USING QFD FOR ASSESSING AND OPTIMIZING SOFTWARE ARCHITECTURES THE SYSTEM ARCHITECTURE ANALYSIS METHOD

Michael Gloger, Stefan Jockusch and Norbert Weber

Siemens AG, Corporate Technology

Otto-Hahn-Ring 6, Munich, Germany

Fax: +49 89 636 44424; E-mail: Norbert.Weber@mchp.siemens.de

Keywords: Software architecture; Quality Function Deployment; System Architecture Analysis.

Abstract

To assure superiority in today's competitive market it is essential to emphasize customer orientation. The System Architecture Analysis (SAA) method integrates structured elements from Quality Function Deployment (QFD) and the Design Space Approach to develop a procedure for customizing software architectures to meet customer and market requirements. The SAA approach also demonstrates how QFD can be extended to encompass the architecture design phase in software development.

Using SAA, attention can be systematically focused on customer satisfaction, even in the architecture design phase of software systems. Since 1993 SAA has been utilized world-wide in the Computer System and Industrial Process Groups at Siemens.

The Challenge

To assure superiority in today's competitive market a company must orient its products and systems to meet customer and market requirements. This is the sole means to guarantee customer satisfaction and market success. Quality Function Deployment (QFD) supports this objective by providing a systematic method for determining customer and market requirements and for deploying them during the development life-cyle.

The first step in the process towards fulfilling the requirements for a marketable product is the design of an architecture. Therefore, the system architecture is of essential importance to systems and products and their development efforts. Many system characteristics which are noticed by customers as well as the costs required for development and maintenance are determined essentially by the system's architecture. It also provides the basis for subsequent development activities. Changes made to technical decisions during this phase result in complex modifications and lead to high costs.

Up to now the QFD methodology and related technical references (see Akao and Mizuno, 1994; King, 1989; Zultner, 1990; Zultner, 1992; and Zultner, 1997) have provided very little information about how to include QFD in the software development phases which follow requirement analysis. The System Architecture Analysis (SAA) Method is an approach for extending QFD to the architecture design phase. It assists in tailoring system architectures to meet market conditions and organizational requirements. SAA adopts methodical elements of QFD and incorporates them with the Design Space Approach (see Lane, 1990) to create an efficient procedure which can be employed in the early phases of a development project or restructuring project for analyzing and optimizing important decisions about the architecture. It takes into account the perspectives which are most relevant for optimization (e.g. functionality, quality, development time and costs). Since 1993 SAA has been employed internationally throughout Siemens to support architecture development projects.

Fundamental Principles of SAA

The SAA method integrates existing methods to create a procedure for analyzing system architectures. This section describes the principles which formed a basis for SAA and how they are embedded in the method.

The Design Space Approach

One of the most important issues to be resolved is how to describe architectures so that the resulting representation provides a satisfactory basis for assessment and optimization. SAA is based on a pragmatic approach: architectures result from a series of design decisions. These decisions specify the technical concepts about how the requirements placed upon the system are to be implemented. The following example clarifies this (Fig. 1): Let's suppose that a scalable system is to be developed which can be scaled in respect to its functions and also in respect to its selling price. The first idea could be to pursue a monolithic approach in which various configuration levels can be created at system generation time by using the appropriate parameters. A second approach could be a modular approach in which the generated system can be expanded dynamically by linking additional modules to it. And finally, a kernel approach can be pursued, in which there is a basic (kernel) system and modules are added to it statically to enhance the functions of the system. Thus, when defining an architecture it is essential to follow the precept that one of the architecture concepts must be selected by a design decision. This decision defines how the system factor "structure" is to be implemented. Design decisions must also be made about the way other aspects of the system are to be implemented, for example, data base organization, or communication methods throughout the system. All of these design decisions, in effect, define the architecture. Changes to one or more of these design decisions produce different architectures.

This systematic approach is based on the theory of Design Space formulated by T. G. Lane (1990). In this approach all of the different architectures of a system are interpreted as points in a space, the design space. This area of space is expanded using so-called design dimensions. In the example above, these dimensions represent one of the system factors or the design decisions which must be made for each factor. The various realization concepts which exist for each system factor correspond with the coordinates of the design dimension. The position of an architecture in a design space is defined as the position of the selected architecture concept in the associated design dimension.

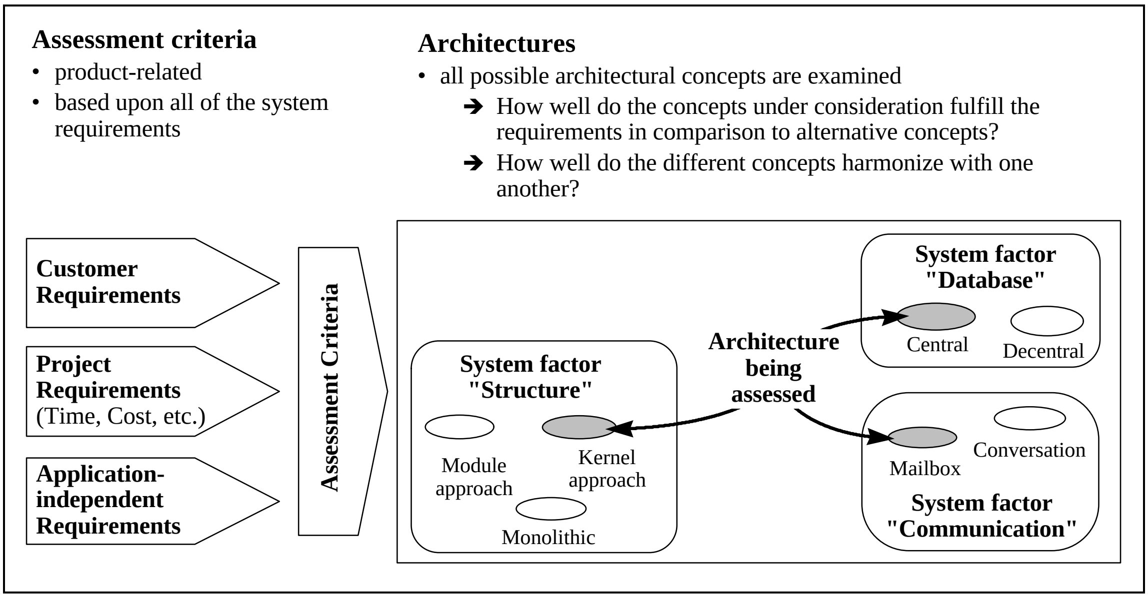

Figure 1 The basic SAA methodology

Experience shows that the design decisions made when defining the architecture dictate the basic characteristics of the system and essentially determine the success of the development project. The SAA methodology analyzes these design decisions.

In addition, this approach makes it possible to examine alternative architecture concepts systematically so that the architecture with the highest optimization potential can be developed. The ultimate goal of SAA is not only to assess architectures for their strengths and weaknesses but to optimize the architectures. Design decisions made for a particular architecture are compared with alternative solutions to compile a group of improvement measures. All possible improvement alternatives for each implementation concept selected per design decision are collected and integrated in the design space.

Quality Function Deployment (QFD)

The main objective of QFD is to fine-tune a system and its development efforts to conform to the most important customer and market requirements. When this principle is applied to architecture analysis, it means that these requirements act as criteria for assessment and optimization.

SAA does not only analyze and optimize an architecture by examining separate, pre-defined criteria, it appraises the architecture by considering all of the aspects relevant to the system and its development efforts. To begin with, these are the customer and market requirements. Associated with these requirements are system characteristics, which focus upon functionality, ease of operation or scaling capacities. In addition to these, there are requirements which the organizational unit developing the architecture poses upon the development project, i.e., primarily time schedule or cost constrictions (time-to-market). Finally, SAA also applies criteria not directly affiliated with the particular application which are drawn from a standard quality model (see International Standard ISO/IEC 9126, 1991) and guarantee that the quality of the system is upheld in respect to engineering standards. The Analytic Hierarchy Process (AHP) (see Saaty, 1990) from QFD assists in structuring the different requirements and formulating the criteria for assessment and optimization.

When exactly can an architecture be considered a good architecture? An architecture is good when it is able to fulfill the requirements placed upon the system. In the terms of the Design Space Approach this means that it is good when the design decision made for each system aspect can be considered to be the one which best-satisfies the requirements.

To implement this evaluation efficiently SAA has made a modification to the "House of Quality", a concept introduced in QFD. In SAA's version of the "House of Quality" (see below) the evaluation criteria which are derived from the requirements or performance characteristics are entered to the left in the rows. The columns contain the various architecture concepts which have been identified. The matrix entries describe to what extent an implementation concept or design decision is able to fulfill an assessment criteria. In this way the "House of Quality" provides a survey of the strengths and weakness in all of the architecture concepts concepts being considered.

But the assessment factor (implementation concept vs. requirements) described above is not the only aspect which has to be considered. The implementation concepts selected should not be evaluated independently, since they must harmonize with each other within the system. Considering the example described above, the decision to implement centralized data processing may have to be revised when a dynamic modular structure approach is selected since a distributed database system is more advantageous for the module approach. This assessment aspect is analyzed by adding a roof to SAA's "House of Quality". This technique is also used in QFD, but in another context.

Cross-Functional Teams

The production of an architecture is subject to opposing forces: from marketing and product strategy, and from technical constraints. As a result the architecture decisions should only be met when inter-departmental consensus exists between development, marketing, sales, service and management. SAA integrates experts from all of these areas in the decision process.

In this way, existing expertise is integrated into the process. This accelerates the procedure considerably. Moreover, it guarantees that the results will be accepted by all participants since the details were mutually agreed upon. Thus, the well-known dilemma that expensive, time-consuming evaluations "end up in the top drawer" can be eliminated.

The SAA Procedure Model

The SAA method is comprised of four steps (see Fig. 2). A core team made up of SAA experts is responsible for organizing and conducting these evaluation steps.

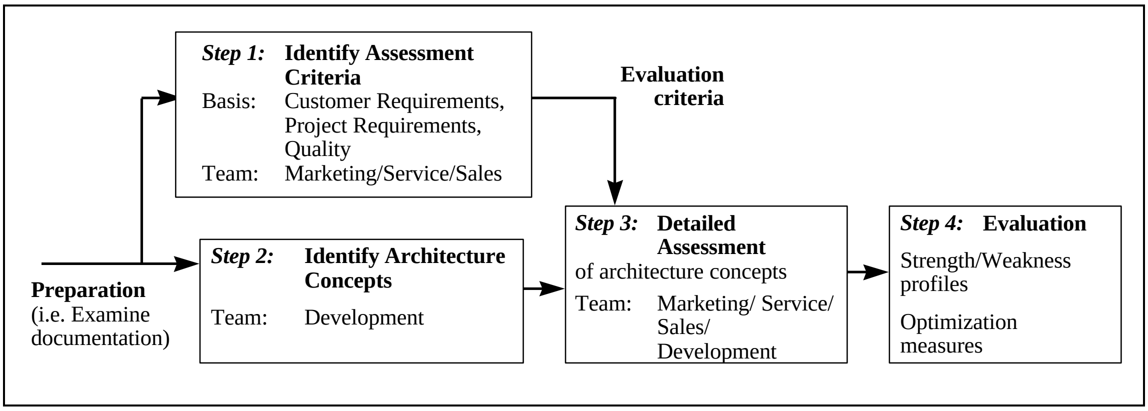

Figure 2 The SAA Procedure

Identify and Set Priorities for the Assessment Criteria (Step 1)

SAA analyzes and optimizes architectures considering all of the aspects relevant to the system. This means that all of the requirements placed on the system and on its development must be reflected in the assessment criteria. The core team is extended by experts from marketing, sales and service. In a series of workshops this group identifies the evaluation criteria.

This step is based on a method which is a variant of the Analytical Hierarchy Process (AHP) (see Saaty, 1990). The process is made up of two sub-steps:

- Defining the hierarchy:

  Using the standard QFD methodology, the requirements are collected and then put in hierarchical order according to their level of abstraction. Hereby, the requirements are classified according to subject matter and indexed with a related keyword, i.e., into requirement categories. The resulting hierarchy usually consists of up to four levels. When necessary, it can be refined to a lower level of abstraction to close any gaps which may have become evident. This hierarchical structure provides a comprehensive survey of the requirements. The requirements from one of the hierarchy levels are chosen as the assessment criteria. It is important to avoid making the criteria too abstract and to refrain from defining too many criteria so that the costs for the evaluation remain within reasonable limits.

- Setting priorities:

  The requirements in a development project vary in their significance. To resolve this condition it is necessary to set priorities for each of the assessment criteria. To simplify this procedure, SAA uses a method which modifies AHP's and restricts analysis to two weighted sequences of values, i.e., two reference criteria are selected and then all other criteria are compared in relation to these two criteria. The final priority value for each criteria is the mean value of the two weighted sequences.

Identify the System Factors and How They were Implemented (Step 2)

SAA evaluates architectures based on the specified design decisions. Improvement recommendations are also based on the design decisions in that the selected architecture concepts are compared with possible alternatives.

To identify and structure the design decisions and implementation alternatives, the core team is extended by development experts who are responsible for designing and implementing the system. This group analyzes the system and identifies the major design decisions. For each of the selected architecture concepts, alternatives are developed and classified according to system factors. Usually per architecture 20-30 design decisions can be identified each having 3-5 alternative solutions.

Systematic Assessment of the Implementation Concepts (Step 3)

Steps 1 and 2 provide the fundamental information necessary for the complex assessment of the entire architecture. They break down the original problem into numerous less complicated detailed evaluations. Thus, the architecture evaluation is simplified to consider:

- To what degree are the architecture concepts capable of fulfilling each of the requirements?
- How well do the architecture concepts harmonize with each other?

Only by reducing the evaluation into simple, detailed evaluations which can be easily performed is it possible for the overall evaluation to be objective and be readily understood.

SAA integrates the detailed evaluation performed in this step into a modified "House of Quality" (refer to Fig. 3). The requirements or evaluation criteria are entered in the rows in the bottom part of the house. The columns contain the various implementation approaches, grouped according to their system aspects. The matrix entries contain, in effect, the evaluations, which indicate how well each architecture concept fulfills the requirements. The roof contains the evaluations for the second evaluation aspect and shows how well the various implementation concepts harmonize. A plus ("+") means that the two implementation variants harmonize "rather well".

SAA is used in the early phases of a new development project or when restructuring. Quantitative or absolute estimations or assessments are not possible at this stage. For this reason SAA has only 5 values which are interpreted qualitatively (for example, "+" is equivalent to "good") and are only significant when compared with other values ("++" when contrasted with "+" indicates that the one architecture concept is more suitable for satisfying a requirement than the other).

The detailed evaluations are also carried out in workshops, in which both of the teams described in step 1 and 2 participate. The detailed evaluations are simplified by using the reduction process described above. Furthermore, strengths and weaknesses in the various implementations become apparent when compared with alternative solutions. Step 2 provided the fundamental information for this comparison. In this step the alternative solutions for each design decision were recorded, and thus can be compared in the current step. This systematic comparison of the implementations to examine how well they satisfy the requirements is performed in the workshop.

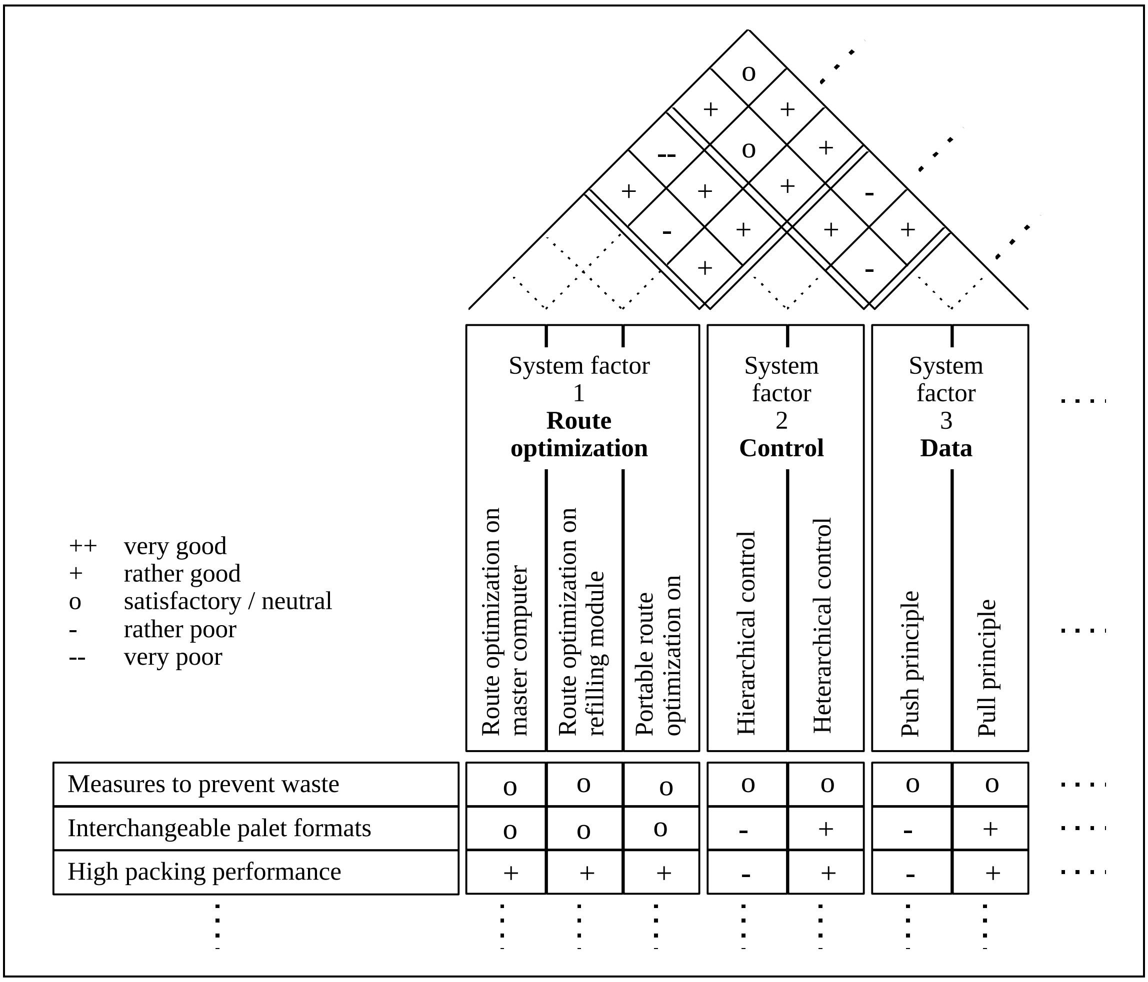

Figure 3 SAA’s House of Quality

Evaluation of the Assessment Results (Step 4)

To evaluate the results detailed analyses are made for the individual architectures using strength / weakness profiles and portfolio diagrams. These are then analyzed to produce recommendations for optimizing the architecture.

Stage 1: Strength / Weakness Profiles

The strength / weakness profiles for the individual architectures provide material for discussion about the following:

- How well does the architecture realize the requirements being considered?
- Which requirements are not satisfied by the architecture adequately?

The bar graph information (refer to Fig. 4) is derived from the detailed evaluations which are summarized in the SAA "House of Quality". The graph indicates how well an architecture and its underlying concepts are able to satisfy the requirements.

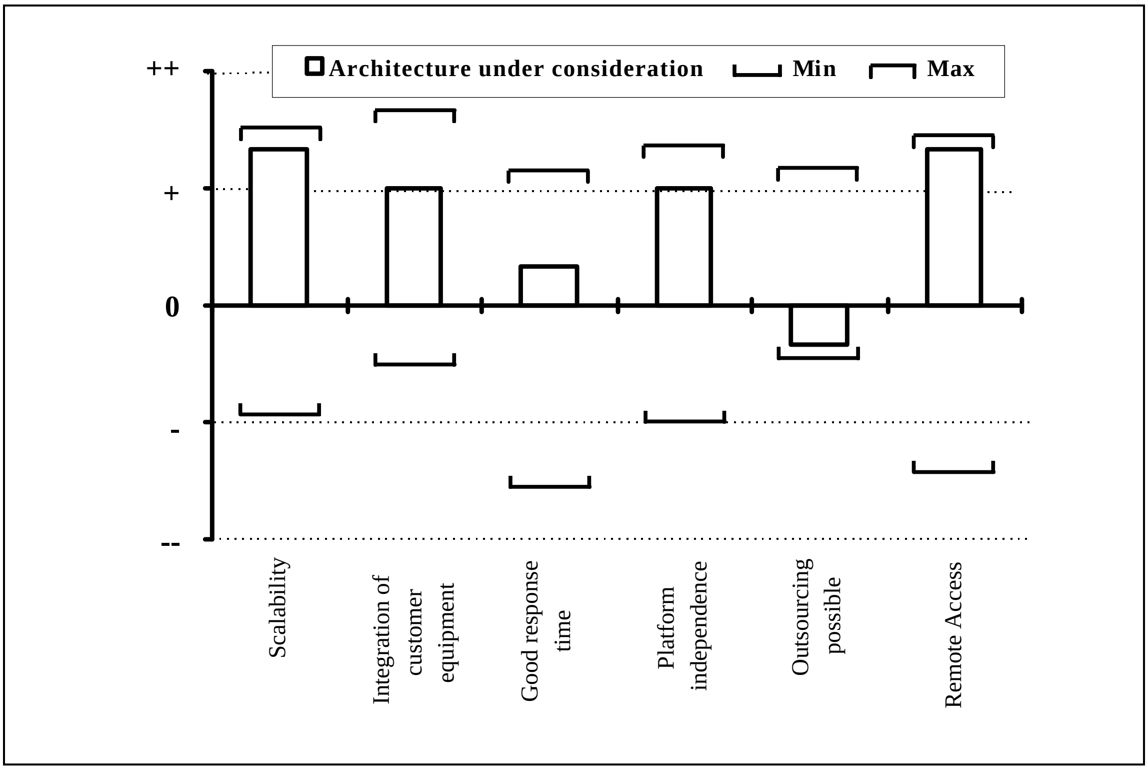

Figure 4 Strength / weakness profiles provide a survey describing how well an architecture fulfills the requirements

The strength / weakness profile demonstrates how an architecture can be improved from the requirement perspective. It identifies those requirements which are implemented inadequately within the architecture or where there is improvement potential.

Stage 2: Portfolios

After determining the above-mentioned deficiencies, it is then necessary to deal with those architecture concepts responsible for the deficits, and those concepts which call for corrective actions. Portfolios (refer to Fig. 5) provide and excellent survey of these factors. All possible architecture concepts are entered in the diagram for two of the evaluation criteria or for two groups of related criteria. The investigation focuses on those criteria or criteria groups which, according to the Strength / Weakness Profiles, are implemented inadequately.

Having built these portfolios, it is then easy to ascertain which concepts require corrective actions.

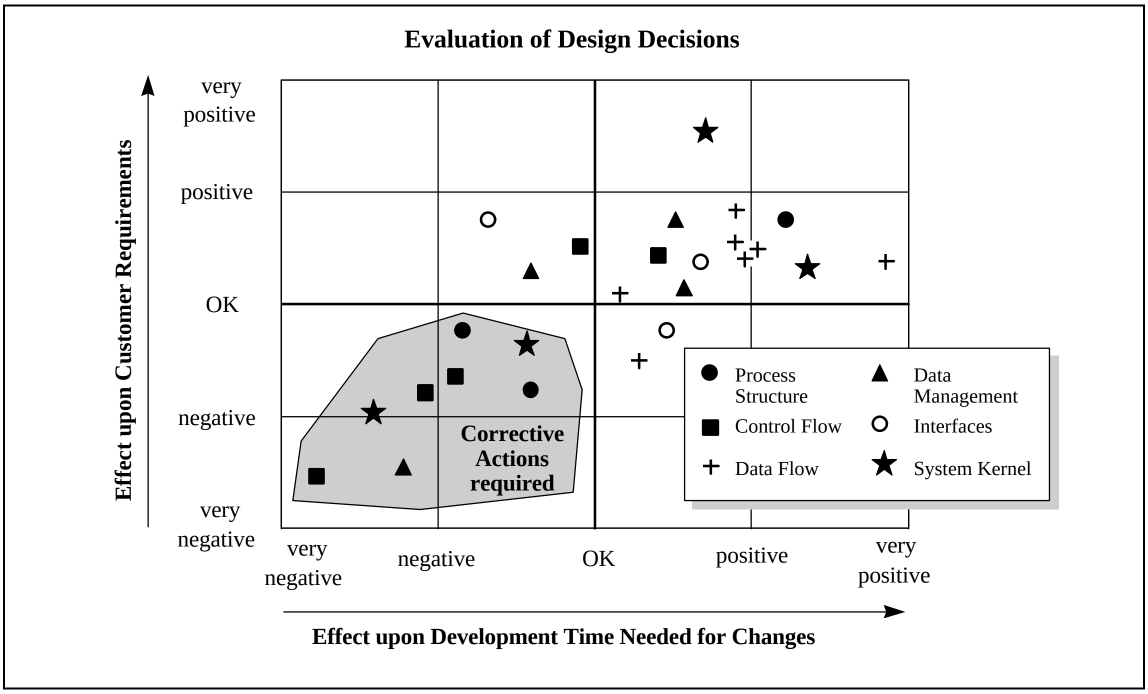

Figure 5 Portfolios provide a survey about the quality of the design decisions and identify the areas where corrective actions are required

Stage 3: Optimization Measures

The analysis should not conclude with the detailed evaluation of the architecture. SAA's main goal is to optimize the architecture. Thus, SAA then compiles various proposals for improving and optimizing the architecture.

The potential optimization factors are provided in Step 2. In this step the various architecture concepts are identified and structured in respect to system aspects and alternative possibilities are also determined.

In stage 3 these alternatives are analyzed to determine if and how the architecture under study can be improved when they are applied. First, the implementation areas which were identified in the portfolio diagram as requiring corrective actions are examined. Later, all of the other implementation areas are scrutinized.

This stage provides a comprehensive study of all of the design decisions. The study contains a detailed description of the solution which was selected to fulfill the particular system aspect within the architecture. It then outlines the important advantages and disadvantages of this particular implementation concept based upon the requirements. The design decision which was decided on is then evaluated together with the other design decisions. When grave deficiencies come to light or when optimization potential can be identified optimization measures are recommended and their advantages and disadvantages are also listed.

Industrial Applications using SAA

Since 1993 SAA has been utilized world-wide in the Computer System and Industrial Process Groups at Siemens (Automation, Telecommunications, Medical Technology, Control Engineering; refer to Tab. 1). The range of application areas is quite varied. Primarily, of course, SAA is used for evaluating and optimizing architectures being designed for new development projects or for restructuring existing systems which require a systematic analysis. SAA is also used in the beginning stages of a development project as a guide for structuring procedures within project development. SAA has also been employed in harmonization projects where the goals is to define a mutual platform or architecture for products within a heterogeneous product spectrum. The objective here, is to determine common components and interfaces for the diverse systems within a product domain to reduce development costs or to present the customer with a uniform user interface.

Number of SAA projects	8
Application domains	Automation, Control Engineering, Medical Technology, Telecommunication
Project duration (average)	8 weeks
Size of core project team	2-4 members
Number of experts included from the application area	8 - 10 experts: 4 - 5 from Marketing / Sales / Service 4 - 5 from Development
Effort of core project team (average)	2.25 person-months per member
Effort for the application experts (average)	about 1 person-week per expert
Number of evaluation criteria	30 - 40 per evaluation
Number of system factors identified	20 - 30 per architecture being assessed
Number of realization concepts identified	3 - 5 per system factor

Table 1 Overview of SAA projects that have been conducted

Some of the systems examined have been image processing systems, distributed systems with real-time requirements and modern programming systems for diverse applications. Development time for the systems studied varied between 2 and 5 years and occupied 50-200 engineers. Because of the product heterogeneity the focal points of the various technical investigations were quite diverse. Typical problems to be resolved were:

- How can the function blocks in a distributed system be allocated most optimally to the various computers?
- Which operating system and hardware configuration are most appropriate for the multi-

processor system under study?

- How should the coordination and communication activities for parallel processes be organized?

The recommendations aimed at improving system openness, scaling capabilities and reliability from the customer's standpoint. From the viewpoint of the development organization they focused on reducing development, production and maintenance costs.

QFD and Design-Space Methodologies Provide a Flexible Basis for Analyzing Architectures with SAA

The SAA Method was developed based on QFD and the Design Space Approach and it integrates both into a procedure for assessing and optimizing system architectures. QFD and the Design Space Approach provide elementary instruments for structuring and analyzing which are clear-cut and uncomplicated. They have proved to be quite reliable when analyzing system architectures with SAA. They permit many complex correlations to be easily understood. This paper has already referred to how they simplify the classification of architecture alternatives and also assist in breaking down the overall assessment of an architecture into a number of simple detailed evaluations.

The technique of utilizing qualitative assessments for the evaluation, a method which QFD also employs, has proved quite beneficial. SAA is usually used in the beginning phases of a development or restructuring project. At this point, precise metrics cannot be derived or specified to characterize an architecture. Thus, SAA uses qualitative assessments which are very probable in this early development phase to assess the realization concepts (Steps 3 and 4) and for setting requirement priorities (Step 1). These assessments are carried out systematically by a team of experts so that favoritism regarding specific requirements or implementations can be avoided. The assessments are then quantified and used as a basis for further analysis of the architecture. This assures that a very plain, compact and understandable representation of the assessment can be attained. From the numerous individual assessments produced in Step 3 it is possible to make systematic appraisals about the quality of the entire architecture.

SAA can be Employed in Divergent Applications

SAA pursues a very flexible approach allowing its procedures and structuring methods to be adapted to diverse application areas. The major advantage of the method is that it enables experts from marketing, sales and development to be included in the entire analysis process. They provide extensive technical know-how about the application area, about the divergent requirements placed on the system and about the different architecture concepts which are to be considered. In addition, involving the experts assures that acceptance of the results is enhanced. Suggestions for optimization are not far-fetched but rather they are developed by on-site experts familiar with the situation.

SAA Promotes Communication in Projects

In order for an architecture to support customer and market requirements optimally, two pre-requisites must exist: the architecture should be designed as a cooperative effort incorporating participants from all of the functional groups (marketing, sales, development, etc.) and the requirements and technical alternatives have to be harmonized with one another.

In many projects the decisions about the architecture's design are usually made intuitively, rather than by analyzing them in the light of cross-functional facets. These decisions are not necessarily wrong, but often they are difficult for others to understand. As a consequence the decisions are not accepted and the technical staff only supports them half-heartedly.

In the projects where it has been employed, SAA has proved to furnish optimal support. It provides transparency in reviewing decisions and development results and promotes communication within all of the participating groups. Preliminary considerations and ensuing architecture decisions are represented precisely and interrelationships clearly designated. Basing the architecture analysis on design decisions provides documentation which focuses on the fundamental features of the architecture. The individual appraisal of each system factor using an abstract representation method facilitates discovering alternative solutions not yet considered. These alternatives pinpoint aspects with optimization potential.

Looking ahead

This paper has described how the elements of the QFD method can be employed in analyzing architectures using SAA. This demonstrates how QFD can be extended beyond requirement analysis to the architecture design phase, i.e., to the phase following requirement analysis. The basis for interpreting the architectures is provided by the design decisions which define the architecture. In many projects at Siemens where SAA has been utilized to analyze software systems, this approach has proved to be quite efficient for assessing and optimizing architectures.

Usually architectures are documented during development by specifying the components, interfaces, and interacting activities. This forms the basis for further development activities. For the most part independent work packages for further development and integration strategy can be derived in this way. The authors are currently working on a method for expanding QFD for this form of architecture design. The objective is to assure that requirements can be traced consistently up till this phase.

References

Akao, Y. and Mizuno S. (1994), 'QFD - The Customer-Driven Approach to Quality Planning and Deployment', Tokyo.

International Standard ISO/IEC 9126 (1991), ‘Software product evaluation - Quality characteristics and guidelines for their use’.

King, B. (1989), ‘Better Designs In Half the Time - Implementing QFD Quality Function Deployment in America’, Methuen, Massachusetts.

Lane, T.G. (1990), ‘Stydying Software Architecture through Design Spaces and Rules’, Technical Report CMU/SEI-90-TR-18, Carnegie-Mellon University.

Saaty, T.L. (1990), ‘How to make a decision? The analytical hierarchy process’, *European Journal of Operational Research*, Vol. 48, No. 1, pp9-26.

Yoshizawa, T. and Togari, H. (1990), ‘Quality Function Deployment for Software Development’ in *Quality Function Deployment QFD - Integrating Customer Requirements into Product Design*, Editor Y. Akao, Cambridge, Massachusetts, pp329-353.

Zultner, R.E. (1990), ‘Software Quality Deployment - Applying QFD to Software’, Princeton, New Jersey.

Zultner, R.E. (1992), ‘Quality Function Deployment (QFD) for Software - Satisfying Customers’, *Ammerican Programmer*, Vol. 5 (February), pp1-14.

Zultner, R.E. (1997), ‘Project QFD - Managing Software Development Better with Blitz QFD’, *9th Symposium on QFD*, pp15-26.