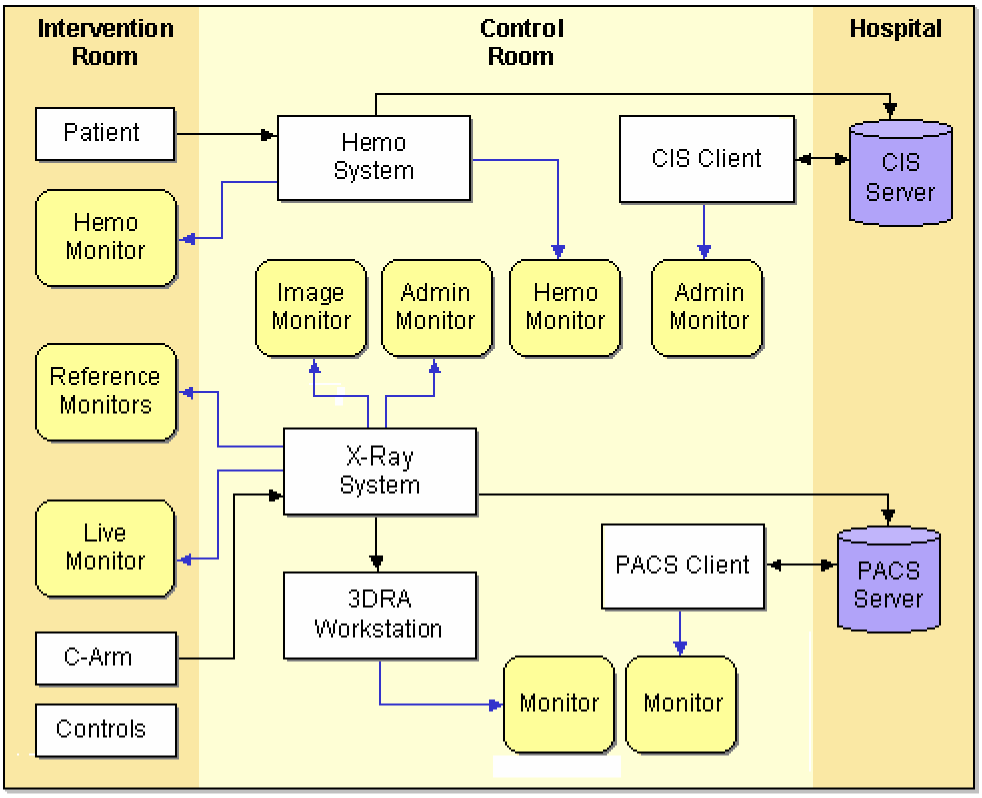


Figure 8-6: The Cathlab systems physical layout for the Data Integration Scenario

8.4.3 The Application View for the Data Integration Scenario

The Cathlab system's layout proposed for the data integration scenario is similar to the one for minimal integration scenario, as presented in the Figure 8-6.

The difference is that now the Hemo system is not a separate workstation anymore, but is connected to the CIS. In this way the ECG and blood pressure information acquired from the patient during the intervention is also stored in the CIS for being referred later if necessary.

The data integration scenario offers the advantages of having extended patient information record, to contain not only the general information about the patient but also the various hemodynamics data collected during the medical interventions. The cardiologists may use this extended record for diagnostic purposes. With this type of integration, no additional risks have been identified

8.4.4 The Application View for Presentation & Control Scenario

For this scenario, there have been proposed two types of possible integrations. One is called *cold integration*, in which the Cathlab systems are still decoupled in terms of physical location, but they offer a single presentation and control work spot. The various data is captured and processed in the individual systems but the presentation is made on a single set of monitors by means of a hardware switch. For looking at the various data provided in the Cathlab, the cardiologist has to manually select the input data source to be displayed on the monitors in the intervention room.

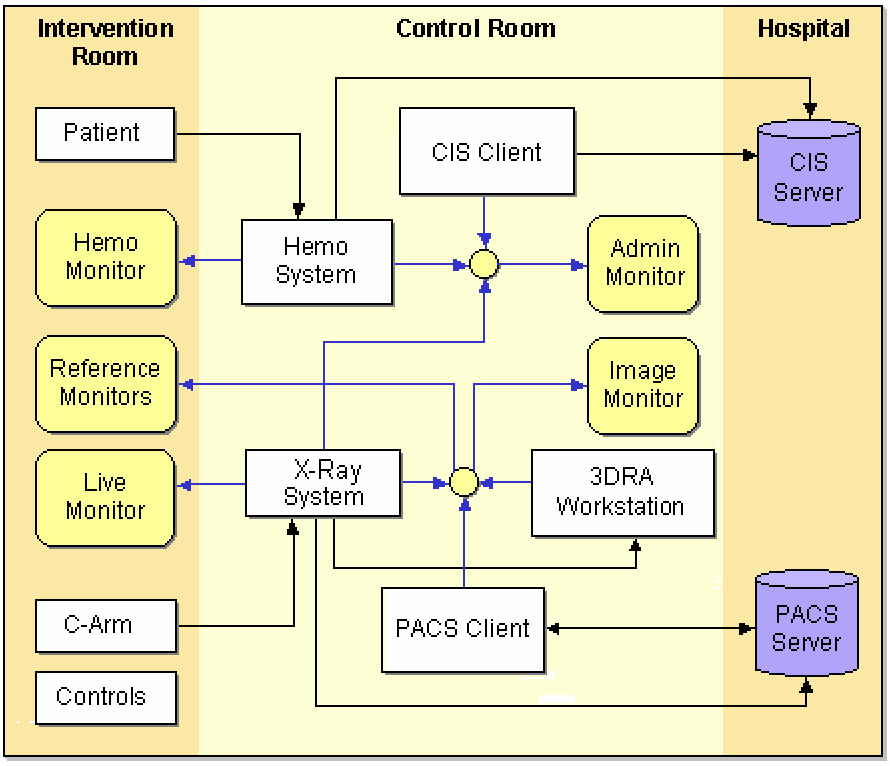


Figure 8-7: The Cathlab systems physical layout for PC Scenario, Cold Integration

The other type is integration is called warm integration, in which the systems are presented and controlled from a single work spot, as well as physically located in the same cabinet, possible sharing some of the hardware resources (i.e. hard disk space, CPU, memory, mother board, etc.).

The cold integration is presented in Figure 8-7. The physical layout of the systems is almost the same as the one described data integration scenario. However, a few differences can be noted: (1) the CIS client and Hemo system are presenting the data on the same sets of monitors, and (2) the X-ray system, the 3DRA workstation and the PACS client share the same presentation monitors as well. In both cases, the data source to be displayed is selected manually by the user from a hardware switch.

The warm integration is presented in Figure 8-8. The physical layout of the systems is now changed. Instead of physically distributed systems it is proposed that now we have a single system on which the CIS client, Hemo system, X-ray system, the 3DRA, PACS client are applications that may be executed singular or in parallel. This type of integration is also called the Alt+Tab integration, because the user can switch between the different applications by a click of a mouse, or the command Alt+Tab.

The advantages offered by the presentation and control integration scenario are two-fold: the reduction of the number of monitors in both control and intervention room by half, and the increase of the Cathlab usability by offering a single presentation and control work spot for the user.

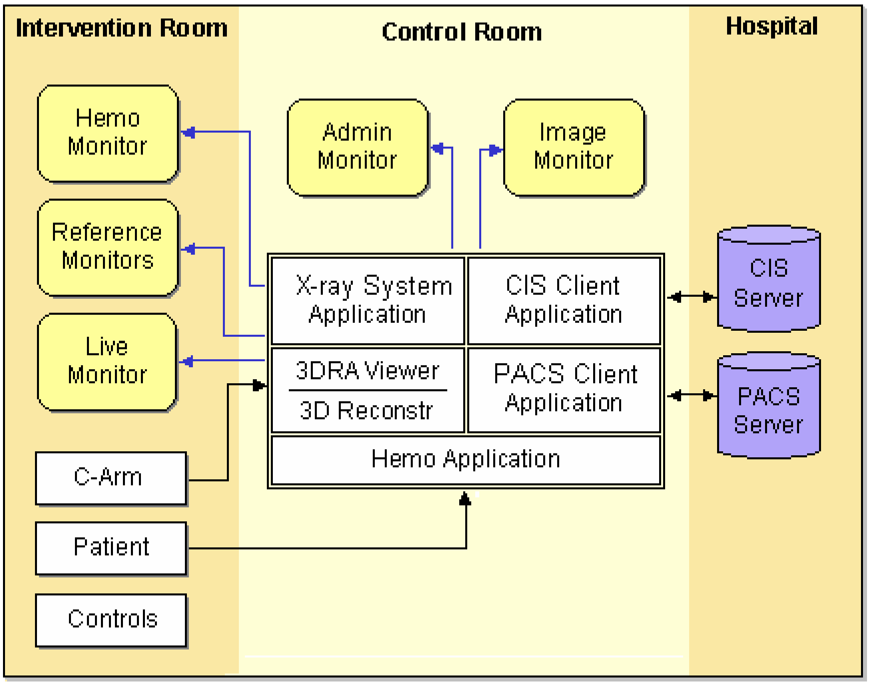


Figure 8-8: The Cathlab systems physical layout for P&C Scenario, Warm Integration

In the case of the presentation and control integration, a few risks are identified:

1. The hardware switches introduce single points of failure in the image display chain. If one of these switches fails, the user is no longer able to visualize any information on the monitors.

2. The hardware switches may affect the sterility of the cardiologist during the intervention. The cardiologist has to manually select the image source to be displayed while operating the patient.

3. The hardware switch solution restricts the Cathlab users in visualising more than one application at a time, while the warm integration, also called the Alt+Tab solution, may solve this problem by displaying the applications in different windows.

4. The warm integration will require tremendous development effort given the fact that individual applications running on dedicated hardware have to be assembled in on single PC sharing the same hardware resources.

8.4.5 The Application View for the Workflow Integration Scenario

The workflow integration scenario builds up on the case of warm presentation and control integration described in the previous section. Here the idea is that of an invisible PACS server for the user, Figure 8-9. Any operation involving the retrieval or storage of images from or onto the PACS is not perceived by the user as a networked activity. For this purpose, an image of the patient information contained in the PACS is cached locally on the integrated system, before the actual intervention. When the user wants to get certain images about the patient, the system provides them from a local storage. Similar, when the user wants to update the set of images about a patient, he does so using his local machine while the replica existing on the PACS is updated automatically at the end of the intervention.

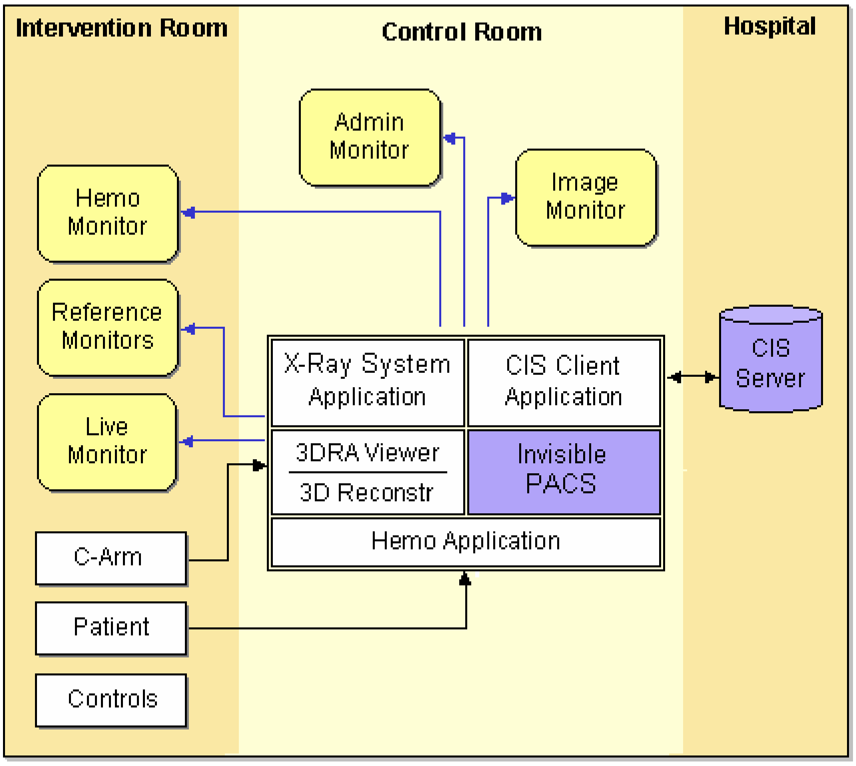


Figure 8-9: The Workflow Integration Scenario – Invisible PACS

The advantages triggered by this configuration are two-fold: the reduction of the networked activities for reviewing or storing MR or X-ray images, and the reduction of image retrieval duration due to the fact that the images are stored locally on the system.

In the case of workflow integration, apart from the risks identified in the case of warm presentation and control integration, which still remain, the implementation of the invisible PACS will be required

8.4.6 The Application View for the Full Integration Scenario

The full integration scenario is the highest degree of integration proposed for the Cathlab. This scenario contains all the innovative ideas already introduced in the previous scenarios. On top of that is provided the adaptation of the Cathlab system to allow the display of the various data on two large flat screens instead of many dedicated monitors.

In addition to the flat screen, a rather expensive feature, this scenario offers the advantage of having all the necessary information displayed on a single large screen in both the intervention and the control room, Figure 8-10.

The risks associated with the full integration scenario are the ones identified for the workflow integration, plus the single point of failure introduced by the flat screen solution. Since the large flat screen replaces the individual dedicated monitors, the failure of such a display adds an extra risk.

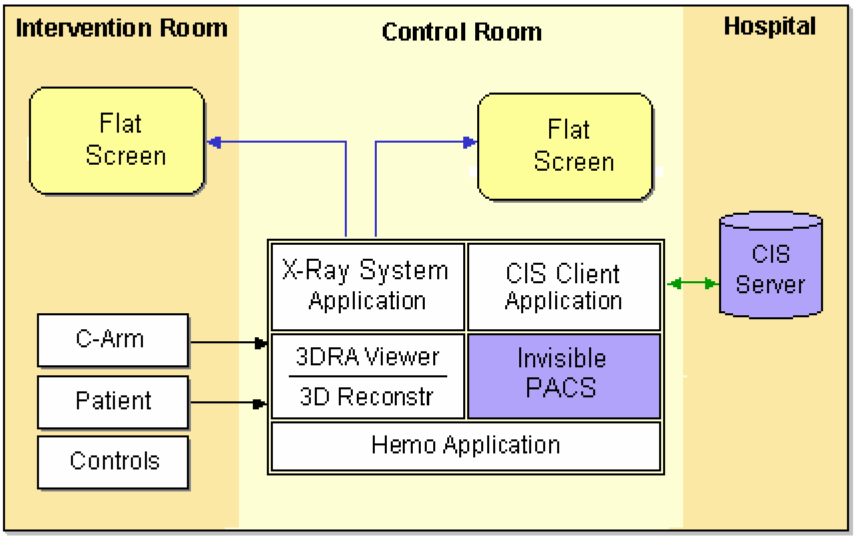


Figure 8-10: The Cathlab systems physical layout for the Full Integration Scenario

8.4.7 The Relevant Performance Attributes

Although a large number of factors have been identified as contributing to the improvement of the Cathlab clinical performance, as presented in Table 8-1, only a small number of these performance attributes require further analysis. This is because the requirements for most of the performance attributes are met by the current systems. Thus, our focus will be on those attributes that are insufficiently managed in the current Cathlab, namely: the *MR study retrieval duration*, the *3D model reconstruction duration*, and the *3D model display frame rate*.

Next, the values of the performance attributes of interest will be studied per scenario, making use of the various configurations of the Cathlab systems presented in the previous section.

8.4.7.1 MR study retrieval duration for the Minimal and Data Scenario

According to the proposed configuration for the minimal and data integration scenarios the patients' MR studies are available in the PACS. To review these studies on a dedicated monitor, the cardiologist has to walk to the control room, and by using a PACS client, to retrieve these pictures via some type of network, Figure 8-11.

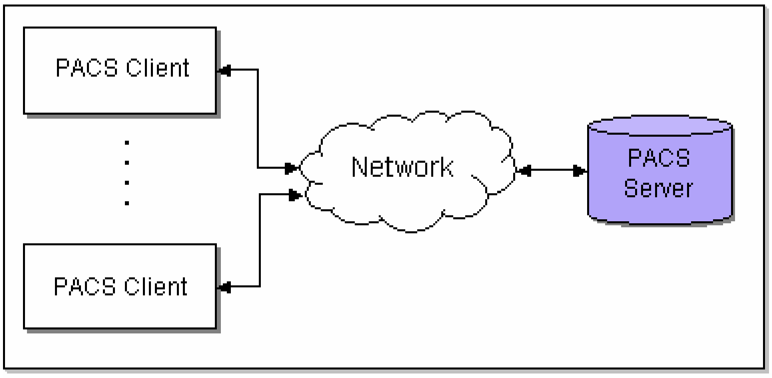


Figure 8-11: PACS server and client configuration for retrieving MR studies

For estimating the duration of retrieving an MR study, the following physical model of the system's architecture is used, Figure 8-12.

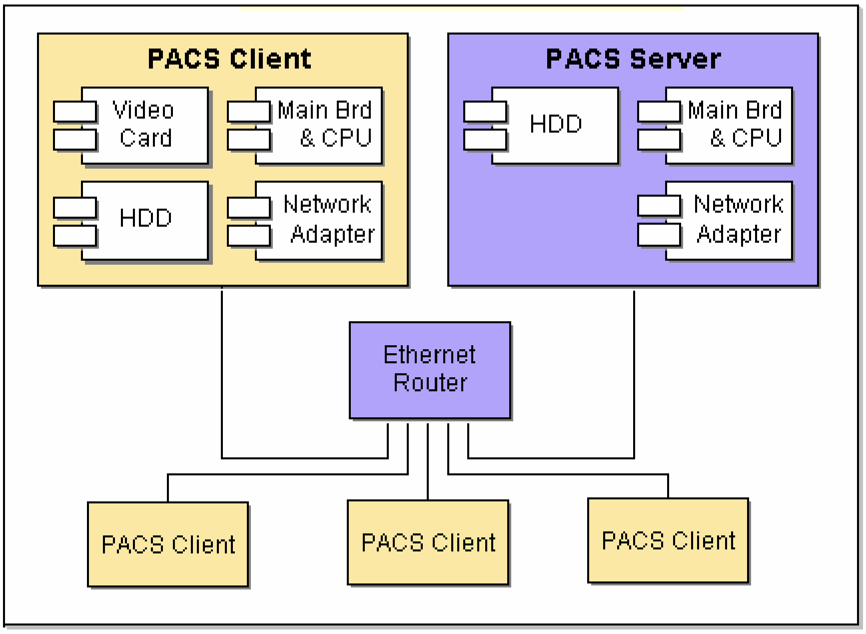


Figure 8-12: The Physical View Model for Minimal Integration Scenario

For the PACS client, as well as for the PACS server, a number of factors have been identified as contributing to the overall MR retrieval duration, namely: the MR study size, the network adapter type, the router type, the network load, the I/O bus type, the CPU speed, and the hard disks speed. The assumptions we make are that the PACS server and its clients are dedicated PCs with sufficient processing power for real time display of the MR studies.

This means that for estimating the duration for displaying an MR study, the analysis will have to concentrate on the communication link between the PACS server and the client. For this purpose we will investigate only the following devices: the MR study size, the I/O bus type, the network adapter type, the router type, and the network load.

The MR Study Size

A typical case of MR study entails 30 slices of 128x128 pixels, 16 bits each with 100 dynamics. The dynamics of a MR represents the number of times a slice is taken in the unit of time in order to capture the transformations that may take place in that slice, for example the movement of the heart. This means that an MR study acquisition size becomes as large as 96 MB, which can be easily approximated at 100MB. However, typically only 6 to 8 slices are displayed at one time, meaning 25MB.

The I/O Bus type

The I/O bus is the path data travels to get to a peripheral I/O card such as the network adapter. The most common I/O bus is the Peripheral Component Interconnect Bus (PCI). The bandwidth offered by the current PCI buses varies from 100MB/s up to 10GB/s, as shown in Table 13-7. Because the data pass the devices in a serial fashion, the estimated durations for MR study retrievals depend on the slowest device and are shown in Table 8-2.

The durations presented in Table 8-2 are calculated under the assumptions that the latency of PACS server is in the order of 1/10 of a second, and the network load is less than 50%. These assumptions are feasible given the fact that a large hospital can have between 5 and 100 clients for a PACS server, with approximately 20 of them active in the same time.

The Network Adapter type

The network adapter sets the speed to which data is transferred via the network. We assume network adapter types with throughputs ranging from 2,125Gbps to 10Mbps.

The Router type

The router is the device that determines the next network node to which a package should be forwarded towards its destination. In our case, the router offers the PACS clients access to the PACS server or to another network in the hospital. The retrieval of a MR study from the PACS is done via the router. The transfer rates offered by existing routers can range from 60Gbps to 100 Mbps.

8.4.8 Minimal and Data Integration Scenario - Discussion

The numbers presented in Table 8-2 can be interpreted as follows: a gigabit transfer rate solution for both the network connection and the PACS client/server is expected to provide MR retrieval durations lower than 1 second. From a user perspective, this is the best case. A 400-megabit transfer rate would be still an acceptable solution for retrieving a typical MR study, while going in the range of 100 megabit transfer rate or lower, would provide unacceptable transfer durations for the user (e.g. between 10 and 300 seconds).

In both minimal and data integration scenarios the retrieval of the MR pictures is done in the same manner - a dedicated workstation which is connected to the PACS server.

Table 8-2: The theoretical duration estimates of the real duration of transferring 100MB data via various network bandwidth for the Minimal and Data Integration scenario

Data Transfer Rate	Data Transfer Rate MB/s	Theoretical transfer time for 100MB in seconds	Estimated transfer time for 100MB in seconds	Relation with Table 8-1
2.12 Gbps	265	0,37	0,46 – 0,925	Best Case
2 Gbps	250	0,4	0,5 – 1	
1.25 Gbps	156	0,64	0,8 – 1,6	Planned level
1 Gbps	125	0,8	1 – 2,8	
400 Mbps	50	2	2,5 – 5	
100 Mbps	12,5	8	10 – 28	
10 Mbps	1,25	80	100 – 280	

8.4.8.1 MR study retrieval duration for the Presentation & Control Scenario

The presentation and control scenario has the two variants of cold and warm integration. For the cold integration, where the only change is the incorporation of a hardware switch, Figure 8-7, the MR retrieval durations estimates presented in Table 8-2 are still applicable.

In the case of warm integration, the proposed architecture for the integrated Cathlab consists of a single workstation connected to the PACS and CIS servers. On this workstation are installed all the different applications, namely: the PACS client for viewing X-ray or MR patient studies, the Hemo system and CIS client for patient hemodynamics monitoring and data logging, the X-ray system for acquiring X-ray images, and the 3DRA application for constructing and viewing 3D models. Although all the applications are running on a single machine, the user scenario specifies that (1) the MR studies are reviewed prior the procedure, (2) new X-ray pictures are not acquired in the same time. In these circumstances, we can conclude that although the workstation may have all the other applications active in the background, these will not require any significant computational power. Thus, the MR application will have available most of the workstation's computing power, bus and network bandwidth.

Given these assumptions, the MR studies retrieval duration estimates which have been calculated for the minimal and data scenarios, Table 8-2, are expected to be also applicable for this type of integration.

8.4.8.2 MR study retrieval duration for the Workflow and Full Scenario

The workflow and full integration scenarios are similar in the sense that for both is introduced the idea of an invisible PACS (i.e. caching locally on the workstation the patient data available in the PACS prior the procedure). In detail, what is happening is the following. Every day there is a number of patients scheduled for treatment in the Cathlab. Before the procedure, the workstation locally downloads the data belonging to the patients scheduled for the next day (e.g. MR studies, patient information, etc). In this way, the network communication will not play a role in the MR study retrieval duration. Thus in these scenarios, the caching solution can be now implemented using slower speed network connections, like the 10 or 100 Mbps.

The possible bottlenecks in the workflow and full scenarios will come now only from the I/O bus speed and the processor load by the moment the MR pictures are retrieved from the local cache. However, under the assumption that no other application is running in the same time the MR pictures are reviewed, the duration for displaying a set of 6 to 8 pictures, 25MB large, is estimated to be as fast as specified in Table 13-7 in the Appendix F, and this speed is sufficient and fulfils the performance objectives.

8.4.8.3 3D Model Reconstruction Duration

For estimating the duration of the 3D model reconstruction, we have to introduce the reconstruction process as currently done in practice, as well as for the different systems architectures proposed for each scenario.

The 3D reconstruction process

The cardiologist needs a better understanding of the distribution of the blood vessels in the body area of interest. He can achieve this using the 3DRA (3D rotational angiography) to build a 3D model of the patient blood vessels. For obtaining the 3D model, the cardiologist has to position the patient table, insert contrast fluid in the interest region of the patient and set the X-ray system for performing a rotational angiography. The result is a set of 100 images X-ray, with an image size of 512x512 pixels and 2 bytes per pixel, which gives in the end a size set of 50MB. After acquisition, the images are calibrated for compensating the movement of the patient (e.g. the breathing or the heart movement of the patient). As soon as the calibration is done, the images are sent to the 3DRA workstation. The 3D reconstruction starts as soon as the first image is received, Figure 8-13.

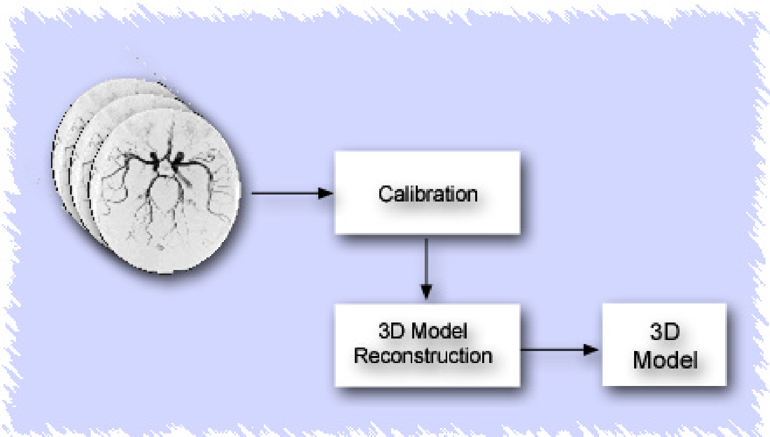


Figure 8-13: Schematic overview of the 3DRA – the 3D model reconstruction process

The duration of these activities are summarized below in Table 8-3, and are based on the performance characteristics of the current systems.

Table 8-3: The activities and durations of the 3DRA reconstruction process for current systems

Activity	Implementation	Duration	Duration Rationale
Table repositioning	-	300 to 1200 seconds	Due to the fact that is done manually and the rotation must be centred on the region of interest.
Contrast fluid injection	-	20 seconds	Due to waiting time for contrast fluid diffusion through the vessels.
3DRA acquisition	Dual Xeon 2.7GHz processor	4 to 8 seconds	100 images of 512x512 pixels x 2B per pixel, which makes in total 50MB
Calibration	Dual Xeon 2.7GHz processor	30 seconds	The duration for compensating for the patient movement
3DRA volume reconstruction	Dual Xeon 2.7GHz processor	60 seconds	Includes the duration of transferring the 2D images to the 3DRA workstation. The reconstruction can start as soon as the first 2D image is available.

The X-ray System's Components

The cardiologist uses an X-ray system when taking X-ray images of a patient.

The X-ray system is basically a standard PC (i.e. x86 Intel architecture, >1GHz, >256MB RAM) equipped with I/O devices like keyboard, mouse, networking, user interface modules, etc, and can communicate via the PCI bus with three specialised modules: image detector, image processing (IP), and image storing (IS).

In the current X-ray system the various modules are described in Figure 8-14. The image detector is the acquisition module for the X-ray pictures. The image processing module is responsible for all real time image-processing functions. These modules are implemented in Asics (application specific integrated circuits). The image-processing rate is 30 images/second at a resolution of 1024^2 and 7 images per second at 2048^2.

All the other non-real time image processing will be executed in software. The X-ray images are made available by the image storage after all images have been acquired. The image storage is a dedicated RAID (redundant array of independent disks) with a maximum rate of 40MB/s. The link between image processor and image storage is a HSL (high speed link), which allows the transport of 30 images/second at 1024^2. The HSL is introduced for avoiding sending real time data on the system's PCI bus.

The 3DRA Model Reconstruction Options

Independent of the integration scenario type, in the Cathlab case study two reconstruction solution were proposed:

Case **(1)** – *Greedy Reconstruction* - The 3DRA reconstruction process will begin as soon as all the X-ray images have been acquired and made available in the IS, Figure 8-15.

The data path starts in point **(1)** and ends in point **(3)**.

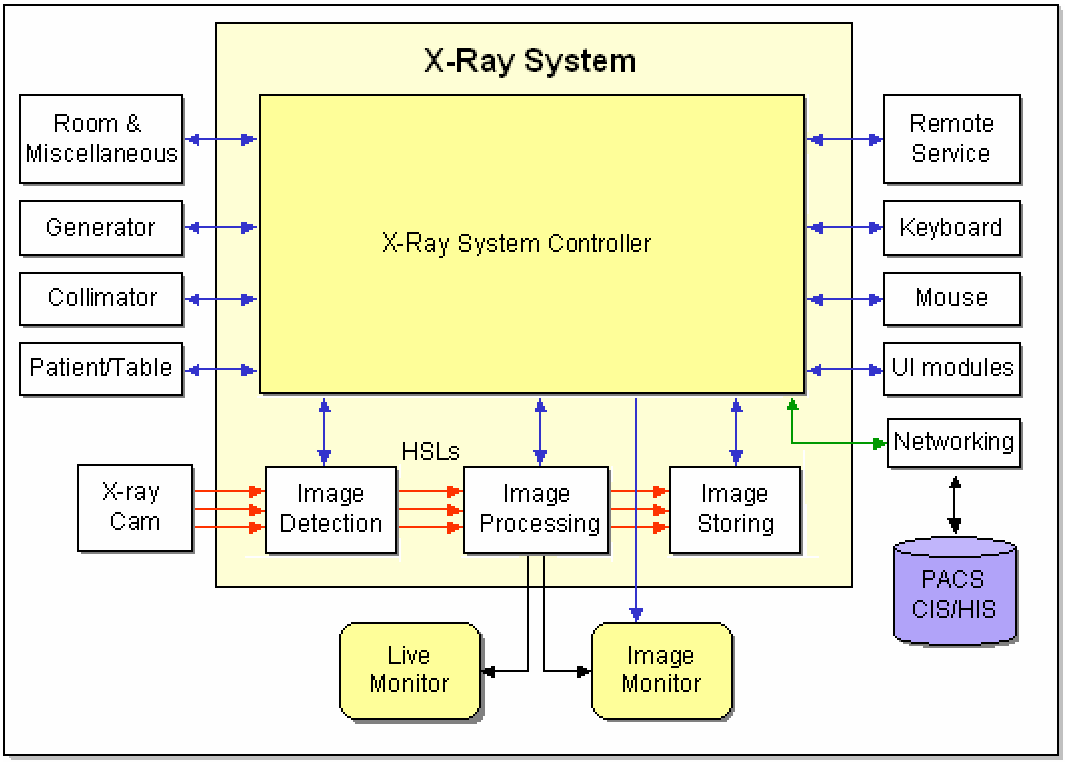


Figure 8-14: The X-ray System Modules

Case **(2)** – *Late Reconstruction* - The 3DRA reconstruction will start as soon as the first image is made available by the IP, Figure 8-14. The data path starts now in point **(2)** and ends in point **(3)**. The images are taken directly from the IP and sent over the PCI to the 3DRA workstation. Although the images are available as soon as they are acquired, the reconstruction process might be the next bottleneck in terms of reconstruction speed. The problem with this solution is its portability to other contexts.

In the Minimal, Data, and Presentation & Control for the cold integration case scenarios, the X-ray system and the 3DRA system are separated workstations. Thus the X-ray images must be sent over the network from a machine to another. The size of the X-ray image set is approximately 50MB.

Next, we will analyse the duration of the 3D model reconstruction using a gigabit Ethernet solution. The transfer via such a network connection is estimated to introduce a half a second delay in the total reconstruction duration. The reconstruction duration in such a configuration will be:

1. In case of the greedy reconstruction, the duration is given by Formula 8-1:

Formula 8-1:

$$t_{3DRA\ reconstruction\ (1)} = t_{all\ Xrays\ aquisition} + t_{network\ transfer} + t_{reconstruction}$$

With data obtained from the current X-ray system, the X-ray image acquisition takes 4 to 8 seconds, the network transfer 0,5 seconds, the calibration for motion compensation takes 30 seconds, and the 3DRA reconstruction itself takes another 19 seconds (all these on an Intel Dual Xeon 2.7 GHz machine). This makes approximate 53,5 to 57,5 seconds for the total 3DRA process.

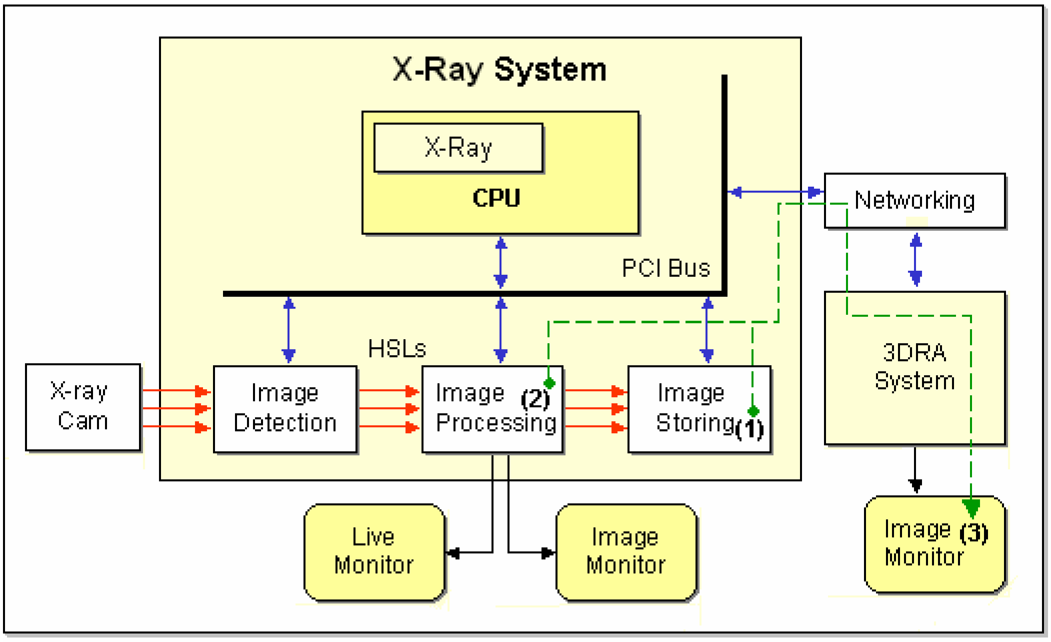


Figure 8-15: 3DRA reconstruction – 2 Cases: Greedy and Late

2. In case of the late reconstruction, the process will start as soon as the first X-ray image is available in IP. Thus, the reconstruction will be at best 4 to 8 seconds faster. The reconstruction process is expected to end with the last image being acquired at the end of the 3DRA process. However, this is true only under the assumption that the reconstruction process itself can keep up with the 30 images/sec which is the speed of acquiring the images which in the current X-ray system is not the case. Thus, the best case estimates for case (2) are 49,5 to 53,5 seconds for incremental reconstruction.

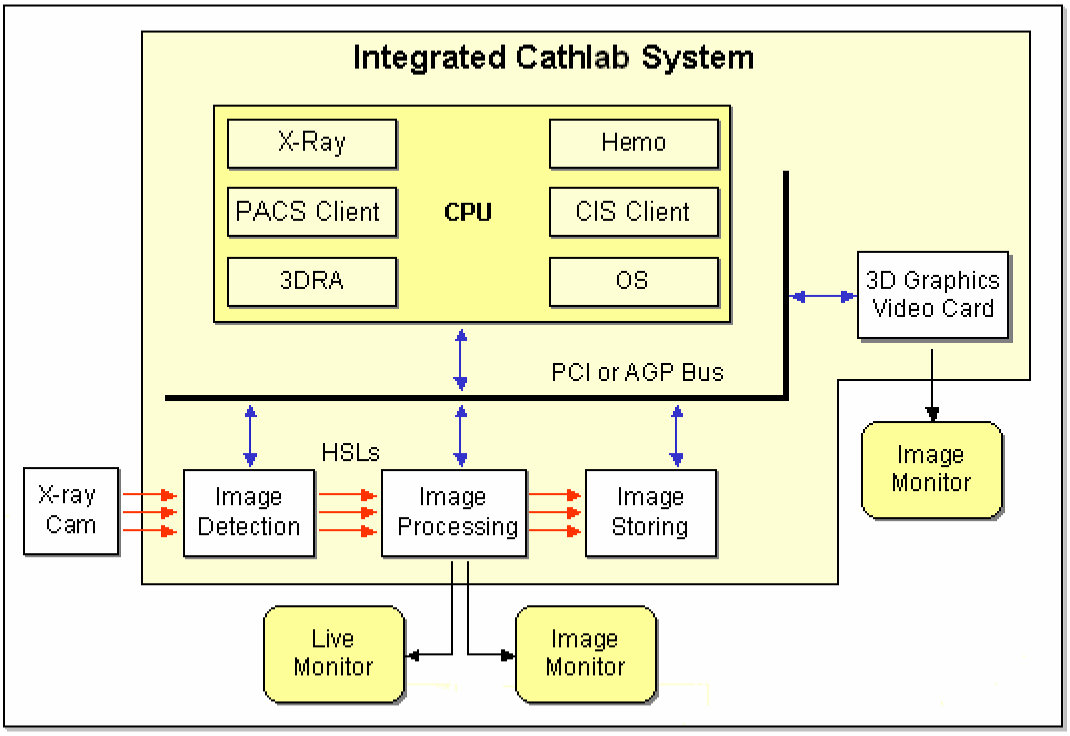


Figure 8-16: The warm integration, applications running on the same machine

For the warm integration case of the Presentation & Control, Workflow, and Full Integration scenarios, the X-ray and the 3DRA systems are now applications that run on the same machine, Figure 8-16. Thus, the estimates presented for the minimal and data scenarios for reconstruction duration, Case (1) and (2), are also valid in these scenarios.

Table 8-4: Estimates of the 3DRA process and reconstruction durations

Individual operations durations \ Scenarios		Minimal Scenario	Data Scenario	Presentation and Control Scenario: Cold Integration	Presentation and Control Scenario: Warm Integration	Workflow Scenario	Full Integration	
C-arm rotation and acquisition of 100 2D images with total size of 50MB	t1	4 -8 sec	4 -8 sec	4 -8 sec	4 to 8 sec	4 -8 sec	4 -8 sec	
Transferring 50MB	t2	0,5 sec	0,5 sec	0,5 sec	0	0	0	
Motion compensation for the 2D pictures	t3	30 sec	30 sec	30 sec	30 seconds	30 sec	30 sec	Relation with Table 8-1
Reconstruction process itself of a 3D model of 256 pixels on Intel 3Ghz	t4	19 sec	19 sec	19 sec	19 seconds	19 sec	19 sec	
In total - 3D reconstruction process duration $total\ 3D\ duration = \sum t_k$	In Case **(1)** $\sum_{k=1}^{4} t_k$	~ 53,5 to 57,5 seconds			~ 53 to 57 seconds			Poor level
	In Case **(2)** $\sum_{k=2}^{4} t_k$	~ 49,5 to 53,5 seconds			~ 49 to 53 seconds			

In conclusion, the expected results for the rotational angiography process and 3D model reconstruction are presented above, in Table 8-4.

8.4.8.4 3D model display frame rate

Once the 3D model is reconstructed, we are interested in the frame rate it is possible this to be displayed. This is because when navigating such a model, it should appear as a continuous movement for the human eye. For estimating the 3D model frame rate, the existing data provided in the current 3DRA workstations is used. This is shown in Table 8-5.

Table 8-5: The current frame rates for 3D model display

3D model size		Frame rate for: Minimal Scenario	Data	Presentation and Control	Workflow Scenario	Full	Relation with Table 8-1
For 128^3	Currently	15 fps					Planned Level
	New built Prototypes	30 fps					Best Case
For 512^3	Currently	4 fps					Poor Level
	New built Prototypes	20 fps					Planned Level
For 1024^3	Not implemented yet						

8.5 SQUASH Step 5: Aggregate the Performance Profiles

Three architecturally relevant performance factors have been analysed in this chapter. In order to come up with feasible data, the performance attributes have been estimated by analysing concrete design proposals.

These performance factors are: the MR study retrieval duration, the 3DRA acquisition and reconstruction process duration, and the 3D model display frame rate. Based on the findings presented in Table 8-2, Table 8-3 and Table 8-5, it can be concluded that it is possible to satisfy the performance requirements described in Table 8-1.

In estimating the performance attributes of the Cathlab systems we used the technical specifications available for the software or hardware components (e.g. the characteristics of the video cards, 3D reconstruction software, or network cards speed). The theoretical values for the different performance attributes were calculated based on these specifications. The accuracy of these calculations is +/- 20%. This is because we neglected aspects like network traffic and/or congestion, CPU load, bus bandwidth limitation, or memory access time.

The overall picture of the performance factors analysed are presented below, Table 8-6.

Table 8-6: Overall performance estimates, summarized

Performance Factor		Minimal Scenario	Data	Presentation Control	Workflow Scenario	Full	Relation with Table 8-1
MR retrieval duration		Can be done in less than a second if a Gigabit Ethernet solution is used.					Best Case
3D image reconstruction duration		~ 1 minute – most of the time is consumed in the motion compensation correction, approx. 30 seconds, and in the 3D model reconstruction, approx. 19 seconds.					Poor Level
3D model display rate	For 128^3	30 fps – with the new prototypes					Best Case
	For 512^3	20 fps – with the new prototypes					Planned Level

This means that in case of a new integrated Cathlab system, it is possible to propose an architecture that improves on the MR retrieval duration (from currently a few minutes to less than a second), and the 3D model frame rate (from currently 8 frames per second up to 30 frames per second). The duration of the 3D model reconstruction will remain an issue that has to be improved. The smallest reconstruction time is estimated to be approx. 60 seconds.

8.6 SQUASH Step 6: Improve the Scenarios

From a performance point of view, all five scenarios proposed exhibited comparable levels for the performance attributes being analyzed. A possible improvement point could regard the image reconstruction duration.

8.7 Conclusions

This chapter presents the SQUASH method for the definition and analysis of the architectural relevant performance attributes for the integrated Cathlab systems, namely the duration of retrieving a magnetic resonance study, the duration of acquiring and reconstructing a three-dimensional X-ray model, and three-dimensional model frame rate display. These attributes were identified by analysing the proposed architecture scenarios, and refine these results during interviews with domain experts. The final results are summarized in Table 8-6.

Analysis of the performance attributes for different design cases (associated with the proposed scenarios) showed that it is possible to come up with architectures that meet their performance requirements. The estimated values for each of the performance factors were presented in Table 8-6. Based on such estimates the decision-makers (architects) could make architectural trade-offs if more quality attributes are taken into account (e.g. usability, cost, etc). The performance estimates have been calculated theoretically, based on the technical specifications of the various hardware/software components involved. Getting the exact values of these attributes requires more modelling effort than spent for this case study. For an early estimate of the integrated Cathlab performance, the figures presented in Table 8-6 have been considered as good enough. However, the real performance values will only be known once there are working prototypes which implement the systems described by the different integration scenarios.

In case of a new system, where not so much information would be available in advance, the performance analysis would probably have to be performed for a restricted set of performance factors. However, all the calculations presented above could still be performed, provided the fact that the theoretical estimates of the performance relevant components, or subsystems, become available.

Chapter 9

9 Cost Analysis with SQUASH

Introduction

This chapter introduces the cost analysis, which is the Step 4.b in SQUASH, as shown in Figure 4-1. In this analysis the attention shifts to the non-technical details of the Cathlab integration scenarios. The goal of this chapter is to present a systematic way to estimate the effort required for implementing the various integration scenarios. To support the decision making process, all effort estimates presented hereafter are made quantitative.

9.1 Existing Cost Estimation Models

In literature there are a couple of cost estimation models that one might use when performing such an analysis. Some of these cost models include: parametric models, expertise-based techniques, learning-oriented techniques, dynamics-based models, regression-based models, and composite-Bayesian techniques. Boehm et all, presents an overview of all these models, (Boehm *et al.* 2000). Their conclusion is that no one model or technique can be nominated as the most suitable for performing a cost analysis. In our case study a straight forward way of estimating the cost has been chosen. This is because using any of the above mentioned cost models would have been a too laborious task for the purpose of our analysis.

9.2 Cost Estimation with SQUASH

To calculate the final costs associated with each of the architecture scenarios, a simple schema was used. The integration scenarios regard the improvement and/or integration of the current Cathlab systems. Therefore two major cost components appeared: the development cost, and the production cost. The development cost accounts for the initial investment required for the implementation of the different integration scenarios. The production cost accounts for the actual construction of the various system configurations, in a mass production type of setting. In addition to these, we tried also to account for other sources of cost such as: the cost of market introduction, manufacturing costs, or the cost of sales.

Here a distinction should be made between the determining view and the assessment view for cost. To identify the sources of cost, the determining view is the Conceptual view of CAFCR, whereas to estimate the actual values of the different cost components, the assessment view is the Realization view.

We start by looking at the cross-view relationship of the architectural scenarios. The cost analysis and estimation for Cathlab scenarios is performed based on the conceptual and respectively realization scenarios introduced in Table 9-1. An initial approach included the assessment of the costs of the individual features. However, that has turned out to be a too lower level of detail for conducting such an analysis. Instead of accounting for the individual features, we looked at clustering the various functionality provided by the systems. Therefore the assessment was finally done in terms of the cost for covering a certain range of features for a given architectural scenario. For example to assess the production cost of the realization scenarios the following judgments have been made. The Multihost realization scenario requires the use of eight CRT monitors and four dedicated PC's used as individual workstations, while the Co-host realization scenario requires a single PC with two CRT monitors only. The Flat screen realization scenario is based on the Co-host scenario, with the adaptation for two large flat screens replacing the CRT monitors.

Table 9-1: The Architecture Scenarios and Cross-view Relationships

<table>
<tr><th>Customer</th><th>Application</th><th>Functional</th><th>Conceptual</th><th>Realization</th></tr>
<tr><td rowspan="3">Academic</td><td>Minimal</td><td>Minimal</td><td>-</td><td>-</td></tr>
<tr><td>Data</td><td>Data</td><td>DM Integration</td><td rowspan="2">Multihost</td></tr>
<tr><td rowspan="2">Presentation & Control</td><td rowspan="2">Presentation & Control</td><td>HW Switch</td></tr>
<tr><td rowspan="3">Production</td><td>Alt-Tab</td><td rowspan="2">Cohost</td></tr>
<tr><td>Workflow</td><td>Workflow</td><td>Coordinator</td></tr>
<tr><td>Full</td><td>Full</td><td>Luxury</td><td>Flat screen</td></tr>
</table>

Below it is explained how the SQUASH method was applied for conducting the cost assessment for the Cathlab scenarios.

9.3 Assessing the Cost for the Cathlab Scenarios

SQUASH was applied to perform the cost assessment for Cathlab scenarios.

SQUASH Step 1: Identify Stakeholders – The stakeholders of the Cathlab remain the same as identified in the previous chapters, these are: the hospitals or clinics, the government, the development organization producing the Cathlab systems, and the patient.

SQUASH Step 2: Identify Objectives – The cost objectives of the above mentioned stakeholders can be summarized as follows: the development organization is interested in maximizing profit; the hospital is mainly interested in minimizing the cost of ownership for the cathlab systems; while the patient is interested in paying less for his treatment.

SQUASH Step 3: Make Objectives Quantifiable – For cost analysis, this step of SQUASH is straight forward. All costs will be expressed in monetary units, hereafter euros.

SQUASH Step 4: Analyze Scenarios – In this step the Cathlab scenarios are analyzed per scene with respect to what are the new features proposed in each of them. A key issue in simplifying this analysis is the clustering the features into groups of features required by a certain integration level of Cathlab scenarios. Table 13-14 to Table 13-19, in Appendix H, show the general overview of what scenarios incorporate which of the feature clusters.

Step 4.b.1.: Estimate the Development Cost – in this step is gathered information about the initial development costs required by each integration scenario. The development costs were gathered by means of interviews with architects. The confidence intervals for these figures were hard to establish. This is because not enough expert opinions could be collected at the time this exercise was conducted. The confidence interval should be the percentage around the estimated value (in plus or minus), the expert considers as plausible for the provided estimate. The confidence coefficient could play a role in the final calculation of cost. To assess the development costs, the conceptual scenarios are considered, Table 9-1. The conceptual scenarios considered are: the DM Integration scenario focusing on the management of data, which is making the various systems in the Cathlab understanding each other by using the same data protocol; the HW Switch scenario in which the presentation of the data on the same displays is realized via a hardware switch to the various workstations; the Alt-Tab scenario in which applications run on the same machine, the switch between the applications is realized with the command Alt+Tab; the Coordinator scenario which builds on top of the Alt-Tab scenario, to which new features for 3D image viewing and X-ray position coordination are provided; and the Luxury scenario in which is the highest level of integration of the Cathlab systems in a luxurious manner, such as large flat screens for display and specialized controls for image or 3D model reviewing and navigation. The results of this step are shown in Table 9-2.

Step 4.b.2.: Estimate the Production Cost – here is estimated the effort to produce and the new systems as proposed in the integration scenarios. The production cost assessment is rather high level, without going too much into details or employing an established technique for such type of cost assessment. It was assumed that the architects have more knowledge and access to specific data which would enable them to reason about the effort that would go into the development of the new Cathlab scenarios, and translate this into monetary values. The assessment is based on the Cathlab realization scenarios which are: Multihost (or multiple PC's running different applications), Cohost (or single powerful PC on which run all applications), and Flat screen (which is a Co-host scenario with luxurious functions such as flat screens replacing the traditional monitors). Based on the realization view, the architects can accurately estimate the development effort for the proposed feature clusters.
The results of this step are summarized in Table 9-2.

SQUASH Step 5: Aggregate the Total Cost – in this step the individual cost components are aggregated, and presented below in the Table 9-2.

Table 9-2: Estimated Development and Production Costs for the Cathlab Architecture Scenarios, aggregated.

Cost Components	Min	Data	PC Hw Switch	PC Alt+Tab	Wf	Full
Development	1300K€	2000K€	4000K€	6000K€	10000K€	10000K€
Production	500K€	500K€	550K€	100K€	100K€	300K€
Total	1800K€	2500K€	4550K€	6100K€	10100K€	10300K€

To visually indicate the acceptance level of a certain cost in a scenario, a five level colour scale is used ranging from excellent (indicated by dark green shading), to good (indicated by light green shading), acceptable (indicated by yellow shading), poor (indicated by orange shading), and unacceptable (indicated by red shading), as shown in Table 9-2.

SQUASH Step 6: Improve Scenarios – in case the resulted development costs are at an unacceptable level, the scenarios have to be revisited and see if either the proposed features can realized in more cost effective, or left out. These tradeoffs have to be cross-checked with the other assessment results (usability, performance and risk) since many of the features target the improvement of some specific quality attributes.

SQUASH Step 7: Select Scenarios – this step could be carried out if the final decision regarding the implementation of one or another scenario would be taken based on cost considerations only. The scenario(s) presenting the most cost effective ways of implementing the desired features would be then selected. However, SQUASH is used only to provide the necessary input for SODA in the final decision making process as will be explained in the following chapter.

9.4 Conclusions

This chapter presented the approach applied when estimating the cost using the SQUASH method. The method accounted for the main components of cost, such as the development cost – which is the cost of designing and implementing the system architecture, and the production costs which account for the actual construction of system as proposed by the various architectural scenarios.

A relevant aspect highlighted by this chapter was the distinction between the determining and the assessment views when conducting the cost analysis. The determining view is the Conceptual view of CAFCR, while the assessment view is the Realization view.

The figures presented in this chapter should be regarded as rough estimates of the effort to build such systems, but good enough for the illustrative purpose of this case study.

Chapter 10

10 Risk Analysis with SQUASH

Introduction

This chapter presents the application of SQUASH Step 4.c for scenario-based risk assessment at a system architecture level, as introduced in Figure 4-1.

It was important to apply the SQUASH method for risk assessment in a concrete case study, to see to what extent the method can be actually carried out. The lessons learned from this exercise are that it is possible to identify, starting from scenarios, the set of critical risks that can be associated with the creation of a new system. The risks are explicitly described in terms of potential hazards, their probability of occurrence and the expected consequences.

10.1 Addressing the Risk in SQUASH

In order to perform the risk assessment activity within SQUASH, we propose a stepwise approach, similar to (Williams *et al.* 1999), consisting of three steps: hazard analysis, quantitative risk assessment, and risk management.

In this thesis, the *risk* is defined as the possibility of loss (Webster Dict.). Risk can be thus characterized by two factors: (1) the probability of occurrence of a specific hazard, and (2) the magnitude of loss or harm in case the hazard occurs.

10.1.1 Step 1: Hazard Analysis

The goal of this step is to identify all plausible hazardous events, together with their possible outcomes (i.e. the type of harm or the magnitude of loss, and the persons, systems, or organizations affected if the hazards occur). This step includes the following.

- Brainstorming the hazards that may affect the system.
- Envisaging possible failure-scenarios that could generate these hazards.
- Identifying the failure-scenarios triggers and transition indicators for monitoring this type of scenarios.

10.1.2 Step 2: Quantitative Risk Assessment

In this step the envisaged hazards are analysed with respect to: (1) their probability of occurrence, and (2) the magnitude of their impact (i.e. harm, injury or loss) in case of occurrence. This step includes the following tasks.

- Estimating the probability of occurrence of each hazard.
- Quantifying the size of loss in each case.
- Calculating the risk exposure levels for each hazard.
- Assigning if possible an expiration condition for each hazard.

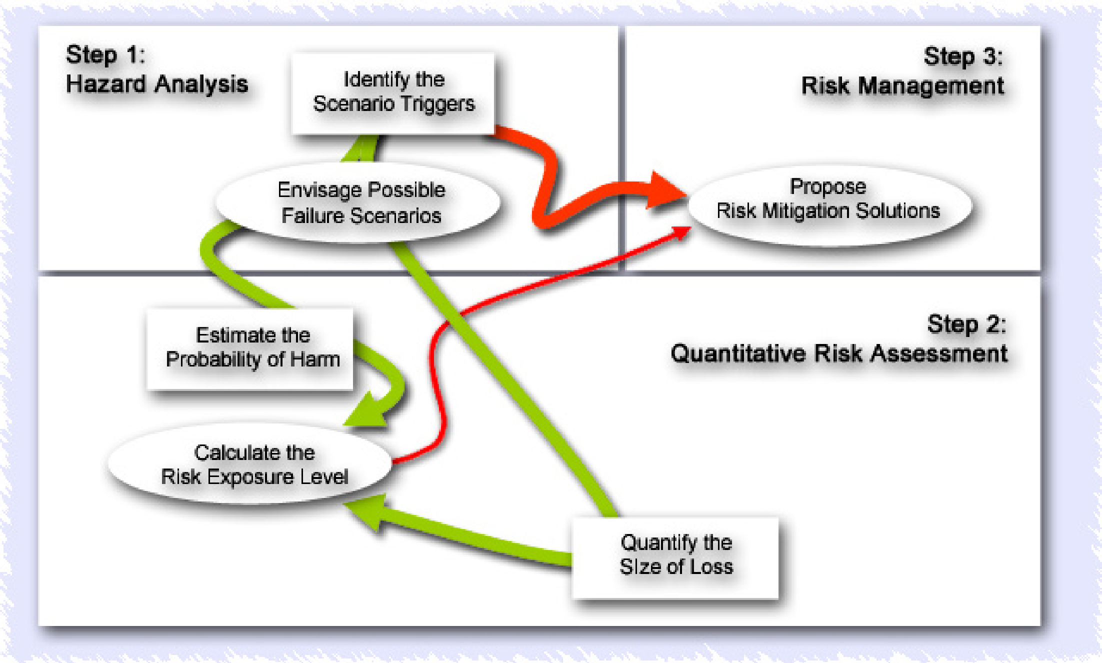


Figure 10-1: Hazard analysis tasks - An Overview of the Risk Assessment Steps

10.1.3 Step 3: Risk Management

In this step solutions are proposed to reduce the effect of the envisaged risks, or where it is possible to even eliminate them. This last step consists of the following tasks.

- Monitoring the transition indicators for each hazard.
- Executing the mitigation strategies if hazards happen to occur

10.2 Collecting the Results

Due to the large amount of data that results from the hazard analysis step, a way of collecting and presenting this data is required. The data can be presented in two ways:

- In the a form of a table having as rows the envisaged hazards and as columns all the other issues related to a specific hazard, like failure scenarios, provoked harm or loss, scenarios triggers, transition indicators, etc. The table form is compact but in practice it becomes very large, containing many columns and large pieces of text, and thus it is more difficult to handle.

- Using a card type of specification. This contains the same type of information as a table does, Figure 10-2. Although the risk cards tend to be less compact, they can be easily exchanged between the participants during the risk assessment exercise.

<table>
<tr><td colspan="2">Type of Hazard: <identifier>, <name></td></tr>
<tr><td rowspan="2">Failure Scenario:
<identifier>, <scenes description></td><td>Scenario Trigger: <identifier>, <name></td></tr>
<tr><td>Transition Indicator 1: <condition>, <description></td></tr>
<tr><td colspan="2">Harm or Loss: <identifier>, <description></td></tr>
<tr><td>Risk Owner: <name></td><td rowspan="2">Risk Mitigation Solutions: <description></td></tr>
<tr><td>Risk Expiration: <condition>, <description></td></tr>
</table>

Figure 10-2: Hazard identification template with Risk Cards – A Template

10.3 Assessing the Scenarios

Once the risks have been identified in step 1, they will be used in step 2 as assessment criteria for the proposed scenarios.

The goal is to provide the decision makers with quantitative information about the probability of occurrence of a certain risk in the various scenarios as well as the magnitude of loss or harm provoked if the envisaged risk becomes real. For this purpose we use a table containing the identified hazards shown in the rows and the scenarios' scenes shown in the columns. The intersection of a row and a column will contain two explicit values, namely the estimated probability (P) of a hazard and its magnitude (M) of loss or harm as described in Table 10-1. The assessment is repeated for each user scenario.

For assigning certain values for P's and M's, quantitative data are used (e.g. percentage estimates, amount of loss in euros, etc). Where quantitative estimates are hard to gather, expert opinion, or qualitative estimates are possible alternatives. For the probability of occurrence, such qualitative estimates would mean for instance be a five-step scale ranging from rare, to occasionally, probable, likely, and certain. For the magnitude of loss or harm the qualitative estimates would for instance be a five-step scale but ranging from minor, to moderate, excessive, severe, to catastrophic, Table 10-1.

Table 10-1: The matrix used to calculate the risk exposure level

Risk Exposure (RE) RE = P*M		Magnitude of Loss or Harm (M)				
		Minor	Moderate	Excessive	Severe	Catastrophic
Probability of Occurrence (P)	Rare	Low Risk **[Lo]**	Medium	High Risk	Huge Risk	Catastrophic
	Occasional	Medium **[Me]**	High Risk	Huge Risk	Catastrophic	
	Probable	High Risk **[Hi]**	Huge Risk	Catastrophic		
	Likely	Huge Risk**[Hu]**	Catastrophic			
	Certain	Catastrophic **[Ca]**				

After all probabilities “P” and magnitudes “M” have been established, the risk exposure (RE) values can be calculated for each scenario, Table 10-2.

The RE values are calculated based on the matrix given in Table 10-1, by multiplying the probability of occurrence (P) with the magnitude of loss (M).

After all the scenarios have been assessed with respect to how well they can deal with the envisaged hazards, an overview is presented. The goal is to come from the details of the individual scenarios, as shown in the Appendix G, to a general overview as shown in Table 10-4.

The overview is called the scenarios’ risk profile, and it will be used also as input the in the final decision-making process among the other scenario profiles, such as the quality and cost profiles.

Table 10-2: An example of risk assessment per scenario scene – the cells represent the values for probability and magnitude of a certain hazard.

		Scenario Scenes		
Hazard		Scene 1	Scene 2	Scene 3
Hazard 1	Probability	20% (occasional)	-	-
	Magnitude	1.000.000.€ loss (excessive)		
Hazard 2	Probability	-	10% (rare)	-
	Magnitude	-	1 month delay (moderate)	-

10.4 The Hazard Analysis Step for the Cathlab Scenarios

The proposed risk model has been applied for the Cathlab scenarios. The major risks that have been identified are presented in detail in the Appendix G, and summarized below in Figure 10-3

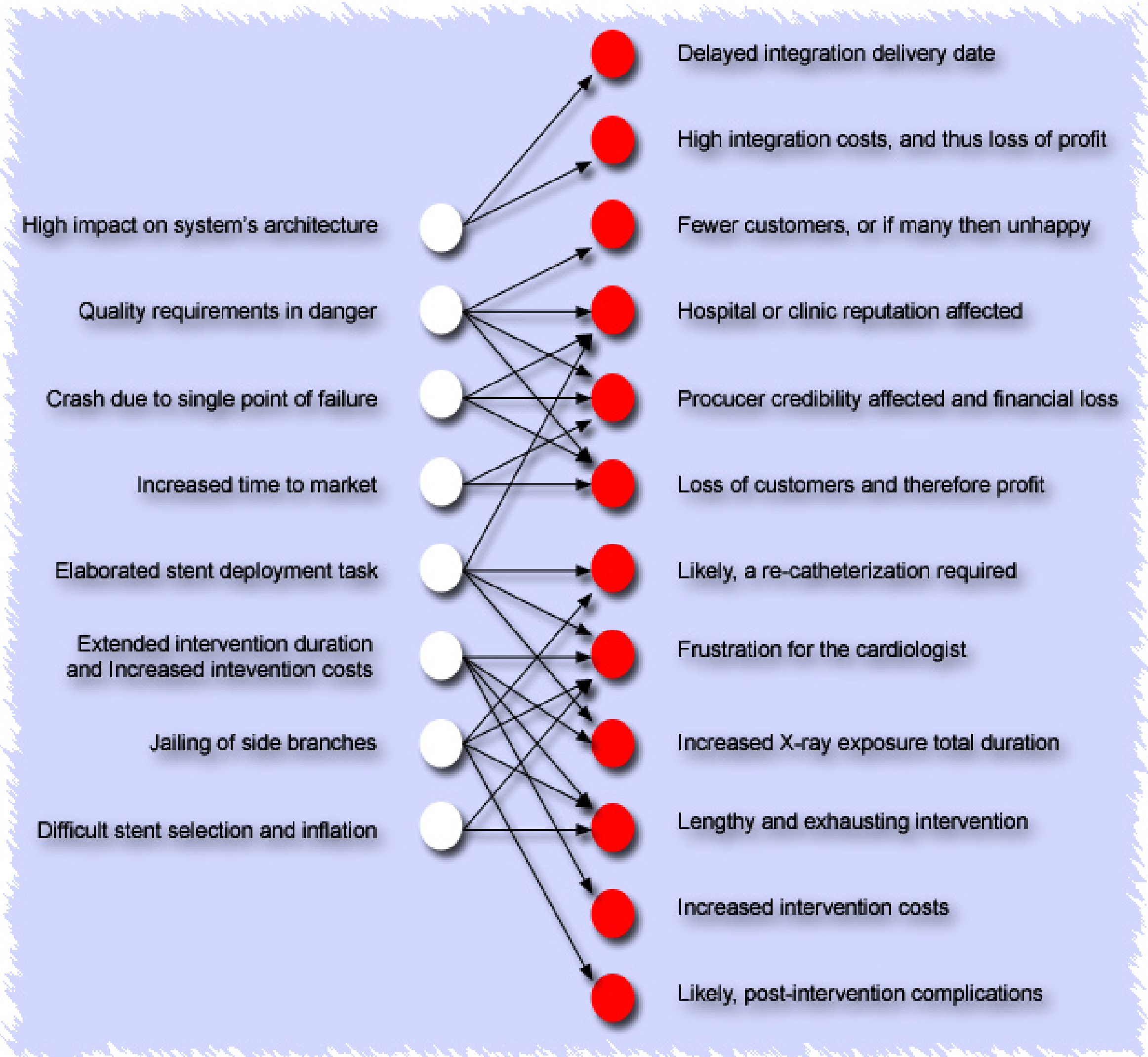


Figure 10-3: The relationships between the most important hazards and consequences

The individual hazards and their consequences are presented in Table 10-3, and summarized in Figure 10-3.

Table 10-3: A summary with the identified risks and their consequences,

Here, these are enumerated as they were brainstormed during the case study, and in the Figure 10-3 they are re-organized to show the interdependencies between specific hazards and their possible consequences.

Hazard Type	Hazard Name	Possible Consequences for the identified Hazards
Technical Hazards	High impact on the current X-ray system's architecture	Delayed integration delivery date
		High integration costs, resulting in loss of profit
	Crash due to a single point of failure	Hospital or clinic reputation heavily affected
		System producer loss of credibility and financial loss in case of complications or damage for the patient
Business Hazards	Quality requirements in danger - Integrated system fails to meet its quality requirements	Fewer customers, since many of then are unhappy with the quality aspects of the system.
	Increased time to market – due to delays in development	Loss of customers and therefore profit
Application Hazards	Elaborate stent deployment task	Patient will have a re-catheterisation.
		Frustration for the cardiologist which has to work with such system
		Hospital or clinic reputation heavily affected.
		Increase in the total amount of X-ray exposure for the cardiologist and the patient
	Extended intervention duration (over 45 minutes as performed with the current systems)	Increase in the total amount of X-ray exposure for the cardiologist and the patient
		Lengthy and exhausting intervention causing pain and fatigue for the cardiologist, which has to wear a radiation protective apron

Application Hazards	Increased intervention costs	Increase in the total amount of X-ray exposure for the cardiologist and the patient.
		Increasing the cost of the intervention with up to 50 to 100%
	Jailing of side branches	Likely a re-catheterization required.
		Frustration for the cardiologist which has to work with such system.
		Lengthy and exhausting intervention
		Increase in the total amount of X-ray exposure for the cardiologist and the patient
	Difficult stent selection and inflation	Lengthy and exhausting intervention.
		Frustration for the cardiologist which has to work with such system

10.5 The Quantitative Risk Analysis for Cathlab Scenarios

Next, the proposed user scenarios are assessed with respect to how well they can deal with the envisaged hazards. For better accuracy the assessment is performed per scenario scene, so that the scenes that exhibit an unacceptable risk exposure value are pointed out explicitly. The results of this analysis are presented in the Appendix G, Table 13-8 to Table 13-13.

The individual risk exposures values calculated per scenario-hazard are then aggregated in form of a general overview as shown below in Table 10-4. The way these individual estimates for risk exposure were calculated is as follows. In Table 13-8 to Table 13-13 one can see that some risk exposure values can be calculated straight forward using the formula the size of loss in monetary values associated with a specific hazard, multiplied with the probability of appearance of that hazard. The size of loss and the probability are estimated having in mind the usual intervention scenario, which is a mid size patient, low probability of interventional side effects, and belonging to the 50+ age group. This makes that almost all the risk exposure estimated to be expressed per procedure. However there are two risks the *High impact on system's architecture* risk and directly correlated with this, the *Increased time to market* risk, which are estimated over a period of time, which can vary from 6 to 18 months. In order to be comparable the risk exposure is calculated also procedure as follows. First the risk exposure is calculated for the given number of months, after which is divided with the number of months, and then further divided with the number of days in a month, and last divided with the number of interventions per day in a usual clinic or hospital. The number of interventions per day is calculated as follows.

Table 10-4: The resulting risk profile for the various integration scenarios, as in the Table 13-8 to Table 13-13 from Appendix G.

Risk	Minimal	Data	PC Cold	PC Warm	Workflo w	Full
High impact on system's architecture	N	2.400€	1.600€	1.600€	1.600€	4.000€
Quality requirements in danger	500€	200€	100€	100€	100€	1€
Crash due to a single point of failure	N	N	N	100€	100€	1000€
Increased time to market	N	2.400€	1.600€	1.600€	1.600€	4.000€
Elaborated stent deployment task	5€	5€	5€	5€	5€	5€
Extended intervention duration	N	200€	100€	100€	100€	1€
Increased intervention costs	10€	10€	10€	10€	10€	5€
Jailing of side branches	20€	20€	20€	20€	20€	20€
Difficult stent selection and inflation	1.000€	1.000€	1.000€	100€	100€	10€

To visually indicate the acceptance level of a certain risk in a scenario, as in the previous chapters, coloured maps are used. Each acceptance level is associated with a colour as follows: level excellent indicated by dark green, level good indicated by light green, level acceptable indicated by yellow, level poor by orange, and level unacceptable indicated by dark red. This is shown in Table 10-4.

The total number of interventions per year (estimated in Section 6.2.1 at 3.000.000 per year) divided with 12 to obtain the interventions per month, divided further with 25, which is the average number of working days per month, and divided further with the total number of healthcare institutions (estimated in Section 6.2.2 at 1774, and here for the ease of calculations rounded at 2000). This is (3.000.000/12 = 250.000 interventions per month in all institutions), (250.000/25 = 10.000 interventions per day in all institutions), and (10.000/2.000 = 5 intervention per day per institution).

Below is given an example of how to translate the risk exposure from an estimate given over a period of time, into an estimate given per procedure.

In Table 13-13 are shown the following values for the hazard called *increased time to market*: size of loss 100.000.000 euros, over a period of 18 months, with a probability of loss of 9%. This means (100.000.000€ x 0,09 = 9.000.000€ risk exposure calculated over 18 months), divided by the number of months is (9.000.000€/18 = 500.000€, which is the risk exposure calculated for one month), divided with the number of working days per month is (500.000€ / 25 = 20.000€ the risk exposure per day), and divided with the number of interventions per day calculated as above, in average 5 interventions per day, (20.000€ / 5 = 4.000€ which is the risk exposure calculated for one intervention). The overall risk exposures calculated per intervention are shown finally in Table 10-4. All these calculations are required in order to provide the architects with a comparative overview of the different risk levels.

10.6 Discussion of the Results

The results presented in Table 10-4 can be interpreted as follows:

- In the Minimal Integration the cardiologist is likely to encounter a difficult stent selection and inflation procedure. This risk is also present in the Data Integration, and Presentation and Control – Cold Integration scenarios.
- The warm type of integrations, such as PC Alt+Tab scenario, Workflow, and Full integration scenario, can be categorized in the "single point of failure" group of scenarios – since here all applications run on the same machine.
- Due to a higher integration of features and subsystems, longer development and testing time, the warm type of integrations are more likely to be deployed on the market later than expected
- Overall, the stent selection and deployment task depends very much on the skills and experience of the cardiologist. New modalities providing some anatomical information about the coronaries would be of great help for the cardiologist.

10.7 The Risk Management Step for the Cathlab Scenarios

The risk management step has not been carried out completely in the Cathlab case study. This was because the system is not being developed yet, and therefore a real risk management activity cannot be actually performed. However, we created the premises for such an activity by associating with each of the envisaged hazards a transition indicator, which is a hazard monitoring mechanism. Also, as much as possible, risk mitigation strategies were proposed, see the Appendix G.

10.8 Conclusions and Lessons Learned

To summarize the scenario-based risk assessment for the new integrated Cathlab, the main conclusions are listed:

- It is possible to identify a set of critical risks associated with the creation of a new system. These risks can be explicitly described in terms of potential hazards, their probability of occurrence and the expected consequences. However, the quantification of all probabilities and consequences was an elaborated process. The risk exposure values are presented qualitatively, using an unique metric which in this case was euro loss per intervention. Together with the calculated values for the risk exposures, an acceptance level has been associated with these, as a visual aid when comparing these numbers.
- The architects should focus on those scenarios for which the risk exposure exhibit a high risk exposure level, such as high, huge, or catastrophic.
- The details of why or how those unacceptable levels occur can be traced back to individual scenario scenes, from which these risks were identified.
- The risk exposure is a suitable indicator of what the consequences of the different hazards, and therefore the quantitative details of the analysis are an important result of SQUASH.
- The scenarios' risk profile creates the means for an informed and systematic decision-making process. Associating with the various scenarios quantitative information about the risk, cost and quality, helps the decision-makers to fine-tune their intuition when reasoning about the benefits and of the proposed integration scenarios.

Chapter 11

11 Aggregating the Results

Introduction

This chapter presents the finalization of the Step 4 of SODA, namely the Feasibility Analysis of the proposed Cathlab scenarios. This step was partially explained in Section 6.4 where it stopped to let the detailed analysis of quality, risk, and cost to be carried out with SQUASH. Now, having the results of this analysis ready, as presented in Chapter 7 to 9, the finalization of the SODA Step 4 can be carried out.

To enable decision making about the scenarios to be further considered into the development, the profit resulted from the Cathlab sales has been chosen as one of the most important factors. This chapter will present how it has been estimated the impact of the qualities of the new Cathlab scenarios on the current market share of the organization. It will be illustrated how the new market share translates into sales, and how finally the cumulative profit for the organization is calculated. Based on the final profit figures, one can make more informed decision about the type of scenarios that are most likely to be required in the future and the yielded profit.

11.1 Estimating the Change in Market Share

After all the architecture scenarios have been assessed with respect to how well they accommodate the different quality factors (see Chapters 7 and 8), it is now estimated the impact of these scenarios on the current organization's market share. For doing this an approximation is used, where it is assumed that the difference in market share is proportional with the quality level of the product weighted with the importance of that specific quality. This is expressed by the Formula 11-1:

Formula 11-1: $$New\_Share_{i,j} = Initial\_Share_i + \sum_{k=1}^{n} w_{i,j,k}.v\left(a_k\right)$$

where $New\_Share_{i,j}$ is the new size of the organization's market share in segment i and future j, $Initial\_Share_i$ is the organization's current market share in segment i, $w_{i,j,k}$ is the relative importance of quality attribute a_k in segment i and future j, and $v(a_k)$ represents the value of quality attribute a_k. More precisely, $v(a_k)$ is the difference between the quality factor in the architecture scenario that is being analyzed and that same factor in the current products (responsible for $Initial\_Share_i$), scaled to a value range from -100% to 100% to account for the units in which different quality factors are expressed. For example, Table 11-1 shows the relative importance $w_{i,j,k}$ for the quality factors of interest, namely the number of walks, number of personnel involved, intervention duration, learning duration, 3D reconstruction duration, intervention average duration, and cost per procedure, in the Minimal integration scenario for the McHealth Strategic Scenario for the two market segments.

Table 11-2 shows the scaled values $v(a_k)$ of the quality factors in the minimal architecture scenario. Note that negative values indicate a quality factor that is worse than in current products, whereas positive values indicate improvements of the quality factors being analyzed.

Table 11-1: An example of relative importance indicators, for a couple of quality factors, for the Minimal Integration Scenario in the McHealth Strategic Scenario. These data come from the upper rows of Table 13-20, located in the Appendix I.

Segment	Quality Factors						
	Number of walks	Number of personnel	Learning duration	Intervention average duration	Intervention success rate	Cost per procedure	3D reconstruction duration
Low end	0.05	0.1	0.2	0.2	0.1	0.2	0.15
High end	0.04	0.1	0.1	0.2	0.5	0.01	0.05

Table 11-2: Scaled values of Quality factors for the Minimal Integration Scenario in the McHealth Strategic Scenario. The values come from middle rows of Table 13-20, located in the Appendix I.

Segment	Quality Factors						
	Number of walks	Number of personnel	Learning duration	Intervention average duration	Intervention success rate	Cost per procedure	3D reconstruction duration
Low end	-2%	0%	0%	0%	-5%	-5%	-5%
High end	-5%	0%	0%	-5%	-20%	-2%	-10%

Table 11-3: Estimated Total Cathlab Market Size [in systems per year] for 2006

Strategic Scenario (s_m)	Low-end Cathlabs (LCL)	High-end Cathlabs (HCL)
Mc Health	4.740	2.520
Clinique de Luxe	4.254	3.492
See Treat Cure	3.822	4.356
Brave New Pharma World	3.606	4.788

Marketeers estimate the current market share of the organization as large as 30% of the total size of the market. The total size of the market was calculated in Table 6-10 of Section 6.2.2, and shown again here in Table 11-3.

For each scenario *j*, the impact of the most relevant quality factors on the current market share is estimated. The new market share is calculated by formula (9). The details of these calculations are shown for each of the Cathlab architecture scenarios in each of the strategic scenarios in the Appendix I, Table 13-20 to Table 13-43. To make it easier to navigate through all the data provided in these tables, an example of such a table is given in Table 11-4 and explained below.

- Row A of such a table contains a reference about the context in which the information was provided, here below it is referred to the Minimal integration scenario of the Cathlab, in the McHealth type of strategic future.
- Row B contains the relative importance of the most relevant quality factors, such as: the number of walks, the number of personnel involved, the intervention accuracy rate, the learning duration, the 3D reconstruction duration, the intervention duration, and the cost per procedure. The values of these preference coefficients were established together with the architects and domain experts.
- Row C contains the individual impacts of the quality factors on the current market share due to a positive or negative change in the exhibited quality.
- Row D contains only the results of the calculations with formula (9)
- Row E contains the total market size, for both low and high-end segments, the current market share (MS) of the organization (i.e. 0.3 or else 30%) and the new market share as the difference between current share and the fraction due to the influence of the quality attributes (QAs on MS)
- Row F contains the number of required Cathlabs per segment, provided initially in Table 6-10 and above in Table 11-3, and the resulted value from the calculations *New Market Share*Total Market Size*.

This example is given to help the reader understanding the details of Appendix I, and to explain how some of the data is reused in the following sections of the chapter.

Table 11-4: Explaining the Table 13-20 and the like.

A	**Minimal Integration Scenario in the McHealth Strategic Scenario**							
B	**Preference coefficients**							
	The preference coefficients	The number of walks	personnel	Intervention accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
	low-end	0.05	0.1	0.1	0.2	0.15	0.2	0.2
	high-end	0.04	0.1	0.5	0.1	0.05	0.2	0.01
C	**the individual change in market share due to the values of the attributes**							
	The impact on the market share	The number of walks	The number of personnel	Intervention accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
		from 1 to 4	from 3 to 3	from 85% to 85%	from 6h to 6h	from 300s to 300s	from 40 min to 40 min	from 2000 to 2000
	low-end	-0.02	0	-0.05	0	-0.05	0	-0.05
	high-end	-0.05	0	-0.2	0	-0.1	-0.05	-0.02
D	**the combined effect = magnitude*importance for each customer segment (i.e. the low-end and the high-end)**							
				segment	correction			
	combined effect			low-end	-0.0235			
				high-end	-0.1172			
E	**McHealth**			**low-end**	**high-end**			
	market size			4138	2647			
	organization market share (MS)			0.3	0.3			
	influence of QAs on MS			0.2765	0.1828			
F	**McHealth**			**low-end**	**high-end**			
	Required Cathlabs			4138	2647			
	Organization Cathlab Sales			1144	484			

11.2 Calculating the Cathlab Sales

Based on Section 12.1, Table 11-5 and Table 11-6 show the organization's sales, calculated as the product of the total market size and the organization's new market share (Row F in Table 11-4), due to the introduction of the different architecture scenarios per market segment. These data are extracted from Table 13-20 to Table 13-43 presented in Appendix I.

Table 11-5: The expected Cathlab sales in the low-end segment per integration scenario.

	Minimal	Data	PC HW Switch	PC Alt+Tab	Workflow	Full
McHealth	1144	979	627	497	1144	979
Clinique de Luxe	1136	1013	657	709	1136	1013
See Treat Cure	1328	982	732	724	1328	982
Brave New Pharma	1117	1037	763	576	1117	1037

The same calculations were repeated for the high-end customers segment.

Table 11-6: The expected Cathlab sales in the high-end segment per integration scenario

	Minimal	Data	PC HW Switch	PC Alt+Tab	Workflow	Full
McHealth	484	495	528	547	877	870
Clinique de Luxe	531	548	597	627	1525	1882
See Treat Cure	560	572	610	649	2586	2548
Brave New Pharma	759	783	858	858	2690	3043

11.3 Estimating the Profit

The final feasibility estimates are given in monetary units expressing the expected profit per architecture scenario l in the different strategic scenarios j. The profit is calculated as the difference between the Cathlab market price and its manufacturing cost, multiplied by the expected sales figure, from which the initial development cost and the marketing cost for the new product is subtracted. The different costs or profits are multiplied by a coefficient representing the future value of money (FV_k), as a correction for the delay introduced by the production duration and the time to achieve the new market share (Boehm 1981). This is expressed in Formula 11-2, as explained initially on page 44 of the thesis:

Formula 11-2:
$$Profit_{j,l} = \left(\sum_{i=1}^{n} Sales_{i,l} \cdot \left(MarketPrice_{i,l} - FV_1 * ProductionCost_l \right) \right) - \\ - FV_2 * DevelopmentCost_l - FV_3 * MarketingCost_l$$

11.4 The Cumulative Profit Supporting the Final Decision

The resulting figures for the cumulative profit calculated for each architecture scenario, in the context of the different strategic futures, are given in Table 11-7. This table is calculated by Formula 11-2, based on Table 13-46 and Table 13-47 from the Appendix I.

Visualization is an important aid for the decision-making process. Therefore, Figure 11-1 shows the same data plotted on a single chart. One can observe that there is not a single architecture scenario that is superior for all the envisaged strategic scenarios.

Table 11-7: The Cumulative Profit Over 3 Years per Strategic and Architecture Scenario, [in million euros]

	Minimal	Data	PC HW Switch	PC Alt+Tab	Workflow	Full
McHealth	251	267	337	370	293	258
Clinique de Luxe	232	255	284	370	455	546
See Treat Cure	180	196	238	309	633	591
Brave New Pharma	191	243	284	315	545	592

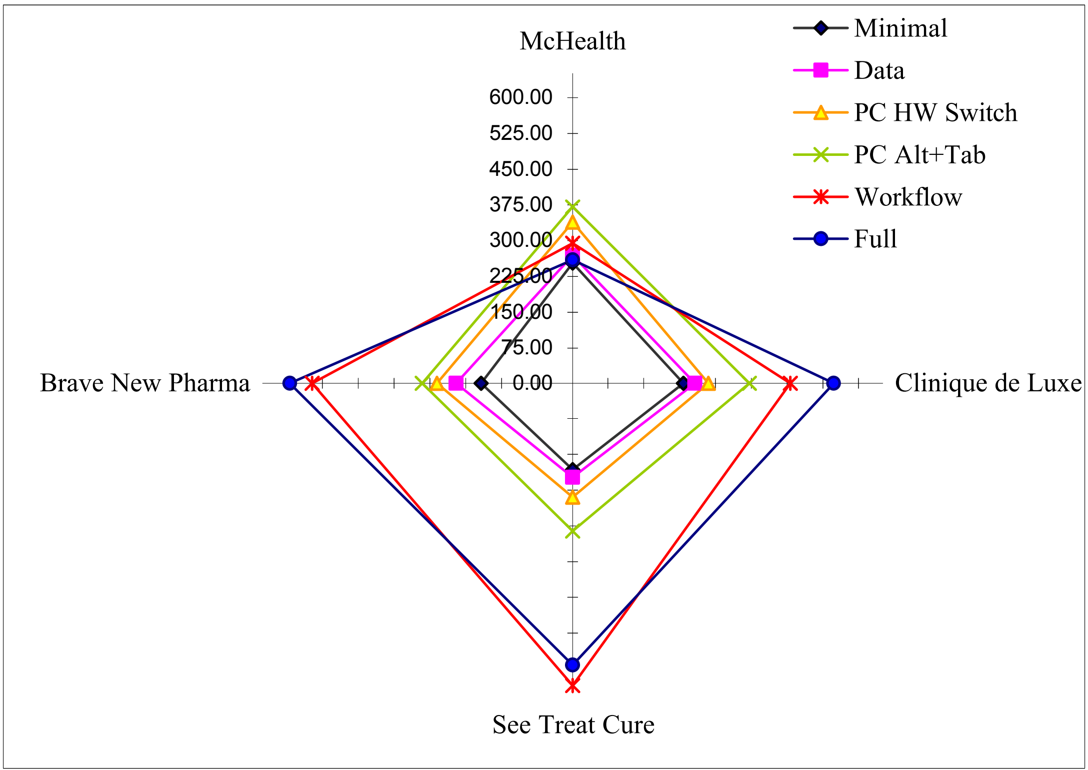


Figure 11-1: Plot of the Cumulative Profit per Scenario

After making the most urgent improvements to the scenarios (not shown in this case study), the architectural decisions can be made on the basis of the quality profiles and the profit estimates of the individual scenarios. This is rarely a matter of simply selecting the best scenario, since typically each scenario has advantages and disadvantages when compared to others. Moreover, the whole point of scenario-based architecting was to make architectures more future-proof, which means that they can respond gracefully to new, as yet unknown requirements.

Therefore, the best way to proceed is to choose a suitable architecture scenario for the short term, based on the currently available information. It is also a good idea to identify for each strategic scenario at least one architecture scenario that is a reasonable response. For example, in our cathlab case study one could safely start working towards a PC Alt+Tab scenario, which outperforms the less sophisticated architecture scenarios for all strategic scenarios. Later, one can assess the global developments to see whether further investments in the Workflow or Full scenarios are meaningful.

However, such decisions are not meant to be final. Instead, the whole set of steps should be repeated at regular intervals (e.g., each year) to see where the analysis must be changed on the basis of new information and where decisions must be revised. Fortunately, such a revision typically requires much less effort than the original analysis.

In the Cathlab case study no decision has been made on the basis of this analysis. The goal of the case study was to provide the industrial partners with an initial estimate of how much effort would go in such an analysis, and second what would be the output of this method.

11.5 Conclusions

This chapter finalizes the feasibility analysis of SODA method, initiated in section 6.4. It shows how the SODA approach deals with the feasibility analysis of the proposed architecture scenarios, namely quantifying the impact of quality factors on the organization market share and translating it into sales and ultimately profit. This approach is new in the sense that allows the stakeholders to reason about the proposed scenarios not only from a technical perspective, but from a business one as well. Such an analysis enables for a more informed decision making process, in which the final scenarios to be considered for implementation are selected not only based on their technical merits but also based on the estimated profit the systems will potentially yield in the future.

Chapter 12

12 Final Conclusions

This chapter summarizes the results presented in this thesis.

The thesis presented two methods supporting the architects in the early phases of the architecting process.

First, Strategic Option Design and Assessment (SODA) is a method for supporting the system architects to develop architectures that are more future proof. It takes a number of different strategic scenarios, and architecture variation models, to come up with different scenarios for designing the architecture of the future system. The strategic scenarios describe different plausible futures, focusing on sketching the changes that might appear in the future business environment. The strategic scenarios are used to guide the tactical decisions to be made at the architecture level. The variation models describe the design space for different architectural views. As a final step of the SODA method, a restricted set of architecture scenarios, representing a consistent set of choices within the variation models, is presented. The relative advantages of the proposed scenario set are calculated by means of a feasibility analysis. This analysis includes a quantitative assessment of the change in market share, and therefore profit, due to the exhibited quality, cost and risks levels associated with the various architectural scenarios.

To provide the necessary data for performing such a quantitative feasibility analysis, a supportive method, called SQUASH, has been developed. It supports the architects in conducting a systematic assessment of the quality, cost and risks aspects associated with the proposed architecture scenarios. If SODA looks at the high-level strategic and tactical choices to be made at a system architecture level, SQUASH looks into the details of the proposed architectural scenarios, to identify possible bottlenecks of the quality aspects or unacceptable costs or risks.

The contributions of the SODA method to the current system architecting practices are as follows:

1. It explicitly incorporates the use of strategic scenarios, which are useful tools for envisaging future new requirements that are likely to be incorporated in the future.
2. Since it is impossible to adapt an architecture in all possible directions, the strategic scenarios help to identify the changes that are most likely to occur in the future, and to translate them into the architectural scenarios. Moreover, the strategic scenarios are used to evaluate the feasibility of the architectural scenarios proposed.
3. By involving detailed knowledge about the customer and future changes in the business environment, the SODA method provides sufficient information for making sound decisions at a strategic and tactical level, early in the design and implementation stages of the proposed system architectures.

The contributions of the SQUASH method to the current system architecture assessment practices are as follows:

1. It supports the analysis of three important aspects of a scenario, namely quality, cost and risk.
2. It supports a quantitative analysis, and the visualization of the relative benefits of different scenarios.
3. It enables a more informed decision-making process, by supporting the selection of the most suitable set of scenarios that best satisfy the stakeholders' objectives, before an elaborate architecture is designed.
4. It explicitly supports the trade-off between various quality attributes throughout the architecting process, starting as soon as the scenarios are proposed.

The two methods have been developed and validated within Philips Research, in two case studies from the medical domain. One of the case studies has been presented in this thesis. The goal of the case studies was first to evaluate the ideas presented in the two methods, and second to refine these ideas to improve the overall method.

12.1 The Answers to the Research Questions

The research presented in this thesis was focusing on improving the architecting process within organizations. The remainder of this chapter discusses the answers given to the initial research questions formulated in Section 1.5.

12.1.1 How to develop architectures that are more future-proof?

Developing system architectures able to survive over long periods of time remains a challenge for most organizations these days. Having a long-view in mind, one can explore the future business environment and the most likely changes to appear within. Strategic scenarios are regarded as excellent tools for communication and adjusting one's perception about the future. Over the past decades, strategic scenarios have been successfully employed in management and long-term planning. In this thesis a new approach to system development is proposed. This approach considers the use of strategic scenarios for the development of a new system by guiding the strategic and tactical decision making process at the architecture level. By considering different strategic scenarios, the premises for designing system architectures which are more resilient to future changes are created.

A scenario-based approach to system architecting, called SODA, is presented in section 3.1 of this thesis. This approach was validated in two case studies for professional systems from the medical domain. The case studies were conducted at Philips Research, one of which is fully presented in this thesis. The goal of the validation was first to apply the method and to evaluate its strong and weak points, and second to provide the industrial partners (here Philips Research, and Philips Medical Systems) with concrete examples on how the various steps of the method can be actually carried out. The case study is described in Chapter 6 of the thesis.

12.1.2 How to come from strategic scenarios to concrete architectural options?

The strategic scenarios describe different plausible future worlds. Starting with these scenarios one can extract business, market, customer and/or architectural relevant information. From this information a couple of business strategies are then defined. These business strategies define the direction the system architecture should follow. For example, a standardization strategy will require a system easy to maintain, modify, and use, with a low cost of ownership and high revenues from operations. The architecture should then satisfy these criteria's. In order to operationalize this, architecture variation models are created. These models describe the range of possible variations of the new architecture in terms of features, applications, and subsystems. A consistent set of choices within these models represent concrete options for the future architecture, referred to as architecture scenarios.

The architecture scenarios describe the possible design variants one could envisage for the future system architecture. However, only a restricted set of these scenarios will be used later on for the development of the future system. The criteria for selecting this final scenario set can be summarized as *fitness for purpose*, where the purpose is defined by the business strategies. To evaluate the architecture scenarios with respect to their relative benefits, a feasibility analysis in terms of critical quality attributes, costs and risks is conducted.

12.1.3 How to analyze the feasibility of the proposed architectural options?

The architecture scenarios in themselves are insufficient for decision making. They have to be annotated with quantitative information about the quality level they support, the costs (i.e. development costs, and production costs), and the possible risks that are associated with their implementation. Making this analysis quantitative is a key improvement with respect to the current state of the art for evaluation. The current assessment methods, which are suitable for such a feasibility analysis, provide only qualitative estimates for the estimation of qualities, costs, or risks. The SQUASH method provides a systematic and step wise approach to look into the details of the proposed scenarios and to identify possible bottlenecks.

The result of the quantitative quality, risk and cost analysis are then aggregated for being presented to the stakeholders of the system. However, the feasibility analysis goes one step further, and tries to quantify the change in market share for each architecture scenario in each strategic future, due to the exhibited quality, cost and risk levels. For comparison reasons, the change in market share is converted into monetary values. Based on these estimates, the architecture scenarios that score best in most strategic scenarios can then be selected.

12.1.4 How to support the decision-making process when multiple architectural variants are envisaged?

This question was tackled as follows. First, the focus has been on data representation. This resulted in an improved way of visualizing the differences between the factors analyzed per scenario, by using coloured maps, also known as heat maps. These are tables, which present not only the value of a certain factor analyzed, but also the position of this value with respect to an a priori defined acceptance level. The differences in the acceptance levels are represented using different colours. Second, the focus shifted towards finding an unique metric for the profitability of the different architecture scenarios in the various strategic futures. This metric has been identified as being the change in the present value of the market share of an organization. This metric has been refined in a later stage, to become more concrete and representative for the stakeholders. The final metric used for decision making is the profit yielded by each architecture scenario in each strategic future.

The two aspects: data representation/visualization, and the unique metric to characterize the various architecture scenarios, made the decision-making process more intuitive and easier to manage for the system stakeholders.

12.2 Future Research Directions

The methods presented in this thesis are far away from being complete or easy to reproduce in a real industrial setting. This is because their validation requires a significant amount of effort and domain knowledge. For example it is assumed that the architects and the system stakeholders are familiar with the strategic scenario creation process, which often is not the case. Consequently, a future research direction would be to refine the process of deriving architectural scenarios from strategic scenarios and to support its introduction in organizations. It is also assumed that the architects are familiar with the variation modeling process, which again, most often is not the case. Therefore any tool support for variability management at an architecture level would be another research direction one might think of.

With respect to the improvement of SODA, one future research direction might be the consideration of existing business-process models for making the translation from strategic scenarios to architecture scenarios more concrete.

For the validation and improvement of SQUASH, possible future research topics could be the investigation of quantitative analysis for other quality attributes, and the support of the analysis process by means of visualization tools.

The cost and risk analysis models with SQUASH could also be refined.

Last but not least, the decision-making process, when multiple strategic and architecture scenarios are considered, deserves more attention. This implies the investigation of current decision-making frameworks as well as possible tool support for the feasibility assessment calculations wherever possible.

13 Appendices

Appendix A - The GBN Scenario Model

The GBN scenario consists of eight steps, as described in (Schwartz 1996).
Step 1: Focal Issue or Decision Identification.
Begin with a specific decision to be made.
Step 2: Key Forces in the Local Environment
Identify the key factors that influence that decision.
Step 3: Driving Forces
List the driving forces in the macro-environment that influence the key factors identified earlier. Defining the driving forces should be preceded by research which may cover political factors, new technology, economic forces, etc.
Step 4: Forces and Factors Ranking by Importance and Uncertainty
Rank the key factors and driving forces on the basis *the degree of importance* for the success of the focal issue or decision identified in step 1, and *the degree of uncertainty* surrounding those factors and trends. The point is to identify the two or three factors that are most important and uncertain.
Step 5: Selecting Scenario Logics
The results of this ranking exercise are, in effect the axes along which the eventual scenarios will differ. The goal is to end up with a just a few scenarios which will help the decision-makers. Only a few scenarios must be developed in detail
Step 6: Scenarios Realization
Fleshing out the skeletal scenarios can be accomplished by returning to the list of key factors and trends identified in steps two and three. Each key factor should be given some attention in each scenario.
Step 7: Future Implications
Once scenarios have been developed in some detail, than it is time to return to the focal issue or decision identified in step one to rehearse the future.
If the decision will look good in only one of several scenarios, then it qualifies a high-risk gamble (a bet-the-company) strategy - especially if the company has little control over the likelihood of the required scenario coming to pass (Schnaars 1986).
Step 8: Select Leading Indicators and Signposts
One must monitor the future flow of the events and associate them with the developed scenarios for a continuous validation of the decisions. Else the whole work will become useless.

Schwartz concludes with a few practical suggestions for a good scenario process:

- *Avoid ending up with three scenarios.*
- *Avoid assigning probabilities to different scenarios.*
- *Name scenarios carefully.*
- *Selection of the scenario development team requires: (a) Support and participation from top level management; (b) Knowledge domain diversity represented in the scenario team; (c) Imaginative people with open minds that can work together as a team.*
- *Good scenarios are both imaginative and surprising.*

Appendix B - Cardiology 2006 Strategic Scenarios

The McHealth Scenario

"The growth of economic activity, measured by gross domestic product, has become less rapid in recent years. Spending by consumers and investment by businesses has become weaker in response to financial instability and economic recession. People prefer to save money at a low but secure interest rate. Because of the economic recession, hospitals prefer to maintain the existing Cathlab systems rather than to acquire new ones.

The good and diligent baby boomers of the 60s, who have carried out the research and development in the past, are now retiring. There are not enough good new scientists and engineers emerging. The aging of the baby boomers is affecting the insurance system and pension funds because fewer people are paying taxes, yet the demand for health-care services is rising.

Several years ago any genomic-related research was encouraged, which led to the available governmental funds being spent quickly. Nevertheless, exploration of the human genome continues. Better drug treatments for cardiovascular disease are available, thanks to the genome project results obtained so far. Better interventional technologies have also become available, such as cardiac MRI. However, it is only the richest people in society who can afford these treatments, as well as MRI or CT screenings and regular preventive controls, because they are not paid for by insurance companies, or government.

Only the most efficient hospitals can afford to remain open in the face of increasing economic pressure. This results in lower subsidies and fewer young graduates specializing in the cardiovascular field. Instead, fast treatment clinics are appearing. They offer boutique services, which for cardiology consists of a standard echo-cardio diagnosis and catheterisation using X-ray. Some of these clinics offer also premium services like cardiac MR and CT to attract the rich. The success of these clinics lies in their ability to reduce costs. Patients with coronary artery disease (CAD) receive standard treatment, no more personal than the service of a fast food restaurant. However, the fast clinics are very successful in Asia and Eastern Europe.

The catheterisation is now performed much faster than in the year 2000. The clinics have invested in information management systems to reduce the bottlenecks in the patient information handling process. Together with the doubling of computing power almost every two years, this has enabled a higher throughput in the treatment of CAD. Some suppliers have introduced multi-processor machines using processors of 10GHz and higher to enable the 3D reconstruction of the heart vessels in real time. Although they have developed new interventional technologies for the Cathlab, such as cardiac MRI, these technologies have not yet been adopted by the fast treatment clinics.

The economic recession also affects the life-style of the population. Only a minority practise sport, whilst the majority live on an unhealthy diet. People do not have time for regular checks, preferring to visit the fast treatment clinics when problems occur. They believe the standard medical treatment they receive in the fast clinics to be good enough".

Clinique de Luxe Scenario

The growth of economic activity had some small up and downs over the past years. However the sweet business opportunities pushed people into higher income brackets. The proportion of people earning more than €50.000 per year is higher than 40%. People put their money in different investment funds, which fuelled the development of new innovative medical technologies. The exploration of the human genome continues. The possible personalized treatments are years away form large-scale deployment on the consumer market. Some drug treatment for cardio vascular diseases is available, due to the genome *project results obtained so far. However, such treatments, as well as screening and regular preventive controls, are affordable but at a relatively high price.*

The friendly economical situation encouraged the hospitals to offer boutique ser-vices for cardiology. Therefore hospitals opened "de Luxe" cardiology clinics and equipped them with the latest technologies for diagnosing coronary artery diseases, such as real time cardiac magnetic resonance imaging (MRI) and computed tomography (CT), intravascular ultrasound and systems for assisting the cardiologists during the difficult parts of the interventions. They make a hefty profit by offering a vast array of ex-pensive and sophisticated services, ranging from simple screenings to multi-modality diagnosis and CAD treatments. The complex CAD cases are treated care-fully. In the difficult cases, to avoid misdiagnosis and improve accuracy, the cardiologists bring up their questions for discussion on web-based forums and health care focus groups for a second opinion. The broadband and satellite communication networks support real time video communications on affordable devices between cardiologists. Patients are then bombarded with lots of suggestions and medication for a quick and clean recovery. Many receive angiogenesis or myogenesis drugs, which are very effective in complex CAD cases. The cost – benefits of the CAD systems led to increased competition among the world's top medical systems manufacturers such as Siemens and GE. Each strives for higher shares on the increasing market of "de Luxe" cardiology equipment. For catheterisation, the drug eluting stents are the de facto standard. The stable economic situation brings more confidence among the population. Many improve on their life style by engaging in more sports and living on healthy diets. The education level is rising. People use any information available on the Internet to learn about the best clinics, insurance ser-vices and government compensation schemas regarding the CAD. They demand the best from the health care clinics. People who are uninsured also have good options. They benefit from better diagnosis and treatment due to the solidarity principle instituted by governments. The catheterisation is now performed much faster than in the 2000s. The hospitals made investments in information management system to reduce the bottlenecks in the patient information handling process.

The computing power doubling every year enabled the development of faster medical systems. The 10 GHz-like processors, and higher, enabled the 3D reconstruction of the heart vessels in real time. This high computing power and the fast video cards enabled the real time navigation of the 3D models. India and China use Linux to move away from the US dominance on the software technology market. Companies like Sun Microsystems, Red Hat and IBM helped to package Linux for any type of business. Consequently, the large medical equipment producers have redesigned their software technology strategy accordingly. The new cardiac software applications of Siemens and GE run on Linux platforms. Because it is open source and free, Linux is taught and used in most universities around the globe. However, Microsoft operating system and software applications are used for the majority of personal computers. The "de Luxe" clinics have low impact in the former eastern states of Europe. This is because there, people still prefer to go for standard services at an acceptable price. The success of the multi-modality high-end medical equipment is limited to the few rich, who can afford CAD treatments at their own expenses.

Brave New Pharma World Scenario

The exploration of the human genome and molecular imaging and diagnosis opened up unbelievable opportunities. This is the era of the much-awaited personalized treatments. Each person can have now a molecular diagnostic test at a price of less than €50. This test reveals in detail the health state of a person, pointing out the risk for developing different cardiac diseases. The old indicators like cholesterol level, diabetic predispositions, or blood pressure are corroborated with specific molecular diagnosis techniques for detecting cardiac diseases.

The booming economic situation made it possible for the hospitals to acquire the latest technologies for molecular diagnosis of the coronary artery diseases (CAD). Cardiology clinics make a hefty profit from offering a vast array of sophisticated molecular imaging *services, ranging from simple screenings to personalized drug therapies for dealing with CAD disease in any form and evolution stage. Due to the broadband and satellite communication networks that can support real time video communications on affordable devices, cardiologists can now remotely monitor the state of their patients on a regular basis. Patients don't have to visit the hospital site any more. From their home they keep in touch with their doctors, and once in a while they visit the closest clinic to have a blood test. The results are sent directly to their cardiologist, who analyses them and prescribes new medication. For the severe CAD cases, drugs are delivered locally to the heart by means of minimally invasive techniques. Because the drugs are personalized for the genetic characteristics of a specific patient, they can successfully combat the plaque with no side effects. Catheter implantation became obsolete. The new drug regimes are less expensive than the conventional catheterisation procedure. Only the poorest insured patients are still using the conventional CAD treatment.*

The booming economic situation brings confidence and comfort among the population. Many improve on their life style by engaging in more sports and living on healthy diets. The healthcare evolved from treatment to prevention. People use any information available on the Internet to learn about the best clinics, insurance services and government compensation schemas regarding the CAD. They demand the best from the health care clinics.

The hospitals also made investments in information management system to reduce the bottlenecks in the patient information handling process. This, together with the computing power that doubled every year, enabled a higher throughput in diagnosing the CAD. IBM sells supercomputers to pharmaceutical giants equipped with the Advanced Micro Devices' 64-bit processor technology, boosting the AMD's latest innovations in server technologies running Linux applications. Clusters of these supercomputers are used for molecular diagnosis and treatment in oncology and cardiology. India and China switched to Linux to move away from the US dominance on the software technology market. Companies like Red Hat and IBM helped to package Linux for any type of business. Consequently, the large medical and pharmaceutical software producers have redesigned their software technology strategy accordingly. The molecular imaging techniques have the same high impact in the former eastern states of Europe. The medical advances in the western world have been successfully transferred to the less developed nations. Although the healthcare costs are quite high, people in these countries are willing to make efforts in getting the best medication possible.

See-Treat-Cure Scenario

Although the exploration of the human genome is still continuing, great progress has been achieved in the molecular imaging and diagnosis. Molecular imaging in comparison with the classical X-ray enables the cardiologists to acquire both functional and anatomical information about the different types of coronary artery diseases (CAD). Ten years ago for example, the cardiologists were using risky X-ray technology to diagnose the plaque in human arteries. The diagnosis regarded the functional aspects of the plaque, such as localization, length and size. With molecular imaging the cardiologists can now assess precisely the type and stage of the plaque, and anatomical information about it. This is a breakthrough especially in the paediatric cardiology. The infantile CAD cases can now be quickly diagnosed and treated. In the US have been signalled over 100.000 cases of CAD at kids with ages between 5 and 13 years old.

Cardiology clinics make good profit from offering a vast array of sophisticated services molecular imaging services, like screenings and diagnosis for CAD on a single multi-modality ma-chine. The stable economical situation made possible for these clinics to acquire the latest technology in molecular imaging workstations. The complex CAD cases are treated carefully. To avoid misdiagnosis and improve accuracy the cardiologists bring up their questions for discussion on web based forums and health care focus groups for a second opinion. The broadband and satellite communication networks support real time video *communications on affordable devices between cardiologists. Based on multiple input received from their peers, the cardiologists can accurately diagnose any CAD case and offer suggestions and medication for a quick and clean recovery.*

The baby boomers of the 60s, which carried out the past research and development, are now retiring. In the past years less and less graduates pursued cardiovascular specialization. The drug treatment for CAD is rather ex-pensive. The poor insured patients receive conventional X-ray diagnosis. The stable economical situation brings confidence and comfort among the population. Many improve on their life style by engaging in more sport and living on healthy diets. The healthcare is still focused on treatment rather than prevention. People took a passive position with respect to learning about how to prevent the CAD. The computing power that doubled every year, which enabled a higher throughput in diagnosing the CAD. IBM sells supercomputers equipped with the Advanced Micro Devices' 64-bit processor technology, boosting the AMD's latest innovations in server technologies running Linux applications. Clusters of these supercomputers are used for molecular diagnosis and treatment in oncology and cardiology. India and China use Linux to move away from the US dominance on the software technology market. Companies like Sun Microsystems, Red Hat and IBM helped to package Linux for any type of business. Consequently, the large medical equipment producers have redesigned their software technology strategy accordingly. The new cardiac software applications of Siemens and GE run on Linux platforms. Because it is open source and free, Linux is taught and used in most universities around the globe. However, Microsoft operating system and software applications are used for the majority of personal computers. The molecular imaging techniques had some impact in the former eastern states of Europe. Some of the academic hospitals in these states acquired multi-modality workstations for molecular imaging. However, the costs for diagnosis are quite high and therefore the majority of population cannot afford yet the best treatment made available.

Appendix C - The Patient Segments Scenarios

The Minimalist Patient Scenario:

"If it ain't broke I won't fix it"

I am the type of patient that requests CAD diagnosis or treatment only when problems appear. I am too busy to think about prevention or I have no means to do so. As a minimalist I prefer standard services at a low price. For me these services are good enough. Only if my health state gets critical, then I will go for more specialized services or clinics.

Patient Drivers: Efficiency, Cost effectiveness, Waiting Time, Security, Privacy, Standard Services, Reimbursement Schemas.

The In-house BioMed Patient Scenario

"I like gadgets"

I like to have all kind of gadgets at home, such as devices for measuring the blood pressure, cholesterol level, sugar level, stress level, weight, and so on. I invest in these devices and like to have them interconnected at home as well as with my personal physician. I pay very much attention to my health state, life style, and diet. As BioMed, I use any kind of media to inform myself about the latest technologies available and best clinics and healthcare services. When CAD appears I refer to my physician. In case of intervention, I prefer to go for standard services if possible.

Patient Drivers: Efficiency, Cost effectiveness, Waiting Time, Security, Privacy, Customisability, Standard Services, Reimbursement Schemas.

The Modernist Patient Scenario

"I heard about a good clinic"

As modernist I spend generously but with care. For me the healthcare is like fashion. If there is a clinic or service that is now trendy, I consider it immediately. I'd like to prevent CAD, but I often find myself fixing things when they appear. I am sufficiently insured to afford the treatment offered by the modern hospitals equipped with the latest technology, which I also choose in case of CAD intervention.

Patient Drivers: Accuracy, Waiting Time, Quality of Care, Comfort, Security, Privacy.

The Premium Patient Scenario

"Best I can get"

As I frequent fine restaurants, buy the last model car, and I invest in vacation houses overseas, I am ready to pay the price for high quality healthcare services. With respect to cardiovascular diseases, I have regular checks and take very good care of my lifestyle and diet. For treating the CAD, as premium, I go to the best clinics recommended by my private physicians. I am well insured; therefore I can afford expensive diagnosis and treatments. If it is necessary, I will pay extra money just to make sure that the diagnosis and follow-up CAD treatment is accurate, complete and the best I can get at the moment.

Patient Drivers: Accuracy, Waiting Time, Quality of Care, Comfort, Security, Privacy, and Personalized Treatment.

Appendix D - The Cathlab User Scenarios

<table>
<tr><th></th><th>Minimal Integration Scenario</th><th>Data Integration Scenario</th><th>Presentation and Control</th><th>Workflow Integration</th><th>Full Integration Scenario</th></tr>
<tr><td>Scene 1</td><td colspan="4">The user scenarios presented in this section
have been developed by Eelco Rommes from Philips Research.
They are presented in this Appendix for exemplification purposes only, with the prior agreement of their author.

The Cathlab that will be used for treating Mr. Bachman is equipped with a monoplane X-ray modality, 3D RA equipment, an PACS client, hemo system and an X-ray workstation.
Central in the Intervention Room (IR), there is a patient table on which Mr. Bachman lies. At the head of this table, the X-ray C-arm is placed. Three monitors are hanging over the patient table: two reference monitors, and the live monitor. All of them are high quality black and white monitors. This layout ensures that Dr. Eter has perfect view over the patient, monitors and the C-arm when performing a procedure. The hemo monitor is placed next to this matrix, in sight of the cardiologist.
In the Control Room (CR), two X-ray monitors are present. The administration monitor is a color monitor, which is used for administrative purposes. Any medical images displayed on this monitor suffer a loss of quality. The second CR monitor is called the image monitor. It displays approximately the same as the live monitor in the intervention room. Also available in the control room is a PACS client, connected to the hospital's cardio PACS server, the hemodynamic system, a CIS client and a 3DRA workstation.
During the procedure, Mr. Fink will be in the control room, while dr. Eter will mostly be in the intervention room, with nurse Barton assisting her.</td><td>The Cathlab that will be used for treating Mr. Bachman has a fully integrated system providing functionality for monoplane X-ray, 3D RA, a PACS client, a CIS client and hemo system.
Central in the Intervention Room (IR), there is a patient table on which Mr. Bachman lies. At the head of this table, the X-ray C-arm is placed. One large, flat monitor is hanging over the patient table, capable of displaying high quality medical images as well as full color applications (e.g.: hemodynamic waveforms). Dr. Eter has perfect view over the patient, the monitor and the C-arm when performing a procedure.
A similar monitor is present in the Control Room (CR). It is used for administrative purposes as well as viewing the images made in the IR, so it has a slightly different screen layout.
During the procedure, Mr. Fink will be in the control room, while dr. Eter will mostly be in the intervention room, with nurse Barton assisting her.</td></tr>
</table>

Scene 2	Dr. Eter has arrived for the procedure. She is in the control room, using the PACS client to review the images from the diagnostic MR procedure that Bachman has undergone. She is concentrating hard, knowing that it will not be possible to view these images during the procedure without leaving the intervention room. When she has a good overview of the situation, she goes off to wash her hands and arms and enters the intervention room.	Dr. Eter has arrived for the procedure. She is in the control room, using the PACS client to review the images from the diagnostic MR procedure that Bachman has undergone. She stores subsequent slices as a secondary capture movie, and sends it to the X-ray modality, in order to make it available on a reference monitor during the procedure. Then she goes off to wash her hands and arms and enters the intervention room.	Dr. Eter has arrived for the procedure. She is in the intervention room, using an X-ray reference monitor and controls to review the diagnostic MR study that Bachman has undergone.		Dr. Eter has arrived for the procedure. She is in the intervention room, preparing the results of the diagnostic MR procedure that Bachman has undergone. Using a volume rendering view, she searches for the right angle for a free view of the coronary stenosis. When she has found a suitable projection angle, she switches it to a maximum-intensity projection (MIP) and places it in the reference area at the lower right corner of the screen.
Scene 3	During the procedure, Mr. Fink logs the important clinical steps taken at the CIS client. He constantly monitors the patient's hemodynamic and ECG data, ready to warn if necessary.	During the procedure Mr. Fink logs the important clinical steps taken on the CIS client. He constantly monitors the patient's hemodynamic and ECG data, ready to warn if necessary. The hemodynamic data are transferred automatically to CIS on the press of a button. After the procedure, Dr. Eter can select and process any of the hemodynamic data acquired.	During the procedure Mr. Fink logs the important clinical steps taken on the CIS client. He constantly monitors the patient's hemodynamic and ECG data, ready to warn if necessary. The hemodynamic data are transferred automatically to CIS at the press of a button. Mr. Fink uses a single control panel in the control room. The panel has specialized buttons to control hemodynamics workstation. He enters data efficiently and without duplication.	During the procedure Mr. Fink logs the important clinical steps taken at the Cardio-Logica client running on his workstation. The automatic logging is based on EPX settings and controlled by Mr. Fink. He constantly monitors the patient's hemodynamic and ECG data, ready to warn if necessary. The hemodynamic data are transferred to the CIS client at the press of a button. He uses a single control panel in the control room. The panel has specialized buttons to control the hemodynamics workstation. Mr. Fink enters data efficiently and without duplication.	During the procedure the important clinical steps taken are logged using the built-in Cardio-Logica client. The automatic logging is based on EPX settings and controlled by Mr. Fink. He uses a single control panel for the system. He enters extra data efficiently and without duplication. He constantly monitors the patient's hemodynamic and ECG data, ready to warn if necessary.

<table>
<tr><td>Scene 4</td><td colspan="4">Dr. Eter starts the procedure by entering a catheter through the entry site in Mr. Bachman's femoral artery. She guides the catheter towards his heart using fluoroscopy to be able to see what she's doing. The live monitor shows the catheter carefully moving up Mr. Bachman's chest. It follows the aorta up and around into the opening of the left coronary artery. The catheter tip is now in a good position to make an overview of the status of Bachman's coronary arteries.</td></tr>
<tr><td>Scene 5</td><td colspan="3">Dr. Eter inserts contrast fluid and performs an exposure run to properly view the situation. It takes her two more runs before she finds the right angle to view the stenosis.</td><td>Dr. Eter presses a button and the X-ray geometry is set in the position of the MR MIP she saved earlier. She inserts contrast fluid and performs an exposure run to properly view the situation. Because of the correct geometry projection, no further exposure is needed.</td></tr>
<tr><td>Scene 6</td><td>She wants to compare this run to the MR study. So she walks over to the PACS client and asks Mr. Fink to operate it for her to have a look. When she is satisfied, she walks back to her patient.</td><td>She wants to compare this run to the diagnostic MR study performed earlier. So she brings the stored movie up on the right reference monitor and compares the two. This requires concentration and skill, made harder by the fact that one is a projection, while the other consists of slices.</td><td>She wants to compare this run to the diagnostic MR study performed earlier. So she brings the stored movie up on the right reference monitor and compares the two. This requires concentration and skill, made harder by the fact that one is a projection, while the other consists of slices. She browses through them using the view pad, while comparing to the run on the left reference monitor. She uses the view pad’s contrast and brightness buttons to adjust window width and window level of the MR images.</td><td>She wants to compare this run to the results of the MR diagnosis. So she brings the MR projection up on the screen and compares the two. This is quite easy, as both are projections from the same angle. She browses them using the view pad. She uses the view pad’s contrast and brightness buttons to adjust window width and window level of the MR images.</td></tr>
</table>

<table>
<tr><td></td><td colspan="3">Dr. Eter decides that she needs to perform a rotational angiography of the left and right coronary arteries. She repositions the table. She asks Mr. Bachman to hold his breath, inserts contrast fluid and starts the rotational angiography process. The C-arm starts to rotate around Mr. Bachman, taking pictures of his coronaries. When it has finished, dr. Eter presses a button to send the images to the 3D RA workstation. It takes the workstation three minutes to calculate the 3D model, but the two-dimensional images taken are available on the X-ray machine right away.</td><td>Dr. Eter decides that she needs to perform a rotational angiography of the left and right coronary arteries. Dr. Eter repositions the table. She asks Mr. Bachman to hold his breath, inserts contrast fluid and starts the 3D RA process. The C-arm starts to rotate around Mr. Bachman, taking pictures of the blocked artery in his neck. When it has finished, the images are sent to the 3D RA workstation automatically. It takes the workstation three minutes to calculate the 3D model, but the two-dimensional images taken are available on the X-ray machine right away.</td><td>Dr. Eter decides that she needs to perform a rotational angiography of the left and right coronary arteries. Dr. Eter repositions the table. She asks Mr. Bachman to hold his breath, inserts contrast fluid and starts the 3D RA process. The C-arm starts to rotate around Mr. Bachman, taking pictures of the blocked artery in his neck. When it has finished, the resulting 3D model is available right away.</td></tr>
<tr><td>Scene 8</td><td colspan="4">These two dimensional images are displayed on the left reference monitor as a movie, which dr. Eter watches to get a feel for the situation.</td><td>These two dimensional images are displayed on the left reference monitor as a movie, which dr. Eter watches to get a feel for the situation.</td></tr>
<tr><td>Scene 9</td><td>After a while, the three dimensional model is ready for display, but the 3D RA workstation itself is in the control room. Dr. Eter has to walk over there to watch the model, while nurse Barton stays with the patient. Dr. Eter instructs Mr. Fink how to manipulate the model. She cannot do so her self, as she has to preserve sterility. After a while, she feels she has a clear overview of Mr. Bachman's problem.</td><td>After a while, the three dimensional model is ready for display, but the 3D RA workstation itself is in the control room. Dr. Eter has to walk over there to watch the model, while nurse Barton stays with the patient. Dr. Eter instructs Mr. Fink how to manipulate the model. She cannot do so her self, as she has to preserve sterility. After a while, she feels she has a clear overview of Mr. Bachman's problem.</td><td colspan="2">After a while, the three dimensional model is ready for display. Dr. Eter manipulates it to get a good overview of the situation. She does so using controls that are integrated in the Cathlab user interface.</td><td>Dr. Eter manipulates and views the 3D model until she has a clear overview of Mr. Bachman's problem.</td></tr>
</table>

Scene 10	When she has found a suitable projection of the 3D model to measure the width of the problematic vessel and the width and length of the stenosis, she asks Mr. Fink to do so. Dr. Eter walks back to the intervention room.	When she has found a suitable projection of the 3D model to measure the width of the problematic vessel and the width and length of the stenosis, she asks Mr. Fink to do so. Mr. Fink also sends this geometry position to the X-ray modality. Dr. Eter walks back to the intervention room and presses a button to set the geometry in this position.	She measures the width of the problematic vessel and the width and length of the stenosis, once she has found a suitable projection of the 3D model. She presses a button to set the X-ray geometry in this position.	Next, she chooses a suitable projection of the 3D model to measure the width of the problematic vessel and the width and length of the stenosis. With the click of a button, she programs the X-ray geometry to move to this projection.

Scene 11	Before choosing a stent, Dr. Eter wants to measure the blood pressure in front of and behind the stenosis. She navigates a catheter through the stenosis area using fluoroscopy. The hemodynamics signals are captured and displayed on a dedicated monitor in the control room and on the hemodynamic monitor in the intervention room at the same time. While Dr. Eter is passing the regions of interest she asks technician Fink to mark the blood pressure values. The technician does so using the hemodynamics control panel in the control room. He configures location-dependent hemodynamic algorithms by selecting the heart area that is currently under examination. After Dr. Eter has finished the pullback of the catheter, an analysis of blood pressure values and the percentage of stenosis are displayed.	Before choosing a stent, Dr. Eter wants to measure the blood pressure in front of and behind the stenosis. She navigates a catheter through the stenosis area using fluoroscopy, comparing images with the reference run at synchronized heartbeats. The hemodynamics signals are captured and displayed on a dedicated monitor in the control room and on the hemodynamic monitor in the intervention room at the same time. While Dr. Eter is passing the regions of interest she asks technician Fink to mark the blood pressure values. The technician does so using the hemodynamics control panel in the control room. He configures location-dependent hemodynamic algorithms by selecting the heart area that is currently under examination. After Dr. Eter has finished the pullback of the catheter, an analysis of blood pressure values and the percentage of stenosis are displayed.	Before choosing a stent, Dr. Eter wants to measure the blood pressure in front of and behind the stenosis. She navigates a catheter through the stenosis area using fluoroscopy, comparing images with the reference run at synchronized heartbeats. The hemodynamics signals are captured and displayed on a dedicated monitor in the control room and on the hemodynamic monitor in the intervention room at the same time. While Dr. Eter is passing the regions of interest, she marks the blood pressure values herself, using the X-ray system touch-screen module which has a special tab to control the hemodynamic system. She has to click through a number of menus to get to this tab, though. She configures location-dependent hemodynamic algorithms by selecting the heart area that is currently under examination. After Dr. Eter has finished the pullback of the catheter, an analysis of blood pressure values and the percentage of stenosis are displayed.	Before choosing a stent, Dr. Eter wants to measure the blood pressure in front of and behind the stenosis. She selects a proper EPX procedure to configure the X-ray system. She navigates a catheter through the stenosis area using fluoroscopy. The system's user guidance facilitates Dr. Eter in putting the catheter tip behind the stenosis. Controlled by EPX parameters, the hemodynamic system optimizes its user interface layout to highlight procedure relevant information from its multi-channel data. While Dr. Eter is passing the regions of interest, she marks blood pressure values using the X-ray system touch-screen module, which has a special tab to control the hemodynamic system. This tab is automatically chosen based on EPX settings. She configures location-dependent hemodynamic algorithms by selecting the heart area that is currently under examination. After Dr. Eter has finished the pullback of the catheter, an analysis of blood pressure values and the percentage of stenosis are displayed. This analysis contains an estimate of the percentage of the stenosis.	Before choosing a stent, Dr. Eter wants to measure the blood pressure in front of and behind the stenosis. She selects a proper EPX procedure to configure the integrated Cathlab. She navigates a catheter through the stenosis area using fluoroscopy. The system's user guidance facilitates Dr. Eter in putting the catheter tip behind the stenosis. Controlled by EPX parameters, the hemodynamic system optimizes its user interface layout to highlight procedure relevant information from its multi-channel data. While Dr. Eter is passing the regions of interest she marks blood pressure values using the X-ray system touch-screen module, which has a special tab to control the hemodynamic system. This tab is automatically chosen based on EPX settings. The X-ray system tracks the position of the catheter and configures location-dependent hemodynamic algorithms. After Dr. Eter has finished the pullback of the catheter, an analysis of blood pressure values and the percentage of stenosis are displayed. This analysis contains an estimate of the percentage of the stenosis.

Scene 12	She uses this information to determine the sizes and types of the balloon and stent she will use.	The system provides a list of possible sizes and types of the balloon and stent to use. It recommends a combination, which dr. Eter accepts.
Scene 13	Again using fluo, she moves a stented balloon over the guide wire up to the stenosis. She inflates the balloon using fluo to view the inflation process and its result.	
Scene14	Things look good, so dr. Eter inserts contrast fluid and performs an exposure run again, to properly view the new situation.	
Scene15	Glad that the procedure has gone well, she removes all equipment from Bachman's body. Nurse Barton compresses the puncture in Mr. Bachman’s femoral artery, to help it heal. Mr. Bachman is then moved out of the Cathlab, the procedure has ended.	

Appendix E - Usability Analysis with SQUASH - Details

(This is the analysis which was performed in SQUASH Step 4: Analyze Scenarios, in Chapter 7.4)

Table 13-1: The usability factors in the Minimal Integration Scenario analyzed per scenario scene (s1 to s15)

Usability Factors	**Minimal Integration Scenario Scenes**															
	s1	s2	s3	s4	s5	s6	s7	s8	s9	s10	s11	s12	s13	s14	s15	Function used for the generalization	Overall Result
Number of walks (*NoW*)	0	1	0	0	0	1	0	0	1	1	0	0	0	0	0	$=\sum_{k=1}^{15} NoW(s_k)$	4
Number of persons involved (*PeIn*)	0	1	1	1	1	2	1	1	3	3	2	1	1	1	2	$=Max\left[PeIn(s_k)\right]_{k=\overline{1,15}}$	3
Number of resterilizations (*NoRe*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	$=\sum_{k=1}^{15} NoRe(s_k)$	0
Learning duration (*LeDu*)	-	-	-	-	-	-	2h	-	-	2h	2h	-	-	-	-	$=\sum_{k=1}^{15} LeDu(s_k)$	6h
Intervention average duration (*InAvD*)	-	5 min	-	5 min	3 min	8 min	3 min	-	4 min	3 min	4 min	1 min	1 min	1 min	5 min	$=\sum_{k=1}^{15} InAvD(s_k)$	43 min
Intervention success ratio (*InSuR*)	0,999	0,95	0,99	0,99	0,99	0,99	0,99	0,999	0,95	0,95	0,99	0,99	0,999	0,999	0,999	$=\prod_{k=1}^{15} InSuR(s_k)$	0,80

Table 13-2: The usability factors in the Data Integration Scenario analyzed per scenario scene (s1 to s15)

Usability Factors	Data Integration Scenario Scenes															
	s1	s2	s3	s4	s5	s6	s7	s8	s9	s10	s11	s12	s13	s14	s15	Function used for the aggregation	Overall Result
Number of walks (*NoW*)	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	$= \sum_{k=1}^{15} NoW(s_k)$	3
Number of persons involved (*PeIn*)	0	1	1	1	1	1	1	1	3	3	2	1	1	1	2	$= Max\left[PeIn(s_k)\right]_{k=\overline{1,15}}$	3
Number of resterilizations (*NoRe*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	$= \sum_{k=1}^{15} NoRe(s_k)$	0
Learning duration (*LeDu*)	-	-	-	-	-	-	2h	-	-	2h	2h	-	-	-	-	$= \sum_{k=1}^{15} LeDu(s_k)$	6h
Intervention average duration (*InAvD*)	-	5 min	-	5 min	3 min	3 min	3 min	-	4 min	3 min	4 min	1 min	1 min	1 min	5 min	$= \sum_{k=1}^{15} InAvD(s_k)$	38 min
Intervention success ratio (*InSuR*)	0,999	0,95	0,99	0,99	0,99	0,99	0,99	0,999	0,95	0,98	0,99	0,99	0,999	0,999	0,999	$= \prod_{k=1}^{15} InSuR(s_k)$	0,82

Table 13-3: The usability factors in the Presentation and Control Integration Scenario analyzed per scenario scene (s1 to s15)

Usability Factors	Presentation and Control Integration Scenario Scenes															
	s1	s2	s3	s4	s5	s6	s7	s8	s9	s10	s11	s12	s13	s14	s15	Function used for the aggregation	Overall Result
Number of walks (*NoW*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	$=\sum_{k=1}^{15} NoW(s_k)$	0
Number of persons involved (*PeIn*)	0	1	1	1	1	1	1	1	1	1	2	1	1	1	2	$=Max\left[PeIn(s_k)\right]_{k=\overline{1,15}}$	2
Number of resterilizations (*NoRe)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	$=\sum_{k=1}^{15} No\,Re(s_k)$	0
Learning duration (*LeDu)*	-	-	1h	1h	-	-	2h	1h	1h	2h	2h	-	-	-	-	$=\sum_{k=1}^{15} LeDu(s_k)$	10h
Intervention average duration (*InAvD)*	-	3 min	-	5 min	3 min	2 min	3 min	-	2 min	2 min	3 min	1 min	1 min	1 min	5 min	$=\sum_{k=1}^{15} InAvD(s_k)$	31 min
Intervention success ratio (*InSuR)*	0,999	0,98	0,99	0,99	0,99	0,99	0,999	0,999	0,99	0,99	0,99	0,99	0,999	0,999	0,999	$=\prod_{k=1}^{15} InSuR(s_k)$	0,90

Table 13-4: The usability factors in the Workflow Integration Scenario analyzed per scenario scene (s1 to s15)

Usability Factors	**Workflow Integration Scenario Scenes**																
	s1	s2	s3	s4	s5	s6	s7	s8	s9	s10	s11	s12	s13	s14	s15	Function used for the aggregation	Overall Result
Number of walks (*NoW*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	$=\sum_{k=1}^{15} NoW(s_k)$	0
Number of persons involved (*PeIn*)	0	1	1	1	1	1	1	1	1	1	1	1	1	1	2	$=Max\left[PeIn(s_k)\right]_{k=\overline{1,15}}$	2
Number of resterilizations (*NoRe*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	$=\sum_{k=1}^{15} NoRe(s_k)$	0
Learning duration (*LeDu*)	-	-	1h	1h	-	-	2h	1h	1h	2h	2h	-	-	-	-	$=\sum_{k=1}^{15} LeDu(s_k)$	10h
Intervention average duration (*InAvD*)	-	3 min	-	5 min	3 min	2 min	1 min	-	2 min	2 min	3 min	1 min	1 min	1 min	5 min	$=\sum_{k=1}^{15} InAvD(s_k)$	29 min
Intervention success ratio (*InSuR*)	0,999	0,98	0,99	0,99	0,99	0,99	0,999	0,999	0,99	0,99	0,999	0,99	0,999	0,999	0,999	$=\prod_{k=1}^{15} InSuR(s_k)$	0,91

Table 13-5: The usability factors in the Full Integration Scenario analyzed per scenario scene (s1 to s15)

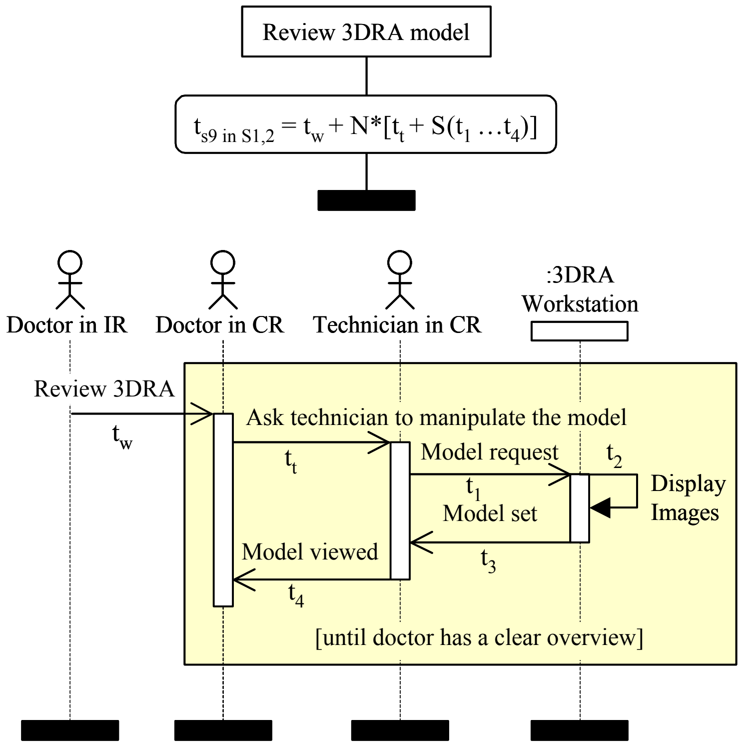
Usability Factors	**Full Integration Scenario Scenes**																
	s1	s2	s3	s4	s5	s6	s7	s8	s9	s10	s11	s12	s13	s14	s15	Function used for the aggregation	Overall Result
Number of walks (*NoW*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	$=\sum_{k=1}^{15} NoW(s_k)$	0
Number of persons involved (*PeIn*)	0	1	1	1	1	1	1	1	1	1	1	1	1	1	2	$=Max\left[PeIn(s_k)\right]_{k=1,15}$	2
Number of resterilizations (*NoRe)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	$=\sum_{k=1}^{15} NoRe(s_k)$	0
Learning duration (*LeDu)*	-	-	1h	1h	-	-	2h	1h	1h	2h	2h	1h	-	-	-	$=\sum_{k=1}^{15} LeDu(s_k)$	11h
Intervention average duration (*InAvD)*	-	2 min	-	5 min	1 min	1 min	1 min	-	2 min	2 min	3 min	1 min	1 min	1 min	5 min	$=\sum_{k=1}^{15} InAvD(s_k)$	25 min
Intervention success ratio (*InSuR)*	0,999	0,99	0,99	0,99	0,99	0,99	0,999	0,999	0,999	0,999	0,999	0,999	0,999	0,999	0,999	$=\prod_{k=1}^{15} InSuR(s_k)$	0,94

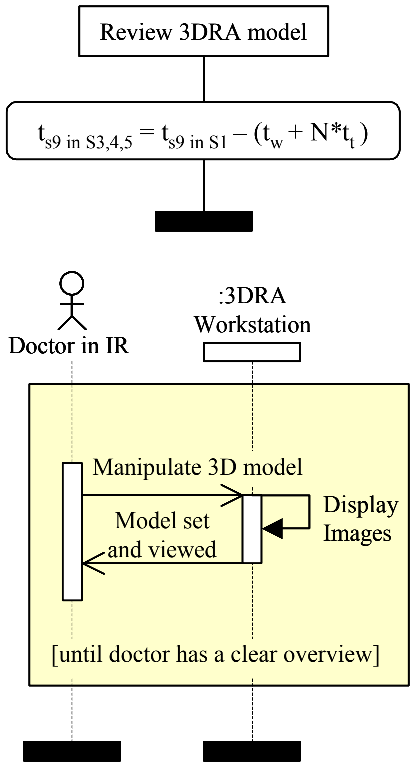
Appendix F - Performance Analysis with SQUASH - Details

Starting with scene 2 – this is because scene 1 contains only the description of the Cathlab, thus not of interest at this point of the analysis.

Scene 9

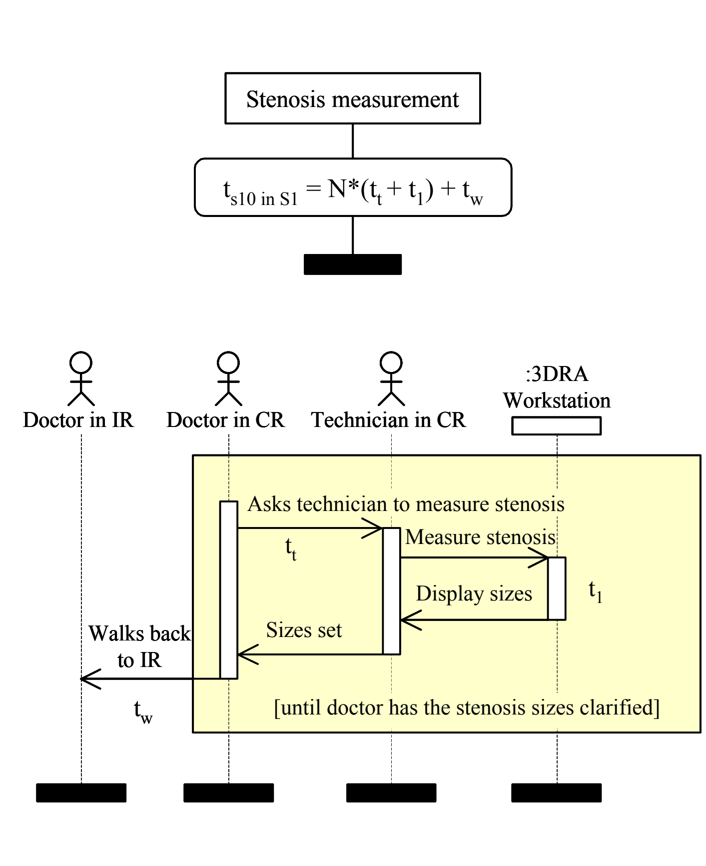
Minimal, Data Integration Scenario	P&C, Workflow, Full Integration Scenario

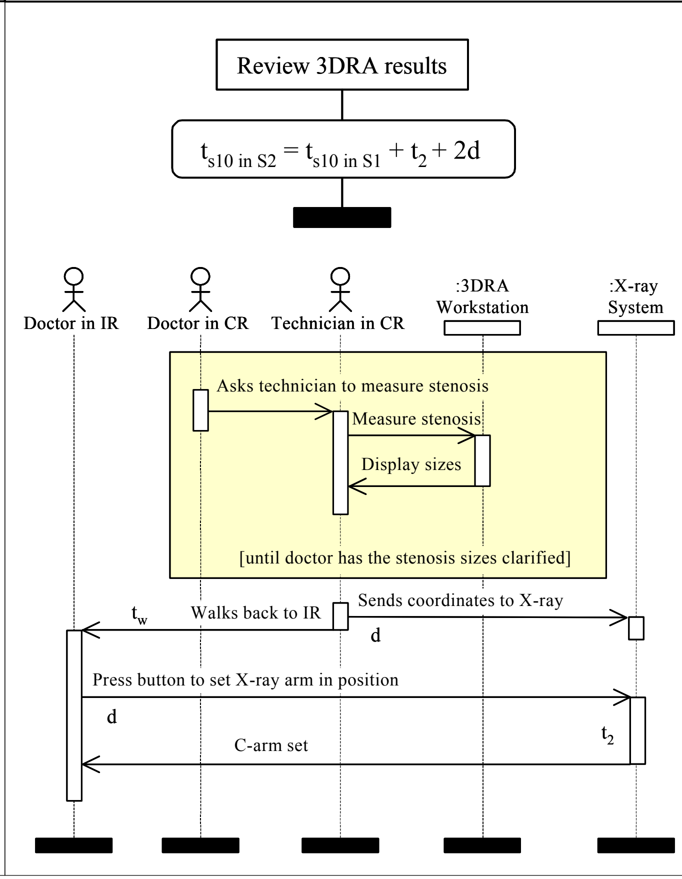




Scene 10

Minimal Integration	Data Integration Scenario	P&C, Workflow and Full Integration Scenario





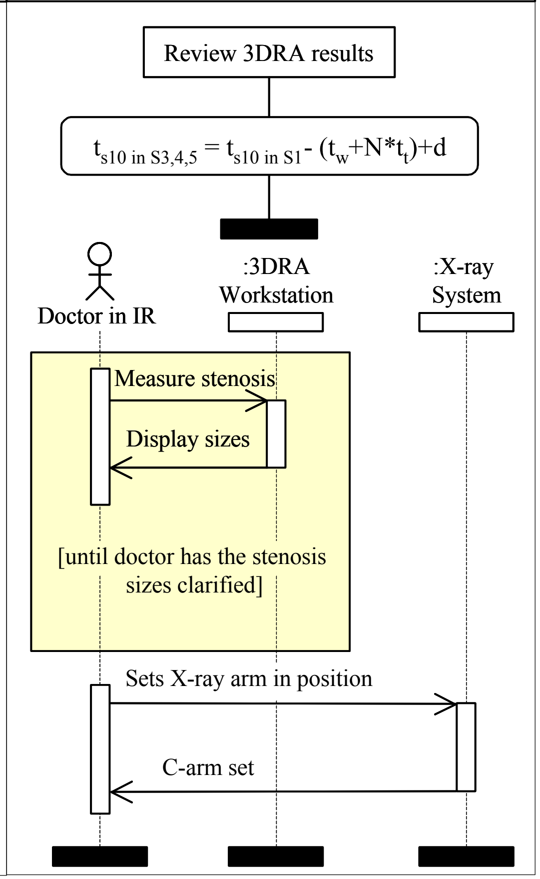


Table 13-6: The performance factors in extracted from the user scenarios, where the "? " sign indicates the most relevant factors. For brevity reasons, only the performance relevant scenes are shown in this table.

<table>
<tr><th rowspan="2"></th><th rowspan="2">Performance Factors</th><th colspan="5">Performance Attributes in each Scenario</th></tr>
<tr><th>Minimal Scenario</th><th>Data Scenario</th><th>Presentation & Control</th><th>Workflow Scenario</th><th>Full Integration Scenario</th></tr>
<tr><td rowspan="4">Scene 2</td><td rowspan="3">Response Time</td><td colspan="5">? Duration for the retrieval of the MR pictures from the PACS</td></tr>
<tr><td colspan="5">MR pictures Display time</td></tr>
<tr><td colspan="5">Visualization time</td></tr>
<tr><td>Duration</td><td></td><td>? Transfer of MR slices to X-ray</td><td></td><td></td><td>Stenosis angle search and maximum intensity</td></tr>
<tr><td>S 4</td><td>Response Time</td><td colspan="5">? Display the position of the catheter's tip</td></tr>
<tr><td rowspan="7">Scene 7</td><td rowspan="3">Response Time</td><td colspan="5">? X-ray exposure image acquisition</td></tr>
<tr><td colspan="5">X-ray Image display duration</td></tr>
<tr><td colspan="5">? X-ray image storage duration</td></tr>
<tr><td>Response Time</td><td colspan="5">? Rotational angiography process duration</td></tr>
<tr><td></td><td colspan="5">? 3D image reconstruction duration</td></tr>
<tr><td>Response Time</td><td colspan="5">? Display stenosis size duration</td></tr>
<tr><td>Response Time</td><td colspan="5">? Blood pressure and stenosis values display duration</td></tr>
</table>

Table 13-7: Speeds of various I/O buses and the duration of the data transfer

Bus type	Width (bits)	Bus Speed (MHz)	Bus Bandwidth (MB/sec)	Transfer duration in seconds			Relation with Table 8-1
				For 100MB	For 25MB	For 0.5MB	
16-bit ISA	16	8.3	15.9	6.2	1.55	0.031	Planned Level
AGP (x2 mode)	32	66x2	508.6	0.19	0.04	0.0008	Best Case
Bus type	Width (bits)	Bus Speed (MHz)	Bus Bandwidth (GB/sec)	Transfer duration in milliseconds			Relation with Table 8-1
				For 100MB	For 25MB	For 0.5MB	
AGP (x4 mode)	32	66x4	1.017	98	26.5	0.53	Best Case
PCI-X (x4 mode)	64	133x4	4.101	24	6	0.12	
Bus type	Width (bits)	Bus Speed (GHz)	Bus Bandwidth (GB/sec)	Transfer duration in milliseconds			Relation with Table 8-1
				For 100MB	For 25MB	For 0.5MB	
3GIO (x1 mode)	1	2.5x1	0.24	410	102.5	2.05	Best Case
3GIO (x32 mode)	1	2.5x32	7.81	12	3	0.06	

Appendix G - Risk Analysis with SQUASH - Details

13.1.1 Technical Risks

<table>
<tr><td colspan="3">Technical Hazard 1 (TC-1): The integration will have a high impact on the X-ray system's architecture, resulting in delayed schedule and excessive integration costs.</td></tr>
<tr><td colspan="2" rowspan="2">Failure Scenario 1:
The architecting team investigates the modifiability of the current X-ray system architecture and finds out that the integration efforts exceed the very optimistic delivery milestones decided upon.</td><td>Scenario Trigger 1:
Use cases that cannot be easily implemented.</td></tr>
<tr><td>Transition Indicator 1: project misses intermediate deadlines.</td></tr>
<tr><td colspan="2" rowspan="2">Failure Scenario 2:
The architecting team assesses the complexity of the involved systems (from a hardware and software point of view) and finds out that the integration efforts exceed the optimistic delivery milestones</td><td>Scenario Trigger 1:
Complex software architecture.</td></tr>
<tr><td>Transition Indicator 1: Project misses some of the intermediate deadlines.</td></tr>
<tr><td colspan="3">Harm or Loss
1. Delayed integration delivery date.
2. High integration costs, resulting in loss of profit.</td></tr>
<tr><td>Risk Owner: Architect</td><td colspan="2" rowspan="2">Risk Mitigation Solutions:
1. A priori assessment of the modifiability of the X-ray systems with respect to the integration.
2. A priori assessment of the complexity and/or the portability of the software.
3. Best people available assigned for the integration.</td></tr>
<tr><td>Risk Expiration:
Releases according to the schedule.</td></tr>
</table>

<table>
<tr><td colspan="2">Technical Hazard 2 (TC-2): Crash due to a single point of failure.</td></tr>
<tr><td rowspan="2">Failure Scenario 1:
The applications are integrated with the basic X-ray system. The software of the modalities runs on the same platform and shares the same resources (memory, CPU). A software or hardware failure causes temporary, or permanent, shut down of the integrated system.</td><td>Scenario Triggers:
1. Software bugs.
2. Hardware failure.</td></tr>
<tr><td>Transition Indicator:
System crashes.</td></tr>
<tr><td colspan="2">Harm or Loss
1. Hospital or clinic reputation heavily affected.
2. System producer loss of credibility and financial loss in case of complications or damage for the patient.</td></tr>
<tr><td>Risk Owner: The Architect</td><td rowspan="2">Risk Mitigation Solutions:
1. The systems are independent and can be quickly replaced in case of failure during the intervention.
2. Redundancy mechanisms in place for the software and hardware components of the integrated system.</td></tr>
<tr><td>Risk Expiration:
1. No errors at software or hardware level
2. Independent systems.</td></tr>
</table>

<table>
<tr><td colspan="2">Technical Hazard 3 (TC-3): Integrated system fails to meet its quality requirements.</td></tr>
<tr><td rowspan="2">Failure Scenario 1:
The individual components of the new system are in their final test phase, ready for being integrated. In parallel the user interface has been implemented as well, but without much knowledge of the actual habits and skills of the final users – the cardiologists. The software components are integrated. They work together pretty fine. However sometimes the system it takes a long time to respond for certain type of jobs - especially when the printing and archiving functions run in parallel. Moreover it takes ages for the clinical experts to accommodate with the new user interface, forget about the ease of learn of the new possible features and capabilities.</td><td>Scenario Triggers:
1. Performance problems
2. Usability problems</td></tr>
<tr><td>Transition Indicator 1:
1. No performance estimation or prediction available.
2. Usability experts involved late in the design process.
3. If any, the intermediate performance and usability assessments scored low.</td></tr>
<tr><td colspan="2">Harm or Loss
1. Few customers, or if many then with lots of complains and troubles.</td></tr>
<tr><td>Risk Owner: The Architect</td><td rowspan="2">Risk Mitigation Solutions:
1. Early, continuous and systematic assessments.
2. Scenario-based architecting and assessment.</td></tr>
<tr><td>Risk Expiration:
1. Assessments score excellent</td></tr>
</table>

13.1.2 Business Risks

<table>
<tr><td colspan="2">Business Hazard 1 (BH-1): Too late on the market.</td></tr>
<tr><td rowspan="2">Failure Scenario 1:
The integration of the new modalities took a long time before the first working systems were ready for shipment. The competition already for one year on the market with systems offering same functionality. The remaining potential customers for the new systems are less and less each day.</td><td>Scenario Trigger: Strong competition.</td></tr>
<tr><td>Transition Indicator: Competitors’ progress and status.</td></tr>
<tr><td colspan="2">Harm or Loss
1. Loss of customers and therefore profit.</td></tr>
<tr><td>Risk Owner: Business Owner</td><td rowspan="2">Risk Mitigation Solutions:
1. Start the integration earlier than the competitors.
2. Secure inventions, patents and copyrights.
3. Create strategic alliances with the owners of the modalities involved in the integration.</td></tr>
<tr><td>Risk Expiration: Ahead of competitors’ plans.</td></tr>
</table>

13.1.3 Application Risks

<table>
<tr><td colspan="2">Application Hazard 1 (AH-1): Inaccurate stent deployment.</td></tr>
<tr><td rowspan="2">Failure Scenario 1:
The cardiologist cannot estimate the exact position and length of the plaque due to the fact that the X-ray images do not offer these details. Therefore he deploys the stent in the best position he can imagine. However, it turns out that the stent covered only part of the plaque. The patient will have a re-catheterisation a few months later.</td><td>Scenario Trigger 1: Lack of anatomical information.</td></tr>
<tr><td>Transition Indicator 1: Patient complains.</td></tr>
<tr><td colspan="2">Harm or Loss
1. Patient will have a re-catheterisation.
2. Frustration for the cardiologist which has to work with such system
3. Hospital or clinic reputation heavily affected.
4. Increase in the total amount of X-ray exposure for the cardiologist and the patient.</td></tr>
<tr><td>Risk Owner: System Owner</td><td rowspan="2">Risk Mitigation Solutions:
1. Improve the accuracy of the X-ray images.
2. Provide the cardiologist with anatomical information about the stenosis.</td></tr>
<tr><td>Risk Expiration: No post-interventional complains from the patient.</td></tr>
</table>

<table>
<tr><td colspan="3">Application Hazard 2 (AH-2): Extended intervention (over 45 minutes).</td></tr>
<tr><td colspan="2" rowspan="2">Failure Scenario 1:
The cardiologist cannot navigate the catheter due to complicated ramifications of some coronaries combined with the rhythmic heartbeat. It takes him a long time to reach the stenosis region. During all this time the patient receives a significant extra doze of X-rays as well as contrast fluid.</td><td>Scenario Trigger 1:
Lack of a system to help the cardiologist in automatically manipulates the catheter.</td></tr>
<tr><td>Transition Indicator 1:
Complex ramifications of the coronaries.</td></tr>
<tr><td colspan="3">Harm or Loss
1. Increase in the total amount of X-ray exposure for the cardiologist and the patient.
2. Lengthy and exhausting intervention causing pain and fatigue for the cardiologist, which has to wear a radiation protective apron.</td></tr>
<tr><td>Risk Owner: System Owner</td><td colspan="2" rowspan="2">Risk Mitigation Solutions:
1. Provide techniques, methods or systems to help cardiologist navigate faster the catheter.</td></tr>
<tr><td>Risk Expiration:
Successful intervention.</td></tr>
</table>

<table>
<tr><td colspan="3">Application Hazard 3 (AH-3): Intervention precision at risk</td></tr>
<tr><td colspan="2" rowspan="2">Failure Scenario 1:
The cardiologist deploys a stent. After the inflating the stent and acquiring a new set of X-ray images, he realizes that the there could be a continuation of the stenosis in the upper part of the just deployed stent. In this case the cardiologist has to deploy a second stent, and acquire a couple of more X-ray images. If he had had anatomical information about the coronaries, one larger stent would have been enough.</td><td>Scenario Trigger 1:
Lack of anatomical information.</td></tr>
<tr><td>Transition Indicator 1:
Complex ramifications of the coronaries.</td></tr>
<tr><td colspan="3">Harm or Loss
1. Increased in the total duration of the intervention with up to 50%, and the associated costs with up to 50-100%
2. Increase in the total amount of X-ray exposure for the cardiologist and the patient.
3. Lengthy and exhausting intervention causing pain and fatigue for the cardiologist, which has to wear a radiation protective apron.</td></tr>
<tr><td>Risk Owner: System Owner</td><td colspan="2" rowspan="2">Risk Mitigation Solutions:
1. Provide the cardiologist with anatomical information about the stenosis.</td></tr>
<tr><td>Risk Expiration:
Anatomical information available.</td></tr>
</table>

Application Hazard 4 (AH-4): Jailing of side branches.

Failure Scenario 1:

The stenosis in located the vicinity of a side branch of a coronary artery. The placement of the stent has to be done very accurately, or otherwise the artery's side branch can be obstructed, Figure 13-1.

Figure 13-1: Incorrect stent deployment as a side branch is now obstructed[6]

Scenario Trigger 1:
1. Side branches of the arteries

2. Lack of anatomical information

Transition Indicator 1:
Stenosis is located in the vicinity of a side branch.

Harm or Loss

1. Post-interventional complications for the patient.
2. Hospital or clinic reputation heavily affected.
3. Increase in the total amount of X-ray exposure for the cardiologist and the patient.

Risk Owner: System Owner

Risk Expiration:
Anatomical information available.

Risk Mitigation Solutions:
1. Provide the cardiologist with anatomical information about the stenosis.

[6] Image provided courtesy of MediGuide www.mediguide.co.il

<table>
<tr><td colspan="3">Application Hazard 5 (AH5): Inaccurate stent size selection and inflation.</td></tr>
<tr><td colspan="2" rowspan="2">Failure Scenario 1:
The cardiologist is reviewing the stenosis location on the screen of the monitor. Based on the available information on the screen he has to take a decision on how large is the stenosis, where ends the vessel wall and where from starts the atherosclerotic material. He also has to decide how much the stent can be enlarged so that the blood vessel walls remain intact. If the decision is wrong, and he chooses a too large stent, the blood vessel wall may break.</td><td>Scenario Trigger 1:
1. Large and eccentric atheroma, Figure 13-2.
2. Lack of anatomical information</td></tr>
<tr><td>Transition Indicator 1:
Large atheroma.</td></tr>
<tr><td colspan="3">Harm or Loss
1. Post-interventional complications for the patient.
2. Frustration for the cardiologist which has to work with such system</td></tr>
<tr><td>Risk Owner: System Owner</td><td colspan="2" rowspan="2">Risk Mitigation Solutions:
1. Provide the cardiologist with the means to get some more anatomical information about the stenosis, for example using intravascular ultrasound (IVUS), Figure 13-2.</td></tr>
<tr><td>Risk Expiration:
Anatomical information available.</td></tr>
</table>

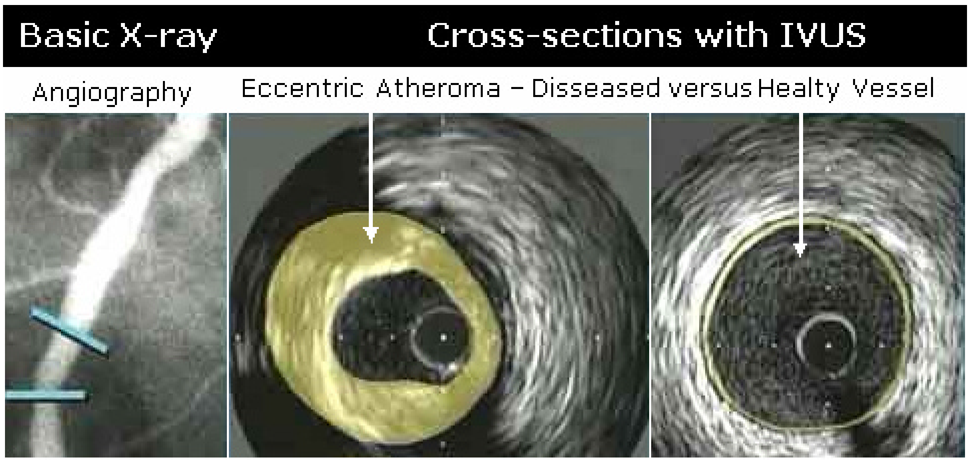


Figure 13-2: X-ray angiography versus IVUS type of cross-section[7]

[7] Image provided courtesy of Philips Medical Systems www.philips.com

Table 13-8: Quantitative risk analysis with SQUASH applied for the Minimal Integration Scenario using the abbreviations from Table 10-1.

For each risk the probability of hazard and the size of loss are estimated. In a second round, the losses are quantified using monetary values, hereafter euros (€). The reason for this is because the risks exposure values need to be comparable. The last column in each of these tables shows the quantitative estimates for the size of loss in euros. The values of these estimates are theoretical, showed here for the purpose of the analysis.

Hazards in Minimal Scenario	s1	s2	s3	s4	s5	s6	s7	s8	s9	s10	s11	s12	s13	s14	s15		all	all
High impact on system's architecture	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	sum	N	N
	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	sum	N	N
Quality requirements in danger	N	N	N	N	N	20%	N	N	20%	N	N	N	N	N	N	sum	40%	40%
	N	N	N	N	N	5min[8]	N	N	5min	N	N	N	N	N	N	sum	10min	2.000€
Crash due to a single point of failure	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	-	N	N
	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	-	N	N
Increased time to market	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	sum	N	N
	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	sum	N	N
Elaborated stent deployment task	N	N	N	N	N	N	N	N	N	N	N	N	1%	N	N	-	1%	1%
	N	N	N	N	N	N	N	N	N	N	N	N	1re[9]	N	N	-	1re	500€
Extended intervention duration	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	sum	N	N
	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	sum	N	N
Increased intervention costs	N	N	N	N	N	N	N	N	N	N	N	1%	1%	N	N	sum	1÷2%	2%
	N	N	N	N	N	N	N	N	N	N	N	1re	1re	N	N	max	1re	500€
Jailing of side branches	N	N	N	N	N	N	N	1%	1%	N	1%	1%	N	N	N	sum	1÷4%	4%
	N	N	N	N	N	N	N	1re	1re	N	1re	1re	N	N	N	max	1re	500€
Difficult stent selection and inflation task	N	N	N	N	N	N	N	N	N	N	N	10%	0,1%	N	N	sum	0,1÷10%	10%
	N	N	N	N	N	N	N	N	N	N	N	out[10]	out	N	N	max	out	10.000€

[8] 100% 8 minutes – should be interpreted as: it is probable that only scene 6 in the Minimal integration scenario will introduce an extra delay of 5 minutes to the intervention total duration. This is due to the fact that the cardiologist is supposed to walk to the control room to review the MR study.

[9] re – stands for recatheterization – for some of the patients a second catheter might be required.

[10] out – stands for *out of Cathlab* – and refers to the fact that the patient has to be transported immediately out of the Cathlab to the surgery because of the internal bleeding.

Table 13-9: Quantitative risk analysis with SQUASH applied for the Data Integration Scenario using the abbreviations from Table 10-1.

Hazards in Data Integration Scenario	s1	s2	s3	s4	s5	s6	s7	s8	s9	s10	s11	s12	s13	s14	s15		all	all
High impact on system's architecture	N[11]	1%	1%	N	N	1%	N	N	N	1%	5%	N	N	N	N	sum	1-9%	9%
	N	1md[12]	1md[13]	N	N	1md[14]	N	N	N	1md	2md	N	N	N	N	sum	6md	20.000.000€
Quality requirements in danger	N	N	N	N	N	10%	N	N	10%	N	N	N	N	N	N	sum	10÷20%	20%
	N	N	N	N	N	3min	N	N	3min	N	N	N	N	N	N	sum	3÷6min	1.000€
Crash due to a single point of failure	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	-	N	N
	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	-	N	N
Increased time to market	N	N	N	N	N	N	N	N	N	N	N	N	N	N	9%	sum	9%	9%
	N	N	N	N	N	N	N	N	N	N	N	N	N	N	6md	sum	6md	20.000.000€
Elaborated stent deployment task	N	N	N	N	N	N	N	N	N	N	N	N	1%	N	N	sum	1%	1%
	N	N	N	N	N	N	N	N	N	N	N	N	1re	N	N	max	1re	500€
Extended intervention duration	N	N	N	N	N	10%	N	N	10%	N	N	N	N	N	N	sum	10÷20%	20%
	N	N	N	N	N	3min	N	N	3min	N	N	N	N	N	N	sum	3÷6min	1.000€
Increased intervention costs	N	N	N	N	N	N	N	N	N	N	N	1%	1%	N	N	sum	1÷2%	2%
	N	N	N	N	N	N	N	N	N	N	N	1re	1re	N	N	max	1re	500€
Jailing of side branches	N	N	N	N	N	N	N	1%	1%	N	1%	1%	N	N	N	sum	1÷4%	4%
	N	N	N	N	N	N	N	1re	1re	N	1re	1re	N	N	N	max	1re	500€
Difficult stent selection and inflation task	N	N	N	N	N	N	N	N	N	N	N	10%	0,1%	N	N	sum	0,1÷10%	10%
	N	N	N	N	N	N	N	N	N	N	N	out	out	N	N	max	out	10.000€

[11] N stands for not applicable for this scene.
[12] 1md = one months delay – Scene 2 of Data Integration scenario introduces the MR retrieval feature on X-ray in the control room, unlikely to introduce delays.
[13] Scene 3 of Data Integration scenario introduces the transfer of the hemodynamic data to X-ray feature, unlikely to introduce large delays.
[14] Scene 6 of Data Integration scenario introduces a new feature "MR movie compared with X-ray", in the intervention room, unlikely to introduce a delays.

Table 13-10: Quantitative risk analysis with SQUASH applied for the Presentation and Control (PC)-Cold Integration Scenario using the same abbreviations as in Table 10-1.

Hazards in (PC)-Cold Integration	s1	s2	s3	s4	s5	s6	s7	s8	s9	s10	s11	s12	s13	s14	s15		all	All
High impact on system's architecture	N	1%	1%	N	N	1%	N	N	1%	1%	1%	N	N	N	N	sum	1-6%	6%
	N	1md	2md	N	N	4md	N	N	1md	1md	3md	N	N	N	N	sum	12md	40.000.000€
Quality requirements in danger	N	N	N	N	N	10%	N	N	10%	N	N	N	N	N	N	sum	10÷20%	20%
	N	N	N	N	N	2min	N	N	2min	N	N	N	N	N	N	sum	2÷4min	500€
Crash due to a single point of failure	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	-	N	N
	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	-	N	N
Increased time to market	N	N	N	N	N	N	N	N	N	N	N	N	N	N	6%	sum	6%	6%
	N	N	N	N	N	N	N	N	N	N	N	N	N	N	12md	sum	12md	40.000.000€
Elaborated stent deployment task	N	N	N	N	N	N	N	N	N	N	N	N	1%	N	N	sum	1%	1%
	N	N	N	N	N	N	N	N	N	N	N	N	1re	N	N	max	1re	500€
Extended intervention duration	N	N	N	N	N	10%	N	N	10%	N	N	N	N	N	N	sum	10÷20%	20%
	N	N	N	N	N	2min	N	N	2min	N	N	N	N	N	N	sum	2÷4min	500€
Increased intervention costs	N	N	N	N	N	N	N	N	N	N	N	1%	1%	N	N	sum	1÷2%	2%
	N	N	N	N	N	N	N	N	N	N	N	1re	1re	N	N	max	1re	500€
Jailing of side branches	N	N	N	N	N	N	N	1%	1%	N	1%	1%	N	N	N	sum	1÷4%	4%
	N	N	N	N	N	N	N	1re	1re	N	1re	1re	N	N	N	max	1re	500€
Difficult stent selection and inflation task	N	N	N	N	N	N	N	N	N	N	N	10%	0,1%	N	N	sum	0,1÷10%	10%
	N	N	N	N	N	N	N	N	N	N	N	out	out	N	N	max	out	10.000€

Table 13-11: Quantitative risk analysis with SQUASH applied for the Presentation and Control (PC)-Warm Integration Scenario using the same abbreviations as in Table 10-1.

Hazards in (PC)-Warm Integration	s1	s2	s3	s4	s5	s6	s7	s8	s9	s10	s11	s12	s13	s14	s15		all	all
High impact on system's architecture	N	1%	1%	N	N	1%	N	N	1%	1%	1%	N	N	N	N	sum	1÷6%	6%
	N	4md	3md	N	N	3md	N	N	1md	1md	3md	N	N	N	N	sum	15md	50.000.000€
Quality requirements in danger	N	N	N	N	N	10%	N	N	10%	N	N	N	N	N	N	sum	10÷20%	20%
	N	N	N	N	N	2min	N	N	2min	N	N	N	N	N	N	sum	2÷4min	500€
Crash due to a single point of failure	N	N	N	N	N	N	1%	N	N	N	N	N	N	N	N	sum	1%	1%
	N	N	N	N	N	N	9min	N	N	N	N	N	N	N	N	sum	9min	10.000€
Increased time to market	N	N	N	N	N	N	N	N	N	N	N	N	N	N	6%	sum	6%	6%
	N	N	N	N	N	N	N	N	N	N	N	N	N	N	15md	sum	15md	50.000.000€
Elaborated stent deployment task	N	N	N	N	N	N	N	N	N	N	N	N	1%	N	N	sum	1%	1%
	N	N	N	N	N	N	N	N	N	N	N	N	1re	N	N	max	1re	500€
Extended intervention duration	N	N	N	N	N	10%	N	N	10%	N	N	N	N	N	N	sum	10÷20%	20%
	N	N	N	N	N	2min	N	N	2min	N	N	N	N	N	N	sum	2÷4min	500€
Increased intervention costs	N	N	N	N	N	N	N	N	N	N	N	1%	1%	N	N	sum	1÷2%	2%
	N	N	N	N	N	N	N	N	N	N	N	1re	1re	N	N	max	1re	500€
Jailing of side branches	N	N	N	N	N	N	N	1%	1%	N	1%	1%	N	N	N	sum	1÷4%	4%
	N	N	N	N	N	N	N	1re	1re	N	1re	1re	N	N	N	max	1re	500€
Difficult stent selection and inflation task	N	N	N	N	N	N	N	N	N	N	N	1%	0,1%	N	N	sum	0,1÷1%	1%
	N	N	N	N	N	N	N	N	N	N	N	out	out	N	N	max	out	10.000€

Table 13-12: Quantitative risk analysis with SQUASH applied for the Workflow Integration – Scenario using the same abbreviations as in Table 10-1.

Hazards in Workflow Scenario	s1	s2	s3	s4	s5	s6	s7	s8	s9	s10	s11	s12	s13	s14	s15		all	all
High impact on system's architecture	N	1%	1%	N	N	1%	N	N	1%	1%	1%	N	N	N	N	sum	1÷6%	6%
	N	4md	3md	N	N	3md	N	N	1md	1md	3md	N	N	N	N	sum	15md	50.000.000€
Quality requirements in danger	N	N	N	N	N	10%	N	N	10%	N	N	N	N	N	N	sum	10÷20%	20%
	N	N	N	N	N	2min	N	N	2min	N	N	N	N	N	N	sum	2÷4min	500€
Crash due to a single point of failure	N	N	N	N	N	N	1%	N	N	N	N	N	N	N	N	sum	1%	1%
	N	N	N	N	N	N	9min	N	N	N	N	N	N	N	N	sum	9min	10.000€
Increased time to market	N	N	N	N	N	N	N	N	N	N	N	N	N	N	6%	sum	6%	6%
	N	N	N	N	N	N	N	N	N	N	N	N	N	N	15md	sum	15md	50.000.000€
Elaborated stent deployment task	N	N	N	N	N	N	N	N	N	N	N	N	1%	N	N	sum	1%	1%
	N	N	N	N	N	N	N	N	N	N	N	N	1re	N	N	max	1re	500€
Extended intervention duration	N	N	N	N	N	10%	N	N	10%	N	N	N	N	N	N	sum	10÷20%	20%
	N	N	N	N	N	2min	N	N	2min	N	N	N	N	N	N	sum	2÷4min	500€
Increased intervention costs	N	N	N	N	N	N	N	N	N	N	N	1%	1%	N	N	sum	1÷2%	2%
	N	N	N	N	N	N	N	N	N	N	N	1re	1re	N	N	max	1re	500€
Jailing of side branches	N	N	N	N	N	N	N	1%	1%	N	1%	1%	N	N	N	sum	1÷4%	4%
	N	N	N	N	N	N	N	1re	1re	N	1re	1re	N	N	N	max	1re	500€
Difficult stent selection and inflation task	N	N	N	N	N	N	N	N	N	N	N	1%	0,1%	N	N	sum	0,1÷1%	1%
	N	N	N	N	N	N	N	N	N	N	N	out	out	N	N	max	out	10.000€

Table 13-13: Quantitative risk analysis with SQUASH applied for the Full Integration Scenario using the same abbreviations as in Table 10-1.

Hazards in Full Integration Scenario	s1	s2	s3	s4	s5	s6	s7	s8	s9	s10	s11	S12	s13	s14	s15		all	all
High impact on system's architecture	N	1%	1%	N	1%	1%	1%	N	1%	1%	1%	1%	N	N	N	sum	1÷9%	9%
	N	4md	3md	N	1md	3md	1md	N	1md	1md	3md	1md	N	N	N	sum	18md	100.000.000€
Quality requirements in danger	N	N	N	N	N	1%	N	N	N	N	N	N	N	N	N	sum	1%	1%
	N	N	N	N	N	1min	N	N	N	N	N	N	N	N	N	sum	1min	100€
Crash due to a single point of failure	N	N	N	N	N	N	1%	N	N	N	N	N	N	N	N	sum	1%	1%
	N	N	N	N	N	N	9min	N	N	N	N	N	N	N	N	sum	9min	10.000€
Increased time to market	N	N	N	N	N	N	N	N	N	N	N	N	N	N	9%	sum	9%	9%
	N	N	N	N	N	N	N	N	N	N	N	N	N	N	18md	sum	18md	100.000.000€
Elaborated stent deployment task	N	N	N	N	N	N	N	N	N	N	N	N	1%	N	N	sum	1%	1%
	N	N	N	N	N	N	N	N	N	N	N	N	1re	N	N	max	1re	500€
Extended intervention duration	N	N	N	N	N	1%	N	N	N	N	N	N	N	N	N	sum	1%	1%
	N	N	N	N	N	1min	N	N	N	N	N	N	N	N	N	sum	1min	100€
Increased intervention costs	N	N	N	N	N	N	N	N	N	N	N	N	1%	N	N	sum	1%	1%
	N	N	N	N	N	N	N	N	N	N	N	N	1re	N	N	max	1re	500€
Jailing of side branches	N	N	N	N	N	N	N	1%	1%	N	1%	1%	N	N	N	sum	1÷4%	4%
	N	N	N	N	N	N	N	1re	1re	N	1re	1re	N	N	N	max	1re	500€
Difficult stent selection and inflation task	N	N	N	N	N	N	N	N	N	N	N	N	0,1%	N	N	sum	0,1%	0,1%
	N	N	N	N	N	N	N	N	N	N	N	N	out	N	N	max	out	10.000€

Appendix H - Cost Analysis with SQUASH - Details

Table 13-14: Cost Analysis with SQUASH – the mapping between new features and scenario scenes for the Minimal Integration

Minimal	s1	s2	s3	s4	s5	s6	s7	s8	s9	s10	s11	s12	s13	s14	s15
Hemo Data Auto Logging [HDAL]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AutoSet of the X-ray Arm [ASXA]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MR in IR [MRIR]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fast 3DRA [F3DRA]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Control for 3D in IR [C3DIR]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Calculate Stent Size [CSS]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Suggest Stent Size [SSS]	**-**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Color Monitors [CM]	**yes**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Flat Screens [FS]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 13-15: Cost Analysis with SQUASH – the mapping between new features and scenario scenes for the Data Integration

Data	s1	s2	s3	s4	s5	s6	s7	s8	s9	s10	s11	s12	s13	s14	s15
Hemo Data Auto Logging [HDAL]	-	-	**yes**	-	-	-	-	-	-	-	-	-	-	-	-
AutoSet of the X-ray Arm [ASXA]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MR in IR [MRIR]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fast 3DRA [F3DRA]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Control for 3D in IR [C3DIR]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Calculate Stent Size [CSS]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Suggest Stent Size [SSS]	**-**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Color Monitors [CM]	**yes**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Flat Screens [FS]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 13-16: Cost Analysis with SQUASH – mapping of new features and scenario scenes for the PC Hardware Switch Integration

PC Hw Switch (cold Integration)	s1	s2	s3	s4	s5	s6	s7	s8	s9	s10	s11	s12	s13	s14	s15
Hemo Data Auto Logging [HDAL]	-		**yes**	-	-	-	-	-	-	-	-	-	-	-	-
AutoSet of the X-ray Arm [ASXA]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MR in IR [MRIR]	-	-	-	-	-	**yes**	-	-	-	-	-	-	-	-	-
Fast 3DRA [F3DRA]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Control for 3D in IR [C3DIR]	-	-	-	-	-	-	-	-	**yes**	-	-	-	-	-	-
Calculate Stent Size [CSS]	-	-	-	-	-	-	-	-	-	-	**yes**	-	-	-	-
Suggest Stent Size [SSS]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Color Monitors [CM]	**yes**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Flat Screens [FS]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 13-17: Cost Analysis with SQUASH – mapping of new features and scenario scenes for the PC Alt+Tab Integration

PC Alt+Tab (warm integration)	s1	s2	s3	s4	s5	s6	s7	s8	s9	s10	s11	s12	s13	s14	s15
Hemo Data Auto Logging [HDAL]	-		**yes**	-	-	-	-	-	-	-	-	-	-	-	-
AutoSet of the X-ray Arm [ASXA]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MR in IR [MRIR]	-	-	-	-	-	**yes**	-	-	-	-	-	-	-	-	-
Fast 3DRA [F3DRA]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Control for 3D in IR [C3DIR]	-	-	-	-	-	-	-	-	**yes**	-	-	-	-	-	-
Calculate Stent Size [CSS]	-	-	-	-	-	-	-	-	-	-	**yes**	-	-	-	-
Suggest Stent Size [SSS]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Color Monitors [CM]	**yes**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Flat Screens [FS]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 13-18: Cost Analysis with SQUASH – the mapping between the new features and scenario scenes for the Workflow Integration

Workflow	s1	s2	s3	s4	s5	s6	s7	s8	s9	s10	s11	s12	s13	s14	s15
Hemo Data Auto Logging [HDAL]	-		**yes**	-	-	-	-	-	-	-	-	-	-	-	-
AutoSet of the X-ray Arm [ASXA]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MR in IR [MRIR]	-	-	-	-	-	**yes**	-	-	-	-	-	-	-	-	-
Fast 3DRA [F3DRA]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Control for 3D in IR [C3DIR]	-	-	-	-	-	-	-	-	**yes**	-	-	-	-	-	-
Calculate Stent Size [CSS]	-	-	-	-	-	-	-	-	-	-	**yes**	-	-	-	-
Suggest Stent Size [SSS]	**-**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Color Monitors [CM]	**yes**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Flat Screens [FS]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 13-19: Cost Analysis with SQUASH – the mapping between the new features and scenario scenes for the Full Integration

Full	s1	s2	s3	s4	s5	s6	s7	s8	s9	s10	s11	s12	s13	s14	s15
Hemo Data Auto Logging [HDAL]	-		**yes**	-	-	-	-	-	-	-	-	-	-	-	-
AutoSet of the X-ray Arm [ASXA]	-	-	-	-	**yes**	-	-	-	-	-	-	-	-	-	-
MR in IR [MRIR]	-	-	-	-	-	**yes**	-	-	-	-	-	-	-	-	-
Fast 3DRA [F3DRA]	-	-	-	-	-	-	**yes**	-	-	-	-	-	-	-	-
Control for 3D in IR [C3DIR]	-	-	-	-	-	-	-	-	**yes**	-	-	-	-	-	-
Calculate Stent Size [CSS]	-	-	-	-	-	-	-	-	-	-	**yes**	-	-	-	-
Suggest Stent Size [SSS]	**-**	-	-	-	-	-	-	-	-	-	-	**yes**	-	-	-
Color Monitors [CM]	**yes**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Flat Screens [FS]	**yes**	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Appendix I - Feasibility Analysis - Details and Results

Table 13-20: Minimal Integration Scenario in the McHealth Strategic Scenario - The impact of quality attributes on the organization market share. A explanation on how to read the tables is given in Table 11-4 on page 135.

Minimal Integration Scenario in the McHealth Strategic Scenario

preference coefficients

importance	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
low-end	0.05	0.1	0.1	0.2	0.15	0.2	0.2
high-end	0.04	0.1	0.5	0.1	0.05	0.2	0.01

the individual change in market share due to the values of the attributes

magnitude	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
	from 1 to 4	from 3 to 3	from 85% to 85%	from 6 to 6 h	from 300s to 300s	from 40 min to 40 min	from 2000 to 2000
low-end	-0.02	0	-0.05	0	-0.05	0	-0.05
high-end	-0.05	0	-0.2	0	-0.1	-0.05	-0.02

the combined effect = magnitude*importance for each customer segment (i.e. the low-end and the high-end)

	segment	correction
combined effect	low-end	-0.0235
	high-end	-0.1172

McHealth	**low-end**	**high-end**
market size	4138	2647
organization market share (MS)	0.3	0.3
influence of QAs on MS	0.2765	0.1828

McHealth	**low-end**	**high-end**
Required Cathlabs	4138	2647
Organization Cathlab Sales	1144.157	483.8716

Table 13-21: Minimal Integration Scenario in the Clinique Strategic Scenario - The impact of quality attributes on the organization market share.

Minimal Integration Scenario in the Clinique Strategic Scenario

preference coefficients

importance	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
low-end	0.05	0.1	0.15	0.2	0.15	0.2	0.15
high-end	0.04	0.1	0.5	0.1	0.05	0.2	0.01

the individual change in market share due to the values of the attributes

magnitude	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
	from 1 to 4	from 3 to 3	from 85% to 85%	from 6 to 6 h	from 300s to 300s	from 40 min to 40 min	from 2000 to 2000
low-end	-2%	0%	-10%	0%	-5%	-2%	-2%
high-end	-5%	0%	-30%	0%	-10%	-5%	-2%

the combined effect = magnitude*importance for each customer segment (i.e. the low-end and the high-end)

segment	correction
low-end	-3.05%
high-end	-16.72%

Clinique	**low-end**	**high-end**
market size	4,138	2,647
organization market share (MS)	30.00%	30.00%
influence of QAs on MS	26.95%	13.28%

Clinique	**low-end**	**high-end**
Required Cathlabs	3,631	3,997
Organization Cathlab Sales	979	531

Table 13-22: Minimal Integration Scenario in the See Treat Cure Strategic Scenario - The impact of quality attributes on the organization market share.

Minimal Integration Scenario **the See Treat Cure Strategic Scenario**

preference coefficients

importance	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
low-end	0.05	0.1	0.3	0.1	0.1	0.2	0.15
high-end	0.04	0.1	0.6	0.1	0.05	0.1	0.01

the individual change in market share due to the values of the attributes

magnitude	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
	from 1 to 4	from 3 to 3	from 85% to 85%	from 6 to 6 h	from 300s to 300s	from 40 min to 40 min	from 2000 to 2000
low-end	-2%	0%	-30%	0%	-5%	-2%	-2%
high-end	-5%	0%	-30%	0%	-10%	-5%	-2%

the combined effect = magnitude*importance for each customer segment (i.e. the low-end and the high-end)

segment	correction
low-end	-10.30%
high-end	-19.22%

See Treat	**low-end**	**high-end**
market size	4,138	2,647
organization market share (MS)	30.00%	30.00%
influence of QAs on MS	19.70%	10.78%

See Treat	**low-end**	**high-end**
Required Cathlabs	3,181	5,197
Organization Cathlab Sales	627	560

Table 13-23: Minimal Integration Scenario in the Brave New Pharma World Strategic Scenario - The impact of quality attributes on the organization market share.

Minimal Integration Scenario **the Brave New Pharma World Strategic Scenario**

preference coefficients

importance	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
low-end	0	0	0.4	0	0	0.1	0.5
high-end	0	0	0.5	0	0	0.3	0.2

the individual change in market share due to the values of the attributes

magnitude	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
	from 1 to 4	from 3 to 3	from 85% to 85%	from 6 to 6 h	from 300s to 300s	from 40 min to 40 min	from 2000 to 2000
low-end	-2%	0%	-30%	0%	-5%	-2%	-2%
high-end	-5%	0%	-30%	0%	-10%	-5%	-2%

the combined effect = magnitude*importance for each customer segment (i.e. the low-end and the high-end)

segment	correction
low-end	-13.20%
high-end	-16.90%

See Treat	**low-end**	**high-end**
market size	4,138	2,647
organization market share (MS)	30.00%	30.00%
influence of QAs on MS	16.80%	13.10%

See Treat	**low-end**	**high-end**
Required Cathlabs	2,956	5,797
Organization Cathlab Sales	497	759

Table 13-24: Data Integration Scenario in the McHealth Strategic Scenario - The impact of quality attributes on the organization market share.

Data Integration Scenario in the McHealth Strategic Scenario
preference coefficients

importance	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
low-end	0.05	0.1	0.1	0.2	0.15	0.2	0.2
high-end	0.04	0.1	0.5	0.1	0.05	0.2	0.01

the individual change in market share due to the values of the attributes

magnitude	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
	from 1 to 3	from 3 to 3	from 85% to 85%	from 6 to 6 h	from 300s to 300s	from 40 min to 35 min	5% higher
low-end	-2%	0%	-5%	0%	-5%	2%	-8%
high-end	-4%	0%	-20%	0%	-10%	-3%	-4%

the combined effect = magnitude*importance for each customer segment (i.e. the low-end and the high-end)

segment	correction
low-end	-2.55%
high-end	-11.30%

McHealth	**low-end**	**high-end**
market size	4,138	2,647
organization market share (MS)	30.00%	30.00%
influence of QAs on MS	27.45%	18.70%

McHealth	**low-end**	**high-end**
Required Cathlabs	4,138	2,647
Organization Cathlab Sales	1,136	495

Table 13-25: Data Integration Scenario in the Clinique Strategic Scenario - The impact of quality attributes on the organization market share.

Data Integration Scenario in the Clinique Strategic Scenario
preference coefficients

importance	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
low-end	0.05	0.1	0.15	0.2	0.15	0.2	0.15
high-end	0.04	0.1	0.5	0.1	0.05	0.2	0.01

the individual change in market share due to the values of the attributes

magnitude	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
	from 1 to 3	from 3 to 3	from 85% to 85%	from 6 to 6 h	from 300s to 300s	from 40 min to 35 min	5% higher
low-end	-2%	0%	-10%	0%	-5%	5%	-5%
high-end	-4%	0%	-30%	0%	-10%	-3%	-3%

the combined effect = magnitude*importance for each customer segment (i.e. the low-end and the high-end)

segment	correction
low-end	-2.10%
high-end	-16.29%

Clinique	**low-end**	**high-end**
market size	4,138	2,647
organization market share (MS)	30.00%	30.00%
influence of QAs on MS	27.90%	13.71%

Clinique	**low-end**	**high-end**
Required Cathlabs	3,631	3,997
Organization Cathlab Sales	1,013	548

Table 13-26: Data Integration Scenario in the See Treat Cure Strategic Scenario - The impact of quality attributes on the organization market share.

Data Integration Scenario in preference coefficients **the See Treat Cure Strategic Scenario**

importance	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
low-end	0.05	0.1	0.3	0.1	0.1	0.2	0.15
high-end	0.04	0.1	0.6	0.1	0.05	0.1	0.01

the individual change in market share due to the values of the attributes

magnitude	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
	from 1 to 3	from 3 to 3	from 85% to 85%	from 6 to 6 h	from 300s to 300s	from 40 min to 35 min	5% higher
low-end	-2%	0%	-30%	0%	-5%	5%	-5%
high-end	-4%	0%	-30%	0%	-10%	-3%	-3%

the combined effect = magnitude*importance for each customer segment (i.e. the low-end and the high-end)

segment	correction
low-end	-9.35%
high-end	-18.99%

See Treat	**low-end**	**high-end**
market size	4,138	2,647
organization market share (MS)	30.00%	30.00%
influence of QAs on MS	20.65%	11.01%

See Treat	**low-end**	**high-end**
Required Cathlabs	3,181	5,197
Organization Cathlab Sales	657	572

Table 13-27: Data Integration Scenario in the Brave New Pharma World Strategic Scenario - The impact of quality attributes on the organization market share.

Data Integration Scenario in the Brave New Pharma World Strategic Scenario
preference coefficients

importance	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
low-end	0	0	0.4	0	0	0.1	0.5
high-end	0	0	0.5	0	0	0.3	0.2

the individual change in market share due to the values of the attributes

magnitude	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
	from 1 to 3	from 3 to 3	from 85% to 85%	from 6 to 6 h	from 300s to 300s	from 40 min to 35 min	5% higher
low-end	-2%	0%	-10%	0%	-5%	5%	-5%
high-end	-4%	0%	-30%	0%	-10%	-3%	-3%

the combined effect = magnitude*importance for each customer segment (i.e. the low-end and the high-end)

segment	correction
low-end	-6.00%
high-end	-16.50%

Brave New Pharma	**low-end**	**high-end**
market size	4,138	2,647
organization market share (MS)	30.00%	30.00%
influence of QAs on MS	24.00%	13.50%

Brave New Pharma	**low-end**	**high-end**
Required Cathlabs	2,956	5,797
Organization Cathlab Sales	709	783

Table 13-28: Presentation and Control (Hardware Switch) Integration Scenario in the McHealth Strategic Scenario - The impact of quality attributes on the organization market share.

PC Hw Switch Integration Scenario in in the McHealth Strategic Scenario

preference coefficients

importance	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
low-end	0.05	0.1	0.1	0.2	0.15	0.2	0.2
high-end	0.04	0.1	0.5	0.1	0.05	0.2	0.01

the individual change in market share due to the values of the attributes

magnitude	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
	from 1 to 0	from 3 to 2	from 85% to 85%	from 6 to 10 h	from 300s to 300s	from 40 min to 30 min	5% higher
low-end	5%	15%	-5%	-2%	-5%	15%	-5%
high-end	2%	5%	-20%	-5%	-10%	2%	-2%

the combined effect = magnitude*importance for each customer segment (i.e. the low-end and the high-end)

segment	correction
low-end	2.10%
high-end	-10.04%

McHealth	**low-end**	**high-end**
market size	4,138	2,647
organization market share (MS)	30.00%	30.00%
influence of QAs on MS	32.10%	19.96%

McHealth	**low-end**	**high-end**
Required Cathlabs	4,138	2,647
Organization Cathlab Sales	1,328	528

Table 13-29: Presentation and Control (Hardware Switch) Integration Scenario in the Clinique Strategic Scenario - The impact of quality attributes on the organization market share.

PC Hw Switch Integration Scenario in the Clinique Strategic Scenario

preference coefficients

importance	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
low-end	0.05	0.1	0.15	0.2	0.15	0.2	0.15
high-end	0.04	0.1	0.5	0.1	0.05	0.2	0.01

the individual change in market share due to the values of the attributes

magnitude	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
	from 1 to 0	from 3 to 2	from 85% to 85%	from 6 to 10 h	from 300s to 300s	from 40min to 30min	10% higher
low-end	5%	15%	-30%	-2%	-5%	10%	-7%
high-end	2%	5%	-30%	-5%	-10%	2%	-4%

the combined effect = magnitude*importance for each customer segment (i.e. the low-end and the high-end)

segment	correction
low-end	-2.95%
high-end	-15.06%

Clinique	**low-end**	**high-end**
market size	4,138	2,647
organization market share (MS)	30.00%	30.00%
influence of QAs on MS	27.05%	14.94%

Clinique	**low-end**	**high-end**
Required Cathlabs	3,631	3,997
Organization Cathlab Sales	982	597

Table 13-30: Presentation and Control (Hardware Switch) Integration Scenario in the See Treat Cure Strategic Scenario - The impact of quality attributes on the organization market share.

PC Hw Switch Integration Scenario in the See Treat Cure Strategic Scenario

preference coefficients

importance	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
low-end	0.05	0.1	0.3	0.1	0.1	0.2	0.15
high-end	0.04	0.1	0.6	0.1	0.05	0.1	0.01

the individual change in market share due to the values of the attributes

magnitude	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
	from 1 to 0	from 3 to 2	from 85% to 85%	from 6 to 10 h	from 300s to 300s	from 40min to 30min	10% higher
low-end	5%	15%	-30%	-2%	-5%	10%	-7%
high-end	2%	5%	-30%	-5%	-10%	2%	-4%

the combined effect = magnitude*importance for each customer segment (i.e. the low-end and the high-end)

segment	correction
low-end	-7.00%
high-end	-18.26%

See Treat	**low-end**	**high-end**
market size	4,138	2,647
organization market share (MS)	30.00%	30.00%
influence of QAs on MS	23.00%	11.74%

See Treat	**low-end**	**high-end**
Required Cathlabs	3,181	5,197
Organization Cathlab Sales	732	610

Table 13-31: Presentation and Control (Hardware Switch) Integration Scenario in the Brave New Pharma World Strategic Scenario - The impact of quality attributes on the organization market share.

PC Hw Switch Integration Scenario in the Brave New Pharma World Strategic Scenario

preference coefficients

importance	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
low-end	0	0	0.4	0	0	0.1	0.5
high-end	0	0	0.5	0	0	0.3	0.2

the individual change in market share due to the values of the attributes

magnitude	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
	from 1 to 0	from 3 to 2	from 85% to 85%	from 6 to 10 h	from 300s to 300s	from 40min to 30min	10% higher
low-end	5%	15%	-10%	-2%	-5%	20%	-7%
high-end	2%	5%	-30%	-5%	-10%	2%	-4%

the combined effect = magnitude*importance for each customer segment (i.e. the low-end and the high-end)

segment	correction
low-end	-5.50%
high-end	-15.20%

Brave New Pharma	**low-end**	**high-end**
market size	4,138	2,647
organization market share (MS)	30.00%	30.00%
influence of QAs on MS	24.50%	14.80%

Brave New Pharma	**low-end**	**high-end**
Required Cathlabs	2,956	5,797
Organization Cathlab Sales	724	858

Table 13-32: Presentation and Control (Alt+Tab) Integration Scenario in the McHealth Strategic Scenario - The impact of quality attributes on the organization market share.

PC Alt+Tab Integration Scenario in **in the McHealth Strategic Scenario**

preference coefficients

importance	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
low-end	0.05	0.1	0.1	0.2	0.15	0.2	0.2
high-end	0.04	0.1	0.5	0.1	0.05	0.2	0.01

the individual change in market share due to the values of the attributes

magnitude	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
	from 1 to 0	from 3 to 2	from 85% to 85%	from 6 to 10 h	from 300s to 30s	from 40 min to 30 min	10% higher
low-end	5%	10%	-10%	-5%	5%	10%	-25%
high-end	2%	5%	-20%	-5%	5%	2%	-7%

the combined effect = magnitude*importance for each customer segment (i.e. the low-end and the high-end)

segment	correction
low-end	-3.00%
high-end	-9.34%

McHealth	**low-end**	**high-end**
market size	4,138	2,647
organization market share (MS)	30.00%	30.00%
influence of QAs on MS	27.00%	20.66%

McHealth	**low-end**	**high-end**
Required Cathlabs	4,138	2,647
Organization Cathlab Sales	1,117	547

Table 13-33: Presentation and Control (Alt+Tab) Integration Scenario in the Clinique Strategic Scenario - The impact of quality attributes on the organization market share.

PC Alt+Tab Integration Scenario in the Clinique Strategic Scenario

preference coefficients

importance	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
low-end	0.05	0.1	0.15	0.2	0.15	0.2	0.15
high-end	0.04	0.1	0.5	0.1	0.05	0.2	0.01

the individual change in market share due to the values of the attributes

magnitude	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
	from 1 to 0	from 3 to 2	from 85% to 85%	from 6 to 10 h	from 300s to 30s	from 40min to 30min	10% higher
low-end	5%	15%	-30%	-2%	5%	10%	-7%
high-end	2%	5%	-30%	-5%	5%	2%	-4%

the combined effect = magnitude*importance for each customer segment (i.e. the low-end and the high-end)

segment	correction
low-end	-1.45%
high-end	-14.31%

Clinique	**low-end**	**high-end**
market size	4,138	2,647
organization market share (MS)	30.00%	30.00%
influence of QAs on MS	28.55%	15.69%

Clinique	**low-end**	**high-end**
Required Cathlabs	3,631	3,997
Organization Cathlab Sales	1,037	627

Table 13-34: Presentation and Control (Alt+Tab) Integration Scenario in the See Treat Cure Strategic Scenario - The impact of quality attributes on the organization market share.

PC Alt+Tab Integration Scenario in the See Treat Cure Strategic Scenario

preference coefficients

importance	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
low-end	0.05	0.1	0.3	0.1	0.1	0.2	0.15
high-end	0.04	0.1	0.6	0.1	0.05	0.1	0.01

the individual change in market share due to the values of the attributes

magnitude	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
	from 1 to 0	from 3 to 2	from 85% to 85%	from 6 to 10 h	from 300s to 30s	from 40min to 30min	10% higher
low-end	5%	15%	-30%	-2%	5%	10%	-7%
high-end	2%	5%	-30%	-5%	5%	2%	-4%

the combined effect = magnitude*importance for each customer segment (i.e. the low-end and the high-end)

segment	correction
low-end	-6.00%
high-end	-17.51%

See Treat	**low-end**	**high-end**
market size	4,138	2,647
organization market share (MS)	30.00%	30.00%
influence of QAs on MS	24.00%	12.49%

See Treat	**low-end**	**high-end**
Required Cathlabs	3,181	5,197
Organization Cathlab Sales	763	649

Table 13-35: Presentation and Control (Alt+Tab) Integration Scenario in the Brave New Pharma World Strategic Scenario - The impact of quality attributes on the organization market share.

PC Alt+Tab Integration Scenario in the Brave New Pharma World Strategic Scenario

preference coefficients

importance	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
low-end	0	0	0.4	0	0	0.1	0.5
high-end	0	0	0.5	0	0	0.3	0.2

the individual change in market share due to the values of the attributes

magnitude	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
	from 1 to 0	from 3 to 2	from 85% to 85%	from 6 to 10 h	from 300s to 30s	from 40min to 30min	10% higher
low-end	5%	15%	-20%	-2%	5%	10%	-7%
high-end	2%	5%	-30%	-5%	5%	2%	-4%

the combined effect = magnitude*importance for each customer segment (i.e. the low-end and the high-end)

segment	correction
low-end	-10.50%
high-end	-15.20%

Brave New Pharma	**low-end**	**high-end**
market size	4,138	2,647
organization market share (MS)	30.00%	30.00%
influence of QAs on MS	19.50%	14.80%

Brave New Pharma	**low-end**	**high-end**
Required Cathlabs	2,956	5,797
Organization Cathlab Sales	576	858

Table 13-36: Workflow Integration Scenario in the McHealth Strategic Scenario - The impact of quality attributes on the organization market share.

Workflow Integration Scenario in the McHealth Strategic Scenario
preference coefficients

importance	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
low-end	0.05	0.1	0.1	0.2	0.15	0.2	0.2
high-end	0.04	0.1	0.5	0.1	0.05	0.2	0.01

the individual change in market share due to the values of the attributes

magnitude	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
	from 1 to 0	from 3 to 2	from 85% to 88%	from 6 to 10 h	from 300s to 30s	from 40 min to 30 min	10% higher
low-end	5%	15%	5%	-2%	5%	10%	-50%
high-end	2%	5%	5%	-5%	5%	2%	-10%

the combined effect = magnitude*importance for each customer segment (i.e. the low-end and the high-end)

segment	correction
low-end	-5.40%
high-end	3.13%

McHealth	**low-end**	**high-end**
market size	4,138	2,647
organization market share (MS)	30.00%	30.00%
influence of QAs on MS	24.60%	33.13%

McHealth	**low-end**	**high-end**
Required Cathlabs	4,138	2,647
Organization Cathlab Sales	1,018	877

Table 13-37: Workflow Integration Scenario in the Clinique Strategic Scenario - The impact of quality attributes on the organization market share.

Workflow Integration Scenario in the Clinique Strategic Scenario
preference coefficients

Importance	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
low-end	0.05	0.1	0.15	0.2	0.15	0.2	0.15
high-end	0.04	0.1	0.5	0.1	0.05	0.2	0.01

the individual change in market share due to the values of the attributes

Magnitude	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
	from 1 to 0	from 3 to 2	from 85% to 88%	from 6 to 10 h	from 300s to 30s	from 40min to 25min	10% higher
low-end	5%	15%	20%	-2%	5%	10%	-10%
high-end	2%	5%	15%	-5%	5%	2%	-8%

the combined effect = magnitude*importance for each customer segment (i.e. the low-end and the high-end)

segment	correction
low-end	5.60%
high-end	8.15%

Clinique	**low-end**	**high-end**
market size	4,138	2,647
organization market share (MS)	30.00%	30.00%
influence of QAs on MS	35.60%	38.15%

Clinique	**low-end**	**high-end**
Required Cathlabs	3,631	3,997
Organization Cathlab Sales	1,293	1,525

Table 13-38: Workflow Integration Scenario in the See Treat Cure Strategic Scenario - The impact of quality attributes on the organization market share.

Workflow Integration Scenario in the See Treat Cure Strategic Scenario
preference coefficients

Importance	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
low-end	0.05	0.1	0.3	0.1	0.1	0.2	0.15
high-end	0.04	0.1	0.6	0.1	0.05	0.1	0.01

the individual change in market share due to the values of the attributes

magnitude	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
	from 1 to 0	from 3 to 2	from 85% to 88%	from 6 to 10 h	from 300s to 30s	from 40min to 25min	10% higher
low-end	5%	15%	10%	-2%	5%	10%	-35%
high-end	2%	5%	30%	-5%	5%	15%	-7%

the combined effect = magnitude*importance for each customer segment (i.e. the low-end and the high-end)

segment	correction
low-end	1.80%
high-end	19.76%

See Treat	**low-end**	**high-end**
market size	4,138	2,647
organization market share (MS)	30.00%	30.00%
influence of QAs on MS	31.80%	49.76%

See Treat	**low-end**	**high-end**
Required Cathlabs	3,181	5,197
Organization Cathlab Sales	1,012	2,586

Table 13-39: Workflow Integration Scenario in the Brave New Pharma World Strategic Scenario - The impact of quality attributes on the organization market share.

Workflow Integration Scenario in the Brave New Pharma World Strategic Scenario

preference coefficients

importance	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
low-end	0	0	0.4	0	0	0.1	0.5
high-end	0	0	0.5	0	0	0.3	0.2

the individual change in market share due to the values of the attributes

magnitude	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
	from 1 to 0	from 3 to 2	from 85% to 88%	from 6 to 10 h	from 300s to 30s	from 40min to 25min	15% higher
low-end	5%	15%	20%	-2%	5%	10%	-35%
high-end	2%	5%	30%	-5%	5%	10%	-8%

the combined effect = magnitude*importance for each customer segment (i.e. the low-end and the high-end)

segment	correction
low-end	-8.50%
high-end	16.40%

Brave New Pharma	**low-end**	**high-end**
market size	4,138	2,647
organization market share (MS)	30.00%	30.00%
influence of QAs on MS	21.50%	46.40%

Brave New Pharma	**low-end**	**high-end**
Required Cathlabs	2,956	5,797
Organization Cathlab Sales	636	2,690

Table 13-40: Full Integration Scenario in the McHealth Strategic Scenario - The impact of quality attributes on the organization market share.

Full Integration Scenario in the McHealth Strategic Scenario
preference coefficients

importance	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
low-end	0.05	0.1	0.1	0.2	0.15	0.2	0.2
high-end	0.04	0.1	0.5	0.1	0.05	0.2	0.01

the individual change in market share due to the values of the attributes

magnitude	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
	from 1 to 0	from 3 to 2	from 85% to 88%	from 6 to 15 h	from 300s to 30s	from 40 min to 25 min	15% higher
low-end	5%	10%	5%	-4%	5%	10%	-60%
high-end	2%	5%	5%	-7%	5%	2%	-15%

the combined effect = magnitude*importance for each customer segment (i.e. the low-end and the high-end)

segment	correction
low-end	-8.30%
high-end	2.88%

McHealth	**low-end**	**high-end**
market size	4,138	2,647
organization market share (MS)	30.00%	30.00%
influence of QAs on MS	21.70%	32.88%

McHealth	**low-end**	**high-end**
Required Cathlabs	4,138	2,647
Organization Cathlab Sales	898	870

Table 13-41: Full Integration Scenario in the Clinique Strategic Scenario - The impact of quality attributes on the organization market share.

Full Integration Scenario in the Clinique Strategic Scenario
preference coefficients

importance	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
low-end	0.05	0.1	0.15	0.2	0.15	0.2	0.15
high-end	0.04	0.1	0.5	0.1	0.05	0.2	0.01

the individual change in market share due to the values of the attributes

magnitude	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
	from 1 to 0	from 3 to 2	from 85% to 88%	from 6 to 15 h	from 300s to 30s	from 40min to 30min	15% higher
low-end	5%	15%	20%	-4%	5%	35%	-15%
high-end	2%	5%	30%	-7%	5%	10%	-5%

the combined effect = magnitude*importance for each customer segment (i.e. the low-end and the high-end)

segment	correction
low-end	9.45%
high-end	17.08%

Clinique	**low-end**	**high-end**
market size	4,138	2,647
organization market share (MS)	30.00%	30.00%
influence of QAs on MS	39.45%	47.08%

Clinique	**low-end**	**high-end**
Required Cathlabs	3,631	3,997
Organization Cathlab Sales	1,432	1,882

Table 13-42: Full Integration Scenario in the See Treat Cure Strategic Scenario - The impact of quality attributes on the organization market share.

Full Integration Scenario in the See Treat Cure Strategic Scenario

preference coefficients

importance	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
low-end	0.05	0.1	0.3	0.1	0.1	0.2	0.15
high-end	0.04	0.1	0.6	0.1	0.05	0.1	0.01

the individual change in market share due to the values of the attributes

magnitude	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
	from 1 to 0	from 3 to 2	from 85% to 88%	from 6 to 15 h	from 300s to 30s	from 40min to 30min	15% higher
low-end	5%	15%	10%	-4%	5%	10%	-35%
high-end	2%	5%	30%	-7%	5%	10%	-10%

the combined effect = magnitude*importance for each customer segment (i.e. the low-end and the high-end)

segment	correction
low-end	1.60%
high-end	19.03%

See Treat	**low-end**	**high-end**
market size	4,138	2,647
organization market share (MS)	30.00%	30.00%
influence of QAs on MS	31.60%	49.03%

See Treat	**low-end**	**high-end**
Required Cathlabs	3,181	5,197
Organization Cathlab Sales	1,005	2,548

Table 13-43: Full Integration Scenario in the Brave New Pharma World Strategic Scenario - The impact of quality attributes on the organization market share.

Full Integration Scenario in the Brave New Pharma World Strategic Scenario

preference coefficients

importance	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
low-end	0	0	0.4	0	0	0.1	0.5
high-end	0	0	0.5	0	0	0.3	0.2

the individual change in market share due to the values of the attributes

magnitude	walks	personnel	interv accuracy success rate	learning duration	3D reconstr duration	intervention duration	cost per procedure
	from 1 to 0	from 3 to 2	from 85% to 88%	from 6 to 15 h	from 300s to 30s	from 40min to 30min	15% higher
low-end	5%	15%	10%	-4%	5%	10%	-35%
high-end	2%	5%	35%	-5%	5%	20%	-5%

the combined effect = magnitude*importance for each customer segment (i.e. the low-end and the high-end)

segment	correction
low-end	-12.50%
high-end	22.50%

Brave New Pharma	**low-end**	**high-end**
market size	4,138	2,647
organization market share (MS)	30.00%	30.00%
influence of QAs on MS	17.50%	52.50%

Brave New Pharma	**low-end**	**high-end**
Required Cathlabs	2,956	5,797
Organization Cathlab Sales	517	3,043

Table 13-44: Cumulative profit [in euros] calculation for the Low-End Segment, Details

			depreciation rate 1.004 per year			
		Development and production time costs		Sales time showing the cumulative profit cumulative profit		
			2005	2006	2007	
nominal profit	100,000	**Minimal Integration**	1,144	458	686	686
corr over 2 years	100,802	McHealth	-5,040,080	41,093,063	110,017,080	178,666,500
			979	391	587	587
corr over 1 year	100,400	Clinique de Luxe	-5,040,080	34,415,864	93,363,987	152,077,257
			627	251	376	376
		See Treat Cure	-5,040,080	20,227,131	57,976,949	95,576,369
			497	199	298	298
		Brave New Pharma	-5,040,080	14,983,472	44,899,138	74,695,618
nominal profit	110,000	**Data Integration**	1,136	454	682	682
corr over 2 years	110,882	McHealth	-10,080,160	40,299,234	115,567,252	190,535,398
			1,013	405	608	608
corr over 1 year	110,440	Clinique de Luxe	-10,080,160	34,851,302	101,979,981	168,841,215
			657	263	394	394
		See Treat Cure	-10,080,160	19,054,089	62,581,353	105,935,202
			709	284	426	426
		Brave New Pharma	-10,080,160	21,385,422	68,395,754	115,218,794
nominal profit	120,000	**PC HW Switch**	1,328	531	797	797
corr over 2 years	120,962	McHealth	-10,080,160	54,189,231	150,209,236	245,846,692
			982	393	589	589
corr over 1 year	120,480	Clinique de Luxe	-10,080,160	37,442,658	108,442,883	179,160,239
			732	293	439	439
		See Treat Cure	-10,080,160	25,319,588	78,207,657	130,885,017
			724	290	435	435
		Brave New Pharma	-10,080,160	24,961,057	77,313,472	129,457,312
nominal profit	150,000	**PC Alt+Tab**	1,117	447	670	670
corr over 2 years	151,202	McHealth	-15,120,240	52,452,717	153,408,331	253,961,731
			1,037	415	622	622
corr over 1 year	150,600	Clinique de Luxe	-15,120,240	47,577,377	141,249,117	234,547,662
			763	305	458	458
		See Treat Cure	-15,120,240	31,053,344	100,037,783	168,747,383
			576	231	346	346
		Brave New Pharma	-15,120,240	19,742,195	71,827,506	123,705,306
nominal profit	175,000	**Workflow**	1,018		407	611
corr over 2 years	176,403	McHealth	-20,160,320		51,667,231	158,979,309
			1,293		517	776
corr over 1 year	175,700	Clinique de Luxe	-20,160,320		71,049,524	207,319,211
			1,012		405	607
		See Treat Cure	636		71,377,301	178,015,745
			636		254	381
		Brave New Pharma	-20,160,320		24,684,094	91,682,721
nominal profit	185,000	**Full**	898		359	539
corr over 2 years	186,483	McHealth	-35,280,560		31,700,091	131,770,785
			1,432		573	859
corr over 1 year	185,740	Clinique de Luxe	-35,280,560		71,568,917	231,204,590
			1,005		402	603
		See Treat Cure	-35,280,560		39,700,210	151,723,273
			517		207	310
		Brave New Pharma	-35,280,560		3,306,494	60,956,475

Table 13-45: Cumulative profit [in euros] calculation for the High-End Segment, Details

			depreciation rate 1.004 per year			sales cumulative profit extended with one more year
			development costs	sales and cumulative profit		
			2005	2006	2007	2008
nominal profit	100,000	**Minimal Integration**	484	194	290	290
corr over 2 years	100,802	McHealth	-5,040,080	14,469,933	43,618,358	72,650,654
			531	212	318	318
corr over 1 year	100,400	Clinique de Luxe	-5,040,080	16,362,180	48,337,669	80,185,765
			560	224	336	336
		See Treat Cure	-5,040,080	17,549,018	51,297,671	84,911,867
			759	304	456	456
		Brave New Pharma	-5,040,080	25,579,696	71,326,374	116,890,794
nominal profit	110,000	**Data Integration**	495	198	297	297
corr over 2 years	110,882	McHealth	-10,080,160	11,873,941	44,673,892	77,343,166
			548	219	329	329
corr over 1 year	110,440	Clinique de Luxe	-10,080,160	14,224,621	50,536,544	86,703,798
			572	229	343	343
		See Treat Cure	-10,080,160	15,298,000	53,213,579	90,978,099
			783	313	470	470
		Brave New Pharma	-10,080,160	24,630,044	76,487,919	128,139,189
nominal profit	120,000	**PC HW Switch**	528	211	317	317
corr over 2 years	120,962	McHealth	-10,080,160	15,483,506	53,676,235	91,716,801
			597	239	358	358
corr over 1 year	120,480	Clinique de Luxe	-10,080,160	18,812,891	61,979,801	104,974,730
			610	244	366	366
		See Treat Cure	-10,080,160	19,440,732	63,545,650	107,474,852
			858	343	515	515
		Brave New Pharma	-10,080,160	31,431,842	93,451,765	155,224,597
nominal profit	150,000	**PC Alt+Tab**	547	219	328	328
corr over 2 years	151,202	McHealth	-15,120,240	17,954,995	67,370,186	116,588,504
			627	251	376	376
corr over 1 year	150,600	Clinique de Luxe	-15,120,240	22,809,142	79,476,546	135,918,183
			649	260	389	389
		See Treat Cure	-15,120,240	24,138,272	82,791,427	141,210,904
			858	343	515	515
		Brave New Pharma	-15,120,240	36,769,763	114,294,667	191,510,707
nominal profit	175,000	**Workflow**	877		614	263
corr over 2 years	176,403	McHealth	-20,160,320		88,127,321	134,351,413
			1,525		1,067	457

corr over 1 year	175,700	Clinique de Luxe	-20,160,320	168,131,826	248,506,959
			2,586	1,810	776
		See Treat Cure	2,690	319,330,397	455,639,891
			2,690	1,883	807
		Brave New Pharma	-20,160,320	311,982,444	453,762,224
nominal profit	185,000	**Full**	870	609	261
corr over 2 years	186,483	McHealth	-35,280,560	78,331,110	126,827,839
			1,882	1,317	565
corr over 1 year	185,740	Clinique de Luxe	-35,280,560	210,364,365	315,221,334
			2,548	1,784	764
		See Treat Cure	-35,280,560	297,342,078	439,326,699
			3,043	2,130	913
		Brave New Pharma	-35,280,560	362,002,272	531,588,000

Table 13-46: Cumulative Profit for the Low-End Segment, summary of Table 13-44.

	Minimal	Data	PC HW Switch	PC Alt+Tab	Workflow	Full
McHealth	178.67	190.54	245.85	253.96	158.98	131.77
Clinique de Luxe	152.08	168.84	179.16	234.55	207.32	231.20
See Treat Cure	95.58	105.94	130.89	168.75	178.02	151.72
Brave New Pharma	74.70	115.22	129.46	123.71	91.68	60.96

Table 13-47: Cumulative Profit for the High-End Segment, summary of Table 13-45.

	Minimal	Data	PC HW Switch	PC Alt+Tab	Workflow	Full
McHealth	72.65	77.34	91.72	116.59	134.35	126.83
Clinique de Luxe	80.19	86.70	104.97	135.92	248.51	315.22
See Treat Cure	84.91	90.98	107.47	141.21	455.64	439.33
Brave New Pharma	116.89	128.14	155.22	191.51	453.76	531.59

Dictionary of Terms and Abbreviations

This section explains the new terms and abbreviations used in this thesis.

3DRA	Three-dimensional rotational angiography – this is a technique for reconstructing the 3D model of the heart vessels out of individual 2D projections taken form different angles. Such a model can help the cardiologist to better diagnose and treat coronary artery diseases
Accuracy	Freedom from mistake or error (Webster Dict.).
ALMA	Architecture-Level Analysis Method (Bengtsson 2002) (Lassing 2002)
Assessment	A process of explicit measurement against external factors that have been a priori defined and agreed upon.
ATAM	Architecture Trade-Off Analysis Method (Bass *et al.* 1998)(Bass *et al.* 2003)
Atomic Action	An indivisible operation (e.g. a press of a button).
Business Strategy	A business strategy can be defined as the actions that need to be taken in order to achieve the goals of the organization (Hill 2002).
CAD	Coronary Artery Disease – disease of the coronaries, which are the blood vessels of the heart – usually a narrowing or obstruction of these vessels due to deposit of plaque, causing stroke, or even heart attack if not treated in time.
Capacity	The maximum number of tasks that can be handled per unit of time
Cathlab	Catheterisation Laboratory – the laboratory in a hospital or clinic where patients suffering from CAD are treated.
CBAM	Cost-Benefit Analysis Method (Bass *et al.* 2003)
Completeness	Having all necessary parts, elements or steps to fully carry out a certain activity (Webster Dict.).
CR	Control Room – a room inside Cathlab, from which the technician assists the cardiologist located in the intervention room.
Ease of Learning	The effectiveness and efficiency with which users can learn how to perform their tasks when working with a particular system for the first time (e.g. menu interface, help menus, etc).
Ease of Use	The effectiveness and efficiency with which users can achieve specified goals when working with a particular system after they become familiar with the system (e.g. short-cuts, customisable toolbars, etc).

Exposure	The technique of acquiring high quality X-ray pictures using high dose of contrast agent and high intensity X-rays.
FAAM	Family Architecture Assessment Method (Dolan 2002)
Fast 3DRA	The time needed to calculate the 3D model of the heart is negligible.
Fluoroscopy	The technique of navigating the catheter inside the heart vessels using low dose contrast agent and low power X-rays to see it advance. The X-ray images acquired during fluoroscopy are low in quality and discarded after the intervention.
Goal	An intended outcome.
Harm	In relation with hazard, harm can be defined as a physical injury, damage to health, to someone's property or to environment, or any combination of these.
Hazard	In relation with risk, hazard can be defined as an event that may produce *harm*, *loss* or *injury* to a person, organization, or system (e.g. an accident).
Injury	Injury can be defined as any damage or violation of, the person, character, feelings, rights, property, or interests of an individual (Webster Dict.).
IR	Intervention Room – a room inside Cathlab, in which the cardiologist performs the catheterisation intervention.
IVUS	Intravascular Ultrasound – this is a non-X-ray modality for navigating the catheter inside the blood vessels. IVUS uses a high frequency real-time transducer to produce 360 radial ultrasound images of the vessel walls. Based on these images, the cardiologist can distinguish the size and type of the stenosis, as well as the size of the blood vessel and the size of plaque. In comparison with conventional X-ray navigation, IVUS is not harmful and unhealthy for the patient. However the images produced with IVUS lack the accuracy of the ones captured with X-ray.
Loss	In relation with hazard, loss can be defined as a person, thing, or an amount that is lost.
LM	Live Monitor – a monitor displaying live the move of the catheter inside the heart using fluoroscopy.
MIP	Maximum Intensity Projection – an imaging technique used for depicting blood vessels exploiting the fact that in MR or CT images the data values of vascular structures are higher than the values of the surrounding tissue.
Modality	They describe the various technologies available for the cardiology department, such as X-ray, magnetic resonance imaging (MRI), or ultrasound (US).

MR(I)	Magnetic Resonance (Imaging) is an imaging technique used for medical diagnosis purposes to produce images of the inside of the human body.
NGUI	Non-graphical user interface
Response Time	The duration of completing a process measured from the moment the request is being made to the moment the response is being received
RM	Reference Monitor – a monitor inside the IR displaying images during the intervention.
PACS	Picture Archiving and Communication System
Phase, Inception	The inception is the first development phase as defined in the Rational Unified Process, in which the seed-idea, or request for proposal, for the previous generation is brought to the point (at least internally) of being funded to enter the elaboration phase (Kruchten 2000).
Phase, Elaboration	The second phase of the Rational Unified Process, in which the product vision and its architecture are defined (Kruchten 2000).
Phase, Construction	The third phase of the Rational Unified Process, in which the software system is brought from an executable architectural baseline to the point at which is ready to be transitioned to the user community (Kruchten 2000).
Phase, Transition	The fourth phase of the Rational Unified Process, in which the software system is turned over to the user community (Kruchten 2000).
PIM	Patient Information Model
PCI	Peripheral Connect Interface or, depending on the context, Percutaneous Coronary Intervention.
Re-stenosis	Treating another time a blood vessel, which has been already repaired by catheterization.
Risk Exposure	*Risk Exposure* (RE) is defined as the product of risk probability of occurrence (P) and the risk magnitude of harm or loss (M), or RE = P*M, (Boehm 1991), (Kansala 1997).
RUP	Rational Unified Process
SAAM	Software Architecture Assessment Method (Bass *et al.* 1998)
Scenario	A story written in natural language describing a plausible sequence of future events arranged in a timely manner.
Scenario, Business	Business scenarios describe how the business operates. They describe the interactions between different departments and/or external parties for achieving the organization's business goals.

Scenario, Exploratory	They are expected to cover extreme changes that are expected to stress the system (Kazman 1999). At a business level, exploratory scenarios are used to depict possible movements in certain domains in conditions of high uncertainty. Market trends, technology trends, political trends or security issues can be analysed by means of exploratory scenarios.
Scenario, Failure	They describe abnormal behaviour of a system. In this context, abnormal behaviour can be defined as behaviour that would not be exhibited when the user observes that the system is operating properly (Chance *et al.* 1998). Failure scenarios can be defined for the business or organization as well. Failure scenarios are particular situations that may occur and threaten the good functionality of the system. They are defined in relation with the success scenario.
Scenario, Investment	They are created for understanding the total product investment. Based on the investment scenarios there is created and delivered and investment plan. The investment scenarios are mainly based on "unquestionable data" regarding the architecture implementation and management together with its full cost accounting. The investment scenarios are concerning the initial investment (i.e. capital, licenses, resources, procurement, training, overhead, etc.) as well as the lifecycle investment (i.e. installation and integration, operations and maintenance, operate services, overhead, ongoing training, etc.) Milligan 2002.
Scenario, Learning	They illustrate ways in which the system itself can be useful in terms of features and user reactions and inputs. They intended to help educate the users about the system features and behaviour by presenting the system in a natural language and user centred. They are also useful for creating the technical documentation of the system (Chance *et al.* 1998).
Scenario, Quality	They are useful to discern additional capacity needed to meet quality constraints. Combining quality scenarios with a simulation tool can provide opportunities to estimate system performance during the early development phases (Chance *et al.* 1998).
Scenario, Rescue	Rescue scenarios are the possible solutions that can be adopted in case of system failure. They are defined in relation with the failure scenarios, being the response to failure.
Scenario, Success	They are the scenarios in which all the agreed-upon interests of the stakeholders are satisfied. The success scenarios are defined in relation with the business scenarios, being the starting point for elaborating the system use-cases (Cockburn 2001).
Scenario, Strategic	Based on the decisions made at corporate level, strategists and marketers create different future scenarios as response to the envisaged trends. These are called strategic scenarios. The goal at this level is to stay in the business by exploring the future and the moves of the different competitors. This type of scenarios can be defined at a business level, but applied at a system development level as well.

Scenario, Technology	Are those types of scenarios that focus on exploring the trends of a particular technology in a certain industry or domain. These are also called technology forecasts or roadmaps.
Scenario Trigger	This is an event, actor, or action that may trigger a certain scenario to unfold
Scenario, User	It is a story describing in natural language the interaction between the user and the system. User scenarios are excellent communication vehicles between the architects and the stakeholders of the system.
Stakeholder	Any person, group, or organization with a vested interest in the success of a product or organization.
Stenosis	An area of a blood vessel, which is narrowed due to the deposit of plaque on the inside of its walls.
Stent	A small metal mesh cylinder.
Stenting	Inserting a stent is a small into a narrowed artery with a balloon catheter. When the balloon tip is inflated, the stent expands to the size of the artery to reopen it again (Chance *et al.* 1998). Afterwards, the balloon is deflated and removed, as the stent will remain there permanently.
Throughput	The number of tasks handled per unit of time
UML	The Unified Modelling Language
US	Ultrasound imaging is a method of making images of the inside of the human body using high frequency sound waves.
Usability Attributes	Features and characteristics of the product that influence learnability, effectiveness, efficiency and satisfaction with which users can achieve specified goals in a particular environment (ISO Std. 9241).
Variation Model	A variation model is a representation of the possible options within a model. This representation can appear in form of a decision tree, workflow diagram, or activity diagram.
Variation Point	The place in a variation model to represent the fact that multiple options exist – similar to a split in branches of a decision tree.

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Summary

This thesis summarizes the research results of Mugurel T. Ionita, based on the work conducted in the context of the STW[15] - AIMES[16] project. The work presented in this thesis was conducted at Philips Research and coordinated by Eindhoven University of Technology. It resulted in six external available publications, and ten internal reports which are company confidential.

The research regarded the methodology of developing system architectures, focusing in particular on two aspects of the early architecting phases. These were, first the generation of multiple architectural options, to consider the most likely changes to appear in the business environment, and second the quantitative assessment of these options with respect to how well they contribute to the overall quality attributes of the future system, including cost and risk analysis. The main reasons for looking at these two aspects of the architecting process was because architectures usually have to live for long periods of time, up to 5 years, which requires that they are able to deal successfully with the uncertainty associated with the future business environment. A second reason was because the quality attributes, the costs and the risks of a future system are usually dictated by its architecture, and therefore an early quantitative estimate about these attributes could prevent the system redesign.

The research results of this project were two methods, namely a method for designing architecture options that are more future-proof, meaning more resilient to future changes, (SODA method), and within SODA a method for the quantitative assessment of the proposed architectural options (SQUASH method). The validation of the two methods has been performed in the area of professional systems, where they were applied in a concrete case study from the medical domain.

The SODA method is an innovative solution to the problem of developing system architectures that are designed to survive the most likely changes to be foreseen in the future business environment of the system. The method enables on one hand the business stakeholders of a system to provide the architects with their knowledge and insight about the future when new systems are created. And on the other hand, the method enables the architects to take a long view and think strategically in terms of different plausible futures and unexpected surprises, when designing the high level structure of their systems.

The SQUASH method is a systematic way of assessing in a quantitative manner, the proposed architectural options, with respect to how well they deal with quality aspects, costs and risks, before the architecture is actually implemented. The method enables the architects to reason about the most relevant attributes of the future system, and to make more informed decisions about their design, based on the quantitative data.

Both methods, SODA and SQUASH, are descriptive in nature, rooted in the best industrial practices, and hence proposing better ways of developing system architectures.

[15] AIMES Architectural Modelling of Embedded Systems project
[16] STW (Stichting Technische Wetenschappen) foundation for technological research

Samenvatting

Dit proefschrift is de samenvatting van de onderzoeksresultaten van Mugurel T. Ionita, uitgevoerd in de context van het STW[17]-AIMES[18] project. Het werk gepresenteerd in dit proefschrift is uitgevoerd bij Philips Research en werd gecoordineerd door de Technische Universiteit Eindhoven. Dit heeft geresulteerd in zes publicaties en tien interne rapporten.

Het onderzoek betrof de methodologie van het ontwikkelen van systeem architecturen, in het bijzonder gericht op twee aspecten van vroege fasen van architectuurontwerp. Deze waren, ten eerste de generatie van verschillende architectuur opties, om de meest voor de hand liggende veranderingen te beschouwen die zich voordoen in een business omgeving, en ten tweede de kwantitatieve beoordeling van deze opties met betrekking tot hoe goed deze bijdragen aan de algehele kwaliteitsattributen van het toekomstige systeem, inclusief kosten- en risico analyse. De hoofdreden om naar deze twee aspecten van het architectuur ontwerpproces te kijken, was dat architecturen meestal lang tot 5 jaar - mee dienen te gaan, wat vereist dat ze in staat moeten zijn succesvol om te gaan met de onzekerheid die inherent is aan de toekomstige business omgeving. Een tweede reden was dat de kwaliteitsattributen, de kosten en risico’s van een toekomstig system meestal gedicteerd worden door zijn architectuur en om die reden een vroege schatting van deze attributen herontwerp van het systeem zou kunnen voorkomen.

De onderzoeksresultaten van dit project zijn twee methoden, namelijk een ontwerpmethode voor architectuuropties die meer toekomstbestendig zijn, dat wil zeggen flexibel voor toekomstige wijzigingen (SODA methode), en binnen SODA een methode voor de kwantitatieve beoordeling van voorgestelde architectuuropties (SQUASH methode). De validatie van de twee methoden is uitgevoerd op het gebied van professionele systemen, waar ze zijn toegepast in een concrete case studie uit het medische domein.

De SODA methode is een innovatieve oplossing voor het probleem van het ontwerpen van systeemarchitecturen die zijn ontworpen om de meest waarschijnlijke veranderingen in de toekomstige business omgevingen van het systeem. De methode maakt het aan de ene kant mogelijk dat belanghebbenden vanuit de business van het systeem de architecten kunnen voorzien van hun kennis en inzichten over de toekomst wanneer nieuwe systemen worden gevormd. Aan de andere kant stelt de methode de architecten in staat om een ver vooruit de kijken en strategisch na te denken in termen van verschillende plausibele toekomsten en onverwachte verrassingen, als zij de structuren op hoog systeemniveau ontwerpen.

De SQUASH methode is een systematische methode om op een kwalitatieve manier de voorgestelde architectuur opties te beoordelen, met betrekking tot hoe goed zij omgaan met kwaliteitsaspecten, kosten en risico’s, voordat de architectuur daadwerkelijk wordt geimplementeerd. De methode maakt het voor architecten mogelijk om te redeneren in termen van de meest relevante attributen van het toekomstige systeem en om beter onderbouwde beslissingen te nemen over hun ontwerp, gebaseerd op kwantitatieve gegevens.

Beide methoden, SODA en SQUASH, zijn beschrijvend van aard, geworteld in de beste industriele praktijkvoorbeelden, en in dat licht bieden zij manieren om systeem architecturen te ontwikkelen.

[17] STW (Stichting Technische Wetenschappen) foundation for technological research
[18] AIMES Architectural Modelling of Embedded Systems project

Curriculum Vitae of Mugurel Theodor Ionita

Mugurel Theodor Ionita was born on the 5th of May 1975, in Bucharest, Romania. In 1999 he obtained his M.Sc. degree in Computer Systems, from the "Politechnica" University of Bucharest, within the Electronics and Telecommunications Department, where he graduated. During his studies, as well as after his graduation, Mugur collaborated with a number of companies, among which Sigma Television Broadcasting Channel, and Universal Trade Company SA. Here he gained sufficient working experience which strongly contributed to his personal and professional development afterwards.

In 2001 Mugur was appointed as a Ph.D. candidate at Eindhoven University of Technology, The Netherlands. Between 2001 and 2004 Mugur conducted his research under the umbrella of AIMES (ArchItectural Modeling of Embedded Systems) Project, sponsored by Technologiestichting STW and conducted within PROGRESS project EWI.4877. This project was coordinated by the Department of Mathematics and Computer Science, and the Department of Technology Management, at Technische Universiteit Eindhoven. The project was coupled with two important industrial partners, namely Philips Research from 2002 to 2004, and Ericsson Laboratories Nederlands from 2001 to 2002. The partners provided concrete case studies for this research to be carried out.

As a result, Mugur together with his colleagues published several papers to international software engineering conferences: ICSE (2002), INTERACT (2003), SPLC (2004), HICSS (2005).

Since December 2004, Mugur works as a post-doc within the Software Engineering and Architectures Group, at the Department of Mathematics and Computing Science of Groningen University.

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