CONFLICT IDENTIFICATION AND RESOLUTION

FOR SOFTWARE ATTRIBUTE REQUIREMENTS

by

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DEDICATION

To the Lord, Jesus

To my wife and children, Kyunghee, Joseph, and David In

To my parents, HyunJoo In & Kwon Jing

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ABSTRACT

A critical success factor in requirements engineering involves determining and resolving conflicts among candidate system requirements proposed by multiple stakeholders. Many software projects have failed due to requirements conflicts among the stakeholders.

The WinWin system developed at USC provides an approach for resolving requirements conflicts among the stakeholders. The WinWin system provides a framework for negotiation between the stakeholders to identify and resolve these conflicts. However, such systems do not scale well for large software projects containing many requirements.

Based on an analysis of the options for addressing this problem, I have focused on semiautomated tools and techniques for identifying and resolving conflicts among software quality attributes. I have developed two prototype support tools, QARCC and S-COST, which expand the capabilities of the WinWin system. QARCC focuses on software architecture strategies for achieving quality attribute objectives. S-COST focuses on tradeoffs among software cost, functionality, and other quality attributes. I have also developed portions of underlying theories and models which serve as the basis for the prototype tools.

Finally, I evaluated the theories, models, and tools with the results of WinWin negotiations, such as the CS577 15-project samples.

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Part I: Overview

This section presents a high-level introduction to the field of conflict resolution in requirements engineering as well as a concise description of the problem stated in the dissertation. The overall strategy for solving the problem will also be presented.

1.0 Introduction

1.1 Motivation

Many software projects have failed because they contained a poor set of quality-attribute requirements (such as Dependability, Interoperability, Usability, Performance, Adaptability, Reusability, and Cost & Schedule), even though they may have had good a set of functional and interface requirements.

An important step in achieving successful software requirements is to achieve the right balance of quality attribute requirements. Some counterexamples which illustrate the importance of achieving this step include [Boehm-In, 1996a]:

- The New Jersey Department of Motor Vehicles' licensing system. This project chose a fourth generation language to satisfy software affordability and timeliness objectives. However, the project failed due to performance scalability problems.
- The initial design of the ARPANet Interface Message Process software. This project focused on performance at the expense of evolvability by designing an extremely tight inner loop.
- The National Library of Medicine MEDLARS II system. The project was initially developed with a plethora of layers and recursions for portability and evolvability, but it was scrapped due to performance problems.

To achieve this step, many requirements engineering techniques (e.g., tools, design methods, and process models for specifying, validating, and verifying requirements) are

necessary and important. However, a number of leaders in the field consider that a more important technique is requirements negotiation. For example, several recent keynote speakers in ICSE (International Conference of Software Engineering) addressed this importance of requirements negotiation as follows:

- *"How the requirements were negotiated is far more important than how the requirements were specified"* (Tom De Marco, ICSE 96)
- *"Negotiation is the best way to avoid "Death March" projects"* (Ed Yourdon, ICSE 97)
- *"Problems with reaching agreement were more critical to my projects' success than such factors as tools, process maturity, and design methods"* (Mark Weiser, ICSE 97)

A key problem of negotiating quality-attribute requirements is identifying and resolving conflicts among desired quality attributes among multiple stakeholders because most conflicts of quality-attribute requirements come from different concerns, priorities, and responsibilities of multiple stakeholders (e.g., users, customers, and developers).

1.2 Problem Statement

This dissertation will address the problem of identifying and resolving conflicts among quality-attribute requirements from multiple stakeholders. It will also examine what the effective models and support systems are for the task of the conflict

identification and resolution. A concise statement of the problem I propose to examine reads as follows,

> *What are effective models and support systems for identifying and resolving the quality conflicts among a large number of requirements resulting from different perspectives of multiple stakeholders?*

In spite of scoping the central problem of conflict identification and resolution, there are several formidable subproblems,

- What are effective theories and models for identifying quality conflicts among a large number of requirements?
- What are effective theories and models for resolving quality conflicts among requirements proposed by multiple stakeholders having their own interests, priorities, and responsibilities?
- What are effective support systems (i.e., tools or aids) for identifying and resolving quality conflicts among requirements?

There are several benefits which can be gained through such theories, models, and support systems. First, time and money can be saved by resolving quality conflicts and risks in early phases of the project life cycle. Second, the tradeoffs among various quality attributes can be better understood so that stakeholders can better understand their options in defining a software product. Third, due to the complexity involved in conflict resolution and the shortage of expertise to deal with this complexity, such support tools for quality-

attribute conflict identification and resolution are needed to capture the expertise and make it broadly available.

1.3 Capability Needs

Three major capabilities are necessary to identify and resolve conflicts between the quality attribute requirements:

- Capabilities to surface and negotiate conflicts and risks among requirements. The USC-CSE WinWin system [Boehm et al., 1994; 1995] provides an effective framework.
- Capabilities to identify conflicts among quality-attribute requirements. COCOMO (COnstructive COst MOdel) provides the capability of identifying conflicts between development affordability & timeliness (i.e., cost & schedule) requirements with functional and some other quality-attribute requirements. QARCC (Quality Attribute Risk and Conflict Consultant), a proposed prototype model and support system, provides the capability of identifying conflicts of other qualities (e.g., assurance, interoperability, usability, performance, evolvability, portability, and reusability).
- Capabilities to generate, visualize, and negotiate potential resolution options. S-COST (Software Cost Option Strategy Tool), another proposed prototype model and support system, provides these capabilities to resolve cost conflicts

1.4 Outline of the Dissertation

The rest of this dissertation is organized as follows. Section 2 summarizes the related work on conflict resolution techniques in requirements engineering. Section 3 provides an overview of the WinWin system, and section 4 presents overall strategies for identifying and resolving conflicts. Section 5 presents basic models for conflict identification, and section 6 presents basic models for conflict resolution. Section 7 presents the support tools based on the models presented in sections 5 and 6. One is QARCC for conflict identification in section 7.2 and another is S-COST for conflict resolution in section 7.3. The experimental results and survey results of these tools are presented in section 8. Key contributions are discussed in section 9, and future work is discussed in section 10. Several appendices provide definitions of the terms used in this thesis (e.g., quality attributes, quality attribute strategies, and architecture strategies).

2.0 Related Work

2.1 Conflict Resolution Techniques in Requirements Engineering

There are many kinds of conflict resolution techniques. These techniques can be classified by their respective application areas (e.g., politics, economics, military, law, or computer science). The conflict resolution technique of interest in this dissertation is requirements engineering and concurrent engineering of software-intensive systems. Conflict resolution techniques for these application areas can be broken down by their degree of cooperation, domain dependence, and automation (Figure 1).

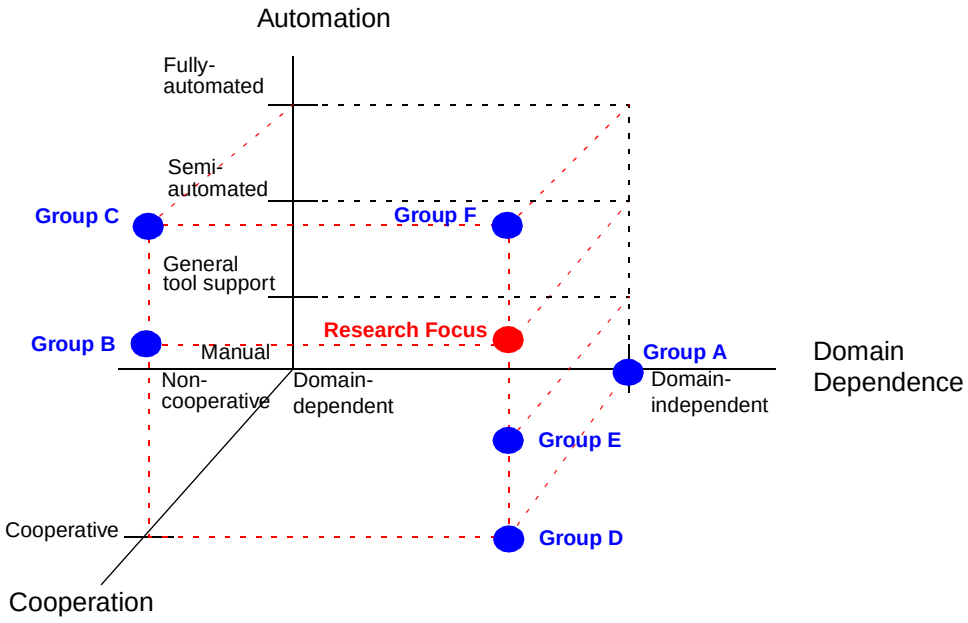


Figure 1. Classification of Conflict Resolution Techniques

The degree of cooperation is a measure used by many theories and formalized models for different conflict resolution techniques. This attribute encompasses non-cooperative theories such as zero-sum game theory as well as very cooperative ones such as Theory W [Boehm-Ross, 1989]. Most conflict resolution techniques involve cooperation, whether they are implicitly or explicitly stated, and they can be categorized accordingly.

The degree of domain dependency is also important in various conflict resolution techniques. This attribute can range from specific knowledge for applying a domain (i.e., domain dependent) to common knowledge for applying multiple domains (i.e., domain independent). Domain independent models provided a general framework of conflict resolution, which could be applied to any domain. Some domain independent models (e.g., [Easterbrook, 1991]) tended to provide such a general framework, but were designed to fill a specific need. WinWin ([Boehm et al., 1994; 1995]) allowed only 4 relation types and 4 artifact types based on the WinWin negotiation model, but PERSUADER ([Sycara, 1991]) didn't restrict any particular relation types and artifact types. Sycara proposed only general semantic nodes and links for labor management contract negotiations. Because models based on specific knowledge of a domain tended to focus on a specific application domain, they resulted in general applicability problems between different domains.

The degree of automation is a characteristic relevant to support tools for the various conflict resolution techniques. These tools can be fully automated, partially automated (i.e., semi-automated), general, or manual. Fully automated tools and systems

often deduced new relations from the existing relations in knowledge base using artificial intelligence techniques (e.g., reasoning, planning). Semi-automated systems, on the other hand, used simple and limited relations to provide simple service (e.g., dependency tracing, change propagation management). General tools did not use formal representation, but they provided the ability to store and retrieve free-text artifacts from a database. Manual tools did not provide any computerized aids.

The degree of automation is closely related to the degree of the interaction between human agents and intelligent agents. In fully-automated systems, intelligent agents solve most problems and the interaction between human agents and intelligent agents are not always necessary. In semi-automated systems, interaction is always necessary because intelligent agents often propose potential solutions and then human agents filter them out. The degree of interaction in general tools is similar to that in semi-automated tools, but intelligent agents provide simple services (e.g., storing and retrieving data) rather than higher decision services (e.g., potential solutions and advice). In manual tools, human agents solve all problems without the help of intelligent agents.

Table 1 shows the conflict resolution techniques grouped by their aforementioned attributes.

Group Name	Cooperation	Domain Dependence	Automation	Techniques
Group A (NIM)	**N**on-cooperative	domain - **I**ndependent	**M**anual	zero sum game theory & non-zero sum non-cooperative game theory [Jones, 1980; Luce-Raiffa, 1958], bargaining theory [Bell et al., 1988]
Group B (CDS)	**C**ooperative	domain - **D**ependent	**S**emi-automated	Easterbrook's Synoptic [Easterbrook, 1991]
Group C (CDF)	**C**ooperative	domain- **D**ependent	**F**ully-automated	Robertson's Oz [Robinson-Fickas, 1994], Sycara's PERSUADER [Sycara, 1991]
Group D (CIM)	**C**ooperative	domain - **I**ndependent	**M**anual	non-zero sum cooperative game theory [Jones, 1980; Luce-Raiffa, 1958], theory W [Boehm-Ross, 1989], decision theory [Bell et al., 1988], Gilb [Gilb, 1988], Rome Lab quality metrics reports [McCall et al., 1977], Pruitt's theory [Pruitt, 1981], Architecture Tradeoff Analysis Method [Kazman et al., 1998; Barbacci et al., 1997]
Group E (CIG)	**C**ooperative	domain - **I**ndependent	**G**eneral tool support	gIBIS [Conklin-Begeman, 1988], Win-Win [Boehm et al., 1994,1995], Coordinator, Lotus Notes, Total Quality Management
Group F (CIF)	**C**ooperative	domain - **I**ndependent	**F**ully-automated	REMAP [Ramesh-Dhar, 1992a], Klein's tool [Klein, 1991; 1996]
Research Focus (CIS)	**C**ooperative	domain - **I**ndependent	**S**emi - automated	recently revised REMAP [Ramesh-Sengupta, 1992b], SIBYL [Lee, 1990], Chung et al. [Chung et al., 1995], MIT DICE Project [Sriram-Logcher, 1993; Sriram et al., 1992], QARCC [Boehm-In, 1996a], S-COST [Boehm-In, 1996b; 1998]

Table 1. Grouping of Conflict Resolution Techniques

- **Group A (NIM: Non-cooperative, domain Independent, Manual)**. Application areas such as economics, politics, and mathematics have developed theories which do not allow cooperative communication. These theories, such as zero-sum game theory

[Jones, 1980, Luce-Raiffa, 1958] and bargaining theory [Bell et al., 1988], have very limited uses in requirements engineering because everyone can lose if just one stakeholder loses. Other non-cooperative theories in this group will not be explored further. For example, building a product quickly and cheaply with very low assurance may be a win for the customer and the developer, but a lose for the user. However, everyone could be a loser eventually because the product could brake down so frequently that nobody could use the product.

- **Group B (CDS: Cooperative, domain Dependent, Semi-automated)**. Because of the scalability problem in the fully automated approach (due to the amount of effort required to formalize domains), Easterbrook's Synoptic [Easterbrook, 1991] has recently proposed to develop a semi-automated tool (Initially, he proposed a fully automated tool). However, theories in this group still have the problem of general applicability.
- **Group C (CDF: Cooperative, domain Dependent, Fully automated)**. Many current research projects such as Robertson's Oz [Robinson-Fickas, 1994] and Sycara's PERSUADER [Sycara, 1991] focus on automated tools using domain dependent knowledge. These research projects may eventually produce detailed methods for conflict resolution, but they may face scalability problems due to the amount of effort required to formalize domains as well as the problem of general applicability due to the narrow domain focus.

- **Group D (CIM: Cooperative, domain Independent, Manual)**. Theory W highlights the importance of cooperation in the software development process. It provides a formal framework of "Make everyone winners". The quality metrics reports from Rome Laboratory [McCall et al., 1977] and Gilb [Gilb, 1988] provide checklists of quality attributes as well as capabilities and frameworks for specifying and assessing desired attribute levels. However, these theories lack support tools beyond simple data management, so that they cannot scale up in large projects. Other theories in this group will not be explored further.
- **Group E (CIG: Cooperative, domain Independent, General)**. Theories in this group (e.g., gIBIS [Conklin-Begeman, 1988], WinWin [Boehm et al., 1994; 1995], Coordinator, Lotus Notes, Total Quality Management) are no better than Group C or Group F. In fact, they are perhaps worse due to the overhead associated with unscalable human process. WinWin exercises indicate that conflict resolution techniques require at the minimum semi-automated tools to be useful.
- **Group F (CIF: Cooperative, domain Independent, Fully-automated)**. REMAP [Ramesh-Dhar, 1992a] provided fully-automated mechanisms for maintaining change propagation by reasoning with the dependencies among primitives, but could not identify conflicts of design descriptions among the primitives automatically. The overhead of capturing, representing, and reasoning human knowledge makes systems in this group unscalable (e.g., REMAP [Ramesh-Dhar, 1992a]). REMAP [Ramesh-Dhar, 1992a] was changed recently to a semi-automated system (in [Ramesh-Sengupta, 1992b]) due to the above overhead.

2.2 Research Focus (CIS: Cooperative, domain Independent, Semi-Automated)

Research in this group includes SIBYL [Lee, 1990], recently revised REMAP [Ramesh-Sengupta, 1992b], and Chung et al.'s tool [Chung et al., 1995].

SIBYL [Lee, 1990] aims at helping users represent and manage the qualitative aspects of the decision making process -- such as Alternatives being considered, Goals to satisfy, and Arguments evaluating alternatives with respect to the Goals -- by providing a representation language called "Decision Representation language (DRL)". SIBYL provides major types of services such as management of dependency, plausibility, viewpoints, and precedents. The difference between SIBYL and our approach comes from the conflict resolution frameworks and types of services based on the frameworks. Decision Problems and Claims in DRL correspond to Issues in our approach, Alternatives correspond to Options, and Goals correspond to Win Conditions. Note that Agreements, which corresponds to requirements that all stakeholders agree, are not represented explicitly in SIBYL. It is important to make Agreements explicit because Agreements serve as an indicator of negotiation status as well as a negotiated result. Another general difference is the number of relation types. SIBYL provides 16 DRL relations whereas ours provide 4 relations. Even though those 16 relations for detailed-level formal descriptions provides more automation services, the 16 relations make it difficult to learn, apply, and manage for users. In WinWin usages, even 4 different relations (e.g., involves, addresses, adopts, and covers) are confusing to learn, apply, and manage because of difficulties of memorizing relation names. Thus, we determined a uniform naming scheme for relations

such as LinkToWinCondition, LinkToIssue, LinkToOption, and LinkToAgreements. Practically, 16 relation types are too much for most users to handle.

Recently-revised REMAP [Ramesh-Sengupta, 1992b] aims to manage conflict in design and management of large systems, as does our model. The REMAP model provides primitives to represent various issues and alternatives by extending Issue Based Information Systems (IBIS). Also, a general difference between REMAP and our model is in the conflict resolution frameworks. Requirements in REMAP correspond to Win Conditions in our negotiation framework, Issue corresponds to Issues, Position and Argument correspond to Options, and Decision corresponds to Agreements. However REMAP provides Assumption, Constraints, CE artifact, and their complex relations to elaborate Argument and Decision. Thus, REMAP provides 8 different artifact types and 18 relation types. Again, 8 different artifact types and 18 relation types are difficult to learn, apply, and manage.

Chung et al. [Chung et al., 1995] proposed a tool based on Non-Functional Requirements (NFRs) to achieve conflicting goals by decomposing the goals, analyzing design tradeoffs, rationalizing design decisions, and evaluating goal achievement. They studied ways of systematically supporting evolution of the software system using an historical record of the treatments of NFRs. Their frameworks are quite different from SIBYL, REMAP, and ours. They focused on requirements traceability with more emphasis on incorporating changes in NFRs -- systematically detecting defects and supporting the process of corresponding changes in design and implementation -- rather than the way of conflict resolution among different stakeholders. Thus, there is no

consideration of stakeholders who have different priorities and interests. Also, there is no representation for Issues and Agreements explicitly. They primarily deal with the change management using means-ends (alternatives-goals) linkages when the goals are changed. Their tool is good for tracing determined design problems in terms of NFRs, but less good for negotiating system design issues. Another drawback of their tool is that the representation (e.g., alternatives-goals linkages) is difficult to scale up when dealing with multiple attribute goals and stakeholders.

2.3 Comparison of Conflict Resolution Techniques

Table 2 shows analysis results of evaluating conflict resolution techniques based on scalability, general applicability, and accuracy of results.

Group Name	Scalability	General Applicability	Accuracy of Results
Group A	Low	High	**High** if human has expert knowledge
Group B	High	Low	**Medium**, but **High** after humans filter initial results
Group C	Low	Low	**High** if the captured system knowledge is accurate and complete
Group D	Low	High	**High** if human has expert knowledge
Group E	Medium	High	**High** if human has expert knowledge
Group F	Low	High	**High** if the captured system knowledge is accurate and complete
Research Focus	High	High	**Medium**, but **High** after humans filter initial results

Table 2. Summary of Evaluating Conflict Resolution Techniques

Figure 2 maps scalability against the degree of automation. The scalability is low in fully automated and manual systems, medium in general systems, and high in semi-

automated systems because the total workload is high in fully automated and manual systems, medium in general systems, and low in semi-automated systems. The total workload is determined by the combination of human-processing workload and computer-processing workload. Computer-processing workload includes interpreting, reasoning, and generating facts and rules in the system's knowledge base. Semi-automated systems have the best scalability because human-processing workload increases sharply from semi-automated to manual systems and computer-processing workload increases sharply from semi-automated to fully automated systems.

General applicability is related to the degree of domain dependency. Systems based on domain independent knowledge are more general and applicable to various domains, while systems based on domain dependent knowledge are not generally applicable since they are more narrowly focused.

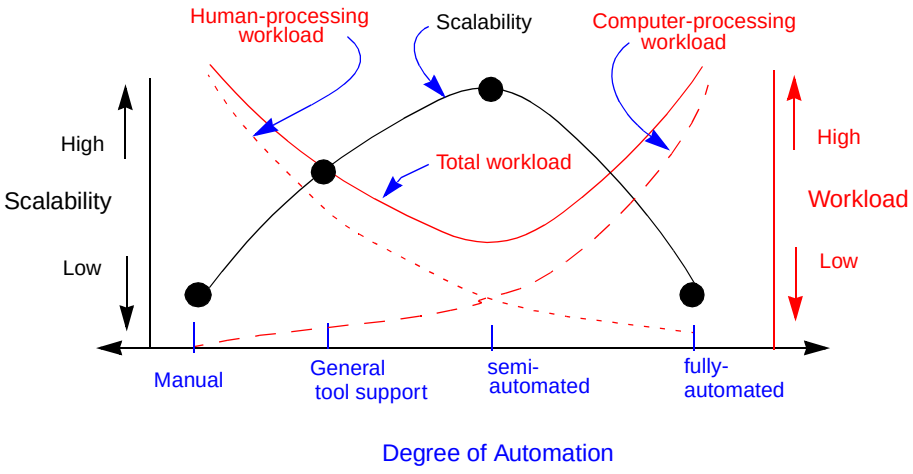


Figure 2. Scalability vs. the Degree of Automation

The accuracy of results depends on the degree of automation. If project personnel are experts in an application domain, high accuracy can be achieved even with manual systems which have no computerized aids. Fully automated systems provide high accuracy (i.e., good) in the results when the formalized knowledge and reasoning algorithms are accurate. Semi-automated systems provide medium (i.e., reasonable) accuracy of initial drafts suggested by the systems, but they provide high accuracy (i.e., good) in the results, where project personnel first filter the initial drafts suggested by the systems.

Many AI researchers have focused on fully-automated systems (e.g., systems in Group C or Group F) which provide low scalability. As a result, some researchers (e.g., REMAP [Ramesh-Sengupta, 1992b]) have changed their focus to semi-automated systems which are in our current Research Focus. Initially, our research was focused on systems in Group E to implement a theory developed in Group D in order to scale up conflict negotiation process with general tool support. However, we changed our research focus to investigate the systems that are cooperative, domain independent, and semi-automated after experiments indicated that the scalability of systems in Group E was not satisfiable for very large projects.

3.0 Context: WinWin and Conflict Resolution

Section 3.1 explains the USC-CSE WinWin system. The system provides a general framework for identifying and resolving software-requirement conflicts by drafting and negotiating artifacts such as win conditions, issues, options, and agreements. Experience with the WinWin system shows that as the number of win conditions increases, the stakeholders have more difficulty in identifying potential conflicts among them. Section 3.2 addresses this scalability problem in detail.

3.1 WinWin

WinWin is a groupware support system for determining software requirements as negotiated win conditions. WinWin is based on the WinWin Spiral Model (section 3.1.2) which uses Theory W (section 3.1.1) to generate objectives, constraints, and alternatives. WinWin assists the stakeholders in identifying and resolving conflicts using the WinWin Negotiation Model (section 3.1.3).

3.1.1 Theory W

The goal of Theory W [Boehm-Ross, 1989] is to “make everyone a winner.” At first glance, this goal appears unattainable. Most situations tend to be zero-sum or win-lose. For example, building a product quickly with little or no documentation may be a low- cost, short-term win for the software developer and the customer, but the maintainer and the user will lose because the lack of documentation makes the product unusable and difficult to maintain. Another example is adding marginally useful software bells and

whistles to a product on a cost-plus contract. This may be a win for the developer and the users whose whims have been satisfied, but the customer will lose due to increased cost.

It is important to avoid win-lose software situations, as they generally evolve into lose-lose situations. An unusable system will not be a win for the developer or customer. An unfinished, out-of-money system with many bells and whistles will not be a win for the developer or user.

Even worse are software development projects which begin in a lose-lose state. Setting unrealistic schedule expectations, staffing with incompatible people, poor planning, or trying to catch up on an already late schedule by adding more people will generally make losers out of all the participants.

Fortunately, win-win situations do exist, and they can often be created by careful attention to the interests and expectations of the people involved in the software development project. For example, providing a profit-sharing arrangement for a software subcontractor provides the subcontractor with a motivation for developing a high quality, widely sold product, which can increase the overall profit for both the subcontractor and the original contractor.

3.1.2 WinWin Spiral Model

Figure 3 illustrates the Theory W extensions to the Spiral Model [Boehm et al., 1995] that form the conceptual basis for WinWin. The additional two sectors in each spiral cycle, “identify next-level stakeholders” and “identify stakeholders’ win conditions” along with the “reconcile win conditions” portion of the third sector provide the collaborative

foundation for the model. They also provide the ability to answer the question, “Where do the next-level objectives and constraints come from and how does one know they are the correct ones?”, which was missing from the original Spiral Model. In addition, the refined Spiral Model explicitly addresses the need for concurrent analysis, risk resolution, definition, and elaboration of both the software product and the software process, based on the Spiral Model extensions described in [Boehm et al., 1994].

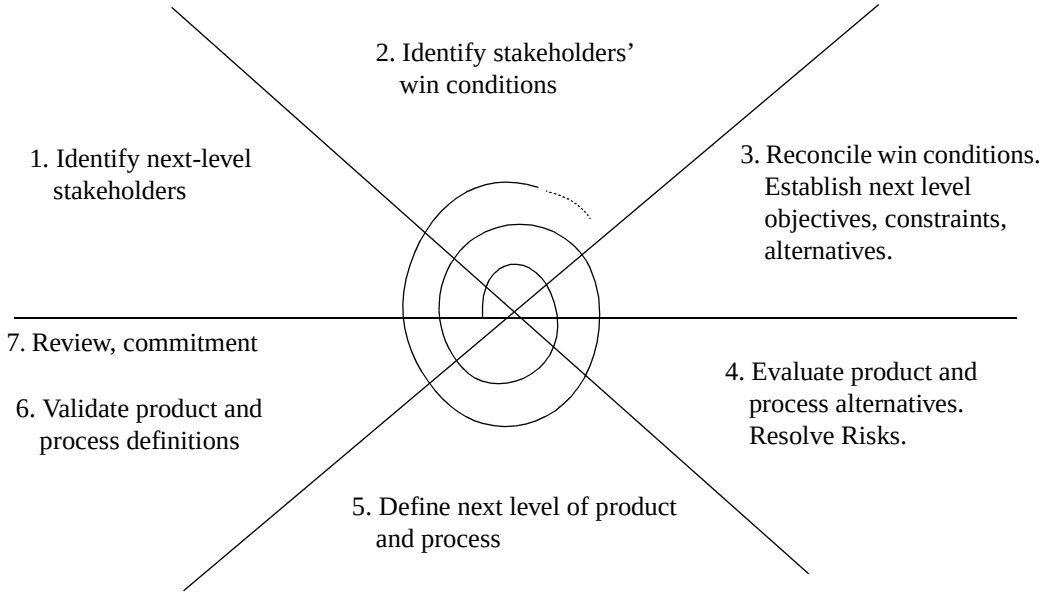


Figure 3. The WinWin Spiral Model

3.1.3 WinWin Negotiation Model

Figure 4 shows the WinWin Negotiation Model used by WinWin in terms of its primary schemas and the relationships between them.

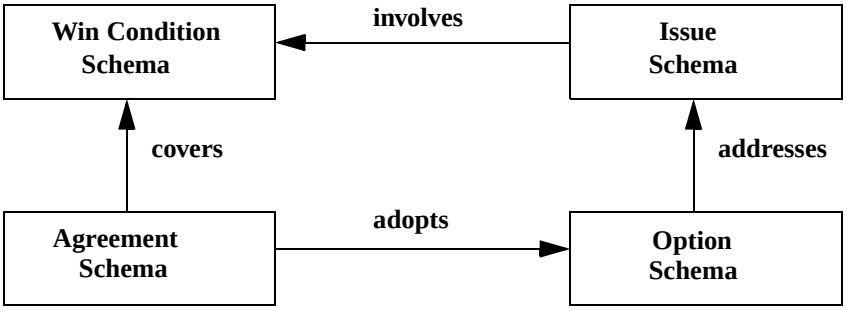


Figure 4. The WinWin Negotiation Model

Stakeholders begin the negotiation by entering their win conditions using the schema provided by WinWin. If a conflict between two or more win conditions is identified, an issue schema is composed which summarizes the conflict and the win conditions involved. For each issue, the stakeholders develop a set of options using the option schemas. The stakeholders then evaluate the different options, iterating on some, rejecting others, and finally converging on a mutually satisfactory (win-win) option. The adoption of this option is formally proposed and ratified by an agreement schema, including a check to ensure that the stakeholders' revised win conditions are indeed covered by the agreement.

WinWin has been applied successfully to various projects, including a SEE/ SGS (Software Engineering Environment for Satellite Ground Station) project.

3.2 Scalability Problem in WinWin: Need for Semi-Automated Assistance

The results of the SEE/SGS project, however, indicated that general tool support like WinWin had some difficulties encountered in conflict identification and resolution when the number of win conditions increased. Specific difficulties in conflict identification included:

- ***Complicated conflict identification process***. In large systems having several dozen or more win conditions, it becomes increasingly more difficult to compare win conditions to identify a conflict. For example, the SEE/SGS project consisted of 21 win conditions, which could require up to 21 factorial (21!) comparisons to identify all conflicts among them.
- ***Ambiguous relationships between quality attributes***. It is not enough to say, "there is a conflict between performance and evolvability." Specific explanations are necessary to understand why they conflicted with each other.
- ***Lack of knowledge about quality conflicts***. Users and customers who lack knowledge of computer systems have no idea of whether what they want is feasible or not. A knowledge-based system would help these people address feasibility issues.

In the context of WinWin, conflict resolution is the process of developing options and negotiating the best one to reach an agreement. Specific difficulties in conflict resolution include:

- ***Difficulties in coordinating multiple stakeholders' interests and priorities.*** Users feel that full functionality and ease of use are the most important attributes. Customers usually focus more on the cost and schedule. Developers are usually concerned with low project risk and easy maintenance. Finding a middle ground among these requirements is difficult.
- ***Complicated dependencies and tradeoff analyses between quality attributes.*** Every decision to improve some quality-attribute requirements may impact on cost and schedule. Some decisions may not be compatible with others.
- ***Exponentially increasing option space.*** In order to resolve a cost conflict (e.g., budget overrun), complicated issues (e.g., Which functions should be reduced, How much to get the project back on track, Which functions can be degraded in terms of their quality attributes, and How much of the quality should be degraded) should be considered.

Two alternative approaches for the conflict identification and resolution were considered. These include:

- ***Fully manual approach***. As indicated above, this approach requires a great deal of effort to compare a large number of win conditions and is not practical.
- ***Fully automated approach***. This approach also requires a great deal of effort to formalize the knowledge about win conditions and agreements. Moreover, this approach is not generally applicable across different domains and will require a great deal of effort to reuse. The ambiguity of interpreting win conditions is another difficulty.

Due to these difficulties, we have concluded that the semi-automated approach is necessary to scale up WinWin in large domains. The next section will present the rationale for focusing the research onto the semi-automated approach.

4.0 Solution Focus

The research focus for the semi-automated assistance of quality conflict identification is explained in section 4.1, and the focus for the semi-automated assistance of quality conflict resolution is explained in section 4.2.

4.1 Focus for Conflict Identification

The rationales for the solution focus (Figure 5) to implement semi-automated assistance of conflict identification are:

1. Instead of analyzing the win condition bodies using formal methods or natural language processing techniques, let stakeholders associate the win conditions with a WinWin Domain Taxonomy tree using relation links.
2. Instead of identifying all kinds of conflicts (e.g., conflicts among infrastructure, functional domain, quality-attribute requirements) in the taxonomy tree, just focus on quality attribute conflicts because the knowledge for identifying quality attribute conflicts is generally stable and it can be applied across multiple domains.
3. Instead of just saying, “A conflict between portability and performance is identified”, build conflict identification models (e.g., quality attribute product and process strategies) to identify the sources of conflicts and insights on how to resolve the conflicts.
4. Instead of collecting, organizing, and summarizing the Quality Attribute Strategies based on non-architecture concepts, focus on Architecture Strategies to reduce the gap

between requirements and design and to capitalize on an emerging source of attribute tradeoff opportunities.

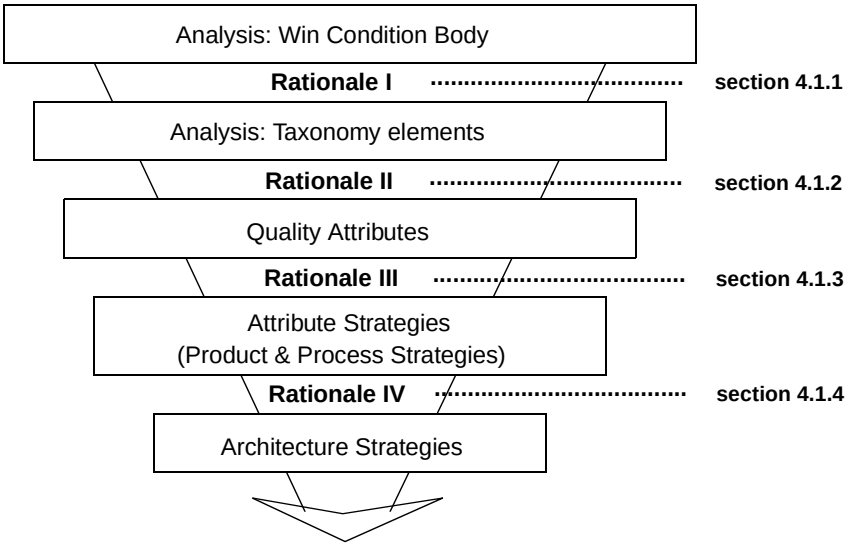


Figure 5. Overall Focus for Semi-automated Assistance

The rationale for focusing on the analysis method based on Taxonomy Elements (section 4.1.1), the rationale for focusing on quality attributes in the taxonomy elements (section 4.1.2), the rationale for developing Quality Attribute Strategies (section 4.1.3), and the rationale for developing Architecture Strategies (section 4.1.4) will be discussed next.

4.1.1 Rationale for Focus on Taxonomy Elements

If there are *n* win conditions, the number of comparisons necessary for identifying conflicts is *n!* in the worst case. It is impossible to manually compare them

one-by-one if n is large. Grouping the win conditions appropriately is required. The taxonomy in WinWin can be used for this purpose.

Each win condition can map into one or more associated WinWin Domain Taxonomy elements in a tree structure. The conflict identification can be carried out by comparing one taxonomy element (i.e, the associated group of win conditions) with another rather than by comparing one win condition with another. It can reduce the number of comparisons (i.e., comparison complexity) from $n!$ to $m!$ where m is the number of Taxonomy elements (i.e., the number of the groups of win conditions). It is also very useful to reduce the complexity in both manual-approaches and fully-automated approaches. However, the semi-automated approach has some merits (summarized in table 3) according to criteria such as workload, scalability, accuracy of computer analysis, granularity, and technology availability.

The analysis based on win condition bodies is more accurate than the analysis based on the Taxonomy because the knowledge was formalized at a very detailed level (low granularity). However, the drawbacks of this analysis are low scalability and high workload. The analysis based on win condition bodies through natural language processing is not our focus because the technology is not currently mature enough. The analysis based on the Taxonomy has a lower associated workload and more scalability, but the drawbacks are low accuracy and a high level of granularity (i.e., abstract level of advice). However, the analysis based on the Taxonomy is better overall, in that the system identifies conflicts initially, then human users take a look at a more detailed-level. This balance provides a good combination of scalability and accuracy.

Criteria	Analysis based on win condition Body			Analysis based on Taxonomy
Methods	**Human** reads through and understands win condition bodies from beginning to end; Let **human** identify conflicts by the comparison of other win condition bodies.	**Human** formalizes win condition Bodies by a formal language; Let **computer** identify conflicts by AI reasoning techniques.	**Computer** perform natural language processing on win condition bodies and formalize them automatically; Let **computer** identify conflicts by AI reasoning techniques.	Attach win conditions into the Taxonomy tree; Let **computer** suggest potential conflicts to human based on the knowledge base. Then, the **human** determines whether the potential conflicts are significant or not; If significant, draft the issus which may be customized. Otherwise, cancel the issues.
Workload for human	**High**: due to the high numbers of comparisons and formalization overhead	**High**: due to a lot of efforts to translate bodies into formal language.	**Low**: due to work saving from automation of translation (when accurate)	**Low**: due to work saving from the linkage and filtering approach
Scalability	**Low**: due to the human-processing overhead.	**Low**: if search space by rules and facts is increased exponentially	**Low to Medium**: depend on simplicity of domain, constraints on natural language.	**High**: due to the best combination between human-processing and computer-processing overhead
Accuracy of Computer Analysis	**High**: depend on the human expertise.	**High**: depend on the captured knowledge base and reasoning methods	**Low to Medium**: depend on simplicity of domain, constraints on natural language.	**Medium**: depend on the correctness and accuracy of linkage information
Granularity	**Very Specific level**	**Specific level**	**Specific level**	**Abstract level**
Technology Availability	**High**: Human experts are available	**High**: Most AI reasoning and plan technologies are available	**Low**: the art-of-state of Natural Language process is premature to understand common knowledge	**High**: tracing relationships among win condition and retrieving the matching resolution cases are easy technology to implement

Table 3. Rationale I: Analysis From Win Condition Body To Taxonomy Elements

4.1.2 Rationale for Focus on Quality Attribute Taxonomy Elements

Taxonomy Elements (Figure 6) can be divided into three areas such as Infrastructure area, Domain area, and Attribute area.

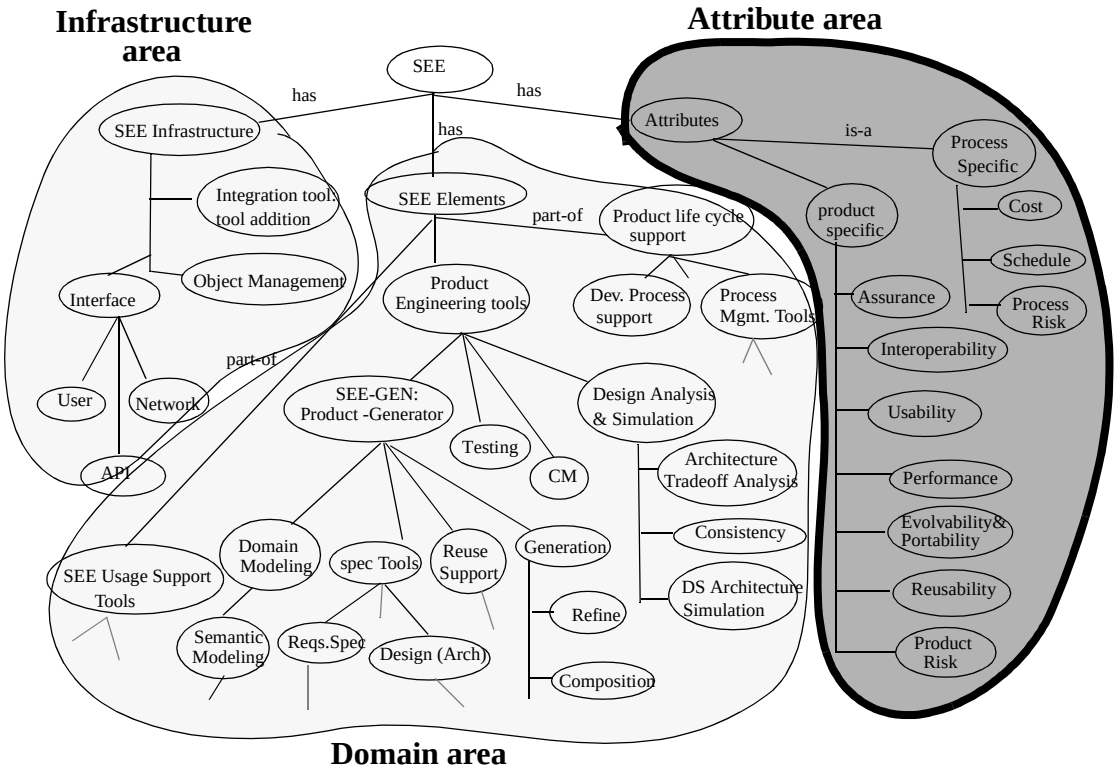


Figure 6. Example of the WinWin Domain Taxonomy

We can build the knowledge base for identifying the conflicts among taxonomy elements in all three areas, but it is difficult to satisfy the results of semi-automated assistance. The reasons are shown in table 4. The symbols -- or ++ mean very high or very low, -/+ means ‘depends on situation’.

	Infrastructure area	Domain area	Attribute area
Generality	+	-	++
Stability	-	+	++
Precision of results	- -	- / +	- / +

Table 4. Rationale II: Focusing on Taxonomy Elements

The knowledge of the infrastructure area has high generality, low stability, and very low precision in the results because the knowledge of infrastructure is updated frequently, but it may have good generality for a popular infrastructure.

The knowledge of the domain area has i) low generality because domains are different from application to application, ii) high stability because (most) domains are not changed very often, and only small parts need to be maintained/updated, and iii) 'situation-dependent' precision in the results because of the difficulties which arise from the generality problem.

The knowledge of the attribute area has i) very high generality because a number of quality attribute studies have been carried out and the knowledge itself is general, ii) high stability because the knowledge itself is not often changed, and iii) 'situation-dependent' precision in the results because of the way in which detailed information is captured and how the ambiguous relationships among quality attributes are dealt with.

This dissertation therefore focuses on the area of quality, because it has the best prospects for supporting the development of a useful knowledge assistance tool due to the very high generality and high stability.

4.1.3 Rationale for Focus on Quality Attribute Strategies

The complex relationships among quality attributes make it often difficult to identify conflicts among quality requirements. The purpose of Quality Attribute Strategies is to provide concise descriptions of the ambiguous relationships among the quality attributes.

Many researchers (e.g., [Boehm et al., 73], [McCall et al., 1977], [Lipow et al., 1977], [Bowen et al., 1985], [Deutsch-Willis, 1988], [Dyson, 1991], [Schulmeyer-McManus, 1992]) studied the relationship between quality attributes using only positive and negative relations. Gillies [Gillies, 1992] tried to elaborate the relationship by adding more relations between quality attributes. However, the positive/negative relationships are insufficient to clarify the ambiguous relationship among quality attributes and to provide the description language for the relationship. Kazman and Bass [Kazman-Bass, 1994b] explored the relationship among quality attributes using design operations called “unit operations”. They provided a useful first-order conflict analysis of the interaction between quality attributes, even though their method of deriving architectures from requirements is somewhat oversimplified. Our research focus, Quality Attribute Strategy, used this concept and extended it with semi-formalized structure to provide a useful description language for using tradeoff analysis.

Without a rationale based on Quality Attribute Strategies or their equivalent, it is not helpful to say “Portability and Performance requirements may conflict with each other.” In order to be helpful, the description based on the Quality Attribute Strategies should be “Portability and Performance requirements may conflict with each other in the

sense that a layered architecture can be used to improve Portability, but it may degrade system Performance due to the overhead of passing data and control across several layers."

Another benefit of the description based on the Quality Attribute Strategies is that it provides insights for resolving quality conflicts by providing the reasons for the quality conflicts. For example, the Quality Attribute Strategy for the conflict between Portability and Performance requirements explains the causes of conflict such as i) layered software architecture needs overhead to pass data/control from layer to layer; ii) use of platform- or feature-specific instructions may increase the performance, but may have porting problems with other platforms or systems; and iii) the independence of the software environment (e.g., JAVA applications) can provide flexibility to port one system to another at the expense of better performance in the software environment (e.g., Motif applications in Unix are generally faster than JAVA applications).

4.1.4 Rationale for Focus on Architecture Strategies

There already exist many strategies developed for improving a quality attribute (i.e., a part of Quality Attribute Strategies); see, for example, [Boehm et al., 73], [McCall et al., 1977], and [Kazman-Bass, 1994b]. However these analyses tend to have very simple relationships among quality attributes (e.g., using + or - to indicate conflict or reinforcement) which is too simple to identify quality conflicts.

Software architecture is becoming an emerging and promising technique for reducing the gaps between requirements and design by providing a language having mid-

level granularity between requirements and design. The rationale is that analyzing the components, connectors, and constraints of software architecture provides a deeper understanding of software-attribute tradeoffs.

4.2 Focus for Conflict Resolution

The quality attributes can be organized into a hierarchical tree. A number of organizing principles for such trees have been developed in [Boehm et al., 73; Bowen et al., 1985; Chung et al., 1995; Deutsch-Willis, 1988; Dyson, 1991; Gillies, 1992; Kahn-Keller, 1990; Lipow et al., 1977; McCall et al., 1977; Vincent et al., 1988; Schulmeyer-McManus, 1992]. For stakeholder win-win negotiation support, we have developed an organizing principle based on the primary quality attribute concerns of stakeholders [Boehm-In 1996a]. In this tree, Dependability, Interoperability, Usability, Performance, Adaptability (i.e., Evolvability and Portability), Cost and Schedule, and Reusability are considered as the top-level quality attributes. Each higher-level quality attribute has more detailed-level quality attributes associated with it. For example, Reliability/Accuracy, Correctness, Availability/survivability, Integrity, Security/privacy, and Safety are associated with Dependability, a top-level quality.

This structure forms the foundation for the Quality Attribute Risk and Conflict Consultant (QARCC) tool and its architecture-strategy analyses to be presented in section 5.0.

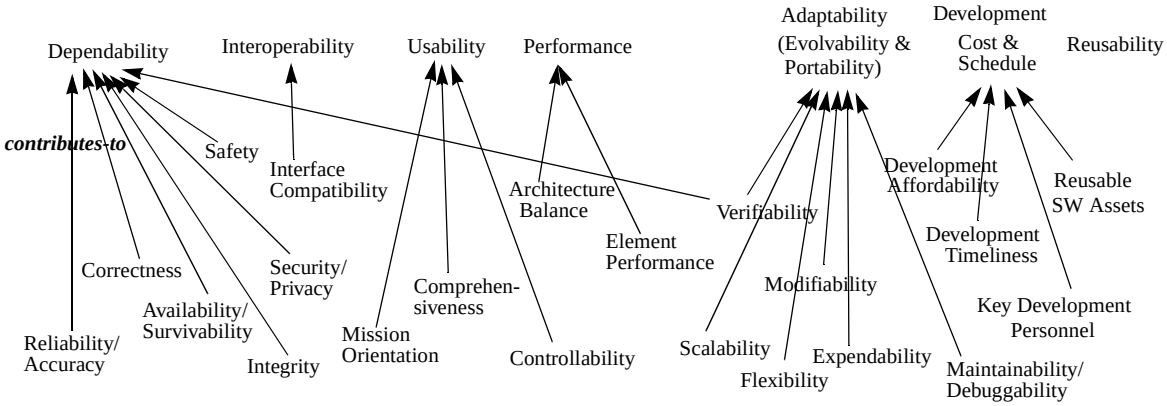


Figure 7. Hierarchical Structure among Quality Attributes

Part II: Contribution

In the following sections, I present my proposed theories, models, and their support systems for identifying quality conflicts among requirements and resolve cost conflicts by creating and negotiating conflict resolution options.

	Applied Domain	**Theories and Models**	**Their Support System**
Conflict Identification	**Quality conflicts**	• Hierarchy of Quality Attributes (section 5.1) • Stakeholder/Quality Attribute Relationship Model (section 5.1) • Quality Attribute Strategies: Produce and Process Strategies (section 5.2 & section 5.3) • Architecture Strategies and their formalism (section 5.4)	**QARCC** (Quality Attribute Risk and Conflict Consultant) (section 7.2)
Conflict Resolution	**Cost conflicts**	• Theories for option creation through added dimensions (section 6.1) • S-COST Resolution Option Strategies and their formalism (section 6.2 & section 6.3) • Stakeholder/Option Strategies Relationship Model (section 6.4)	**S-COST** (Software Cost Option Strategy Tool) (section 7.3)

Table 5. Overview of the Proposed Theories, Models, and Their Support Tools

5.0 Conflict Identification Theories and Models for Quality Attributes

5.1 Overview of the Conflict Identification Models

The context and information available for analyzing quality-attribute conflicts early in the life cycle come primarily from the prioritized requirements, as expressed by different system stakeholders' win condition schemas. The win condition schemas are associated with the quality attribute taxonomy by the owners of the artifacts.

Each stakeholder has different concerns about quality attributes. For example, Maintainers are primarily concerned with Evolvability and Portability, and only marginally concerned with Development Affordability (i.e., Development Cost) and Reusability, which tend to be primary concerns of Customers and Developers. As indicated in the left-hand side of the knowledge base structure of Conflict Identification Models (Figure 8), the structure of these first-order stakeholders concerns' forms a part of the Conflict Identification Models. This structure is capable of associating quality attribute conflicts with the appropriate stakeholders, in order to flag potential concerns for the stakeholders and to provide them with advice for resolving the concerns.

A quality attribute hierarchy is another part of the Conflict Identification Models. It is similar to those in [Basili-Rombach, 1987], [Boehm et al., 1973], and [McCall et al., 1977]. Its major difference is that the highest level of the hierarchy is connected to stakeholders' primary concerns for quality attributes.

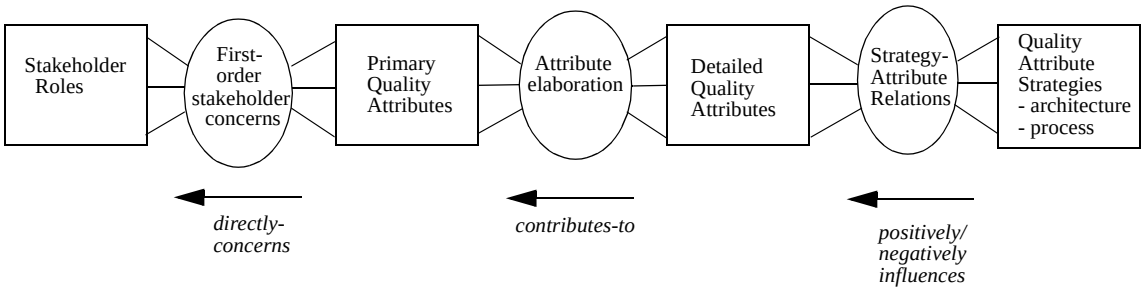


Figure 8. Knowledge Base Structure of Conflict Identification Models

The other major component of the models, shown in the right-hand side of Figure 8, is a set of relationships between software architecture & process strategies and their typical effects on quality attributes. For example, a layered architecture has a positive influence on Portability due to its ability to hide platform dependencies of a layer, whereas it has a negative influence on Performance because in-line machine dependent code may be more efficient. Thus, using a layered architecture strategy to achieve Portability will frequently cause a conflict with Performance objectives.

The following bullets describe the major components:

- **Stakeholder Roles**: The most frequent roles are User, Customer, Developer, Maintainer, Interfacer, and General Public. Others could be Product Line Managers, Testers, or Subcontractors. Complex systems may have more than one individual comprising a role such as Users and Customers.
- **First-Order Stakeholder Concerns and Primary Quality Attributes**: The primary attribute win conditions for each stakeholder's role have been determined from

experience by applying Theory W to complex, multi-stakeholder projects (e.g., Army WIS, STARS, the WinWin project itself) [Boehm-In, 1996a]. They are shown as the top set of arrows in Figure 9. Second-order stakeholder concerns are also important (the Developer cares about Usability because the User does), but are generally addressed via negotiation of first-order stakeholder win conditions. The profile analysis about the directly-concerned relations is shown in section 5.2.

- **Attribute Elaboration and Detailed Quality Attributes**: The next level of detail in the hierarchical ordering of quality attributes is shown as the lower set of arrows in Figure 9. Thus, the overall Dependability attribute, which is a primary concern of Users and the General Public, may have sub-attributes of Reliability, Accuracy, Correctness, Availability, Survivability, Integrity, Safety, Security, Privacy, and Verifiability. In many cases, it is sufficient to deal with attribute conflicts at the Primary attribute level, but at times the lower levels become important as well (e.g., in conflicts between fault-tolerance data distribution for Availability and restricted data access for Security).
- **Strategy-Attribute Relations and Quality Attribute Strategies**: The general set of Quality Attribute Strategies, organized into product and process strategies, has top-level assessments of their impact on other quality attributes. For example, the Input Acceptability checking strategy applies to several Dependability sub-attributes, such as invalid-data checking for Reliability and unauthorized-access checking for Security. Input Acceptability checking also reinforces Interoperability via validity and access checking across the system interfaces. It reinforces Usability by providing rapid

feedback on invalid user inputs. On the other hand, the Input Acceptability checking activities require additional code, memory, and execution cycles, and thus may conflict with the Development Cost/Schedule and Performance attributes. Quality Attribute Strategies will be discussed in further detail in section 5.3.

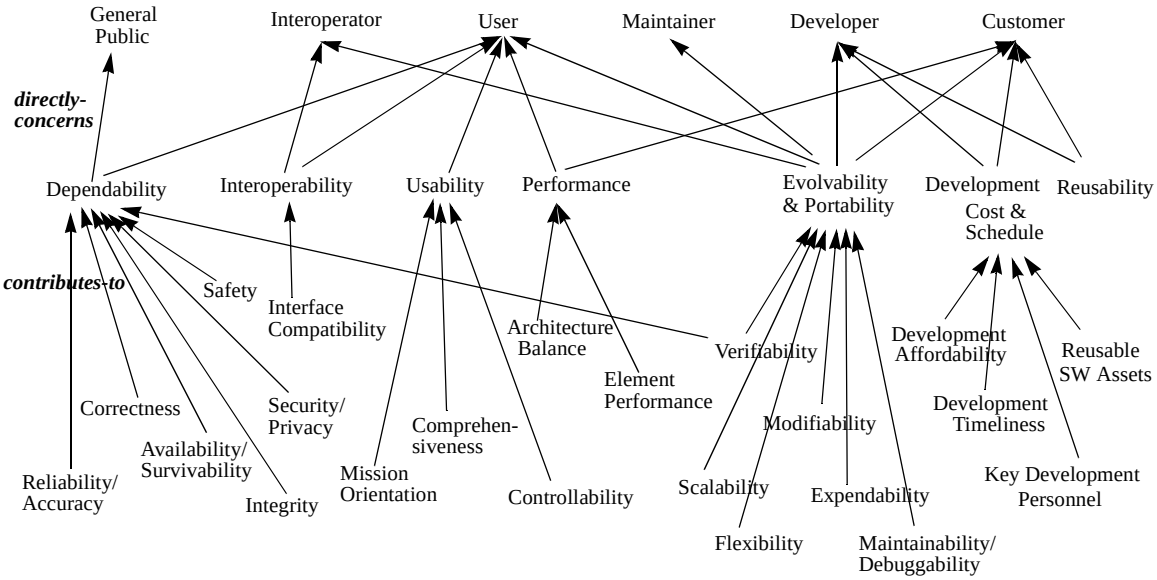


Figure 9. Mapping of Common Stakeholders' Primary Concerns onto Quality Attributes

5.2 The Profile Analysis for Stakeholder/Quality Attribute Relationships

Stakeholders may have different concerns and interests regarding quality attributes. For example, Customers may be much more concerned with Cost rather than with Schedule, or vice versa. Users may be much more concerned with Performance than with Dependability, or vice versa. Overall, however, Customers' primary concerns tend to focus on such attributes as Cost and Schedule, while Users tend to be more directly concerned about such attributes as Performance and Dependability.

Table 6 shows the relationship between stakeholders, their roles & responsibilities, and the quality attributes with which they are concerned. Each stakeholder has roles and primary responsibilities. This information can be used to infer the primary and secondary quality attribute concerns of each stakeholder. A primary quality attribute concern reflects those stakeholder's primary responsibilities. A secondary quality attribute concern does not reflect those stakeholder's primary responsibilities, but it may indirectly cause problems in achieving the primary quality attribute concerns. For example, *Interoperability* is a primary concern for the Interoperator because the Interoperator's roles and primary responsibilities are avoiding current and future interface problems between the system and interoperating systems. However, *Dependability* and *Performance* are secondary concerns to the interoperator because these concerns are not necessarily related to stakeholder's primary roles and responsibilities (even though improving Dependability and Performance can complicate interface problems).

Stakeholder	Roles and Primary Responsibilities	Quality Attribute Concerns	
		Primary	Secondary
General Public	Avoid adverse system side-effects: safety, security / privacy.	Dependability	Evolvability & Portability
Interoperator	Avoid current and future interface problems between system and interoperating system	Interoperability, Evolvability & Portability	Dependability, Performance
User	Execute cost-effective operational missions	Dependability, Interoperability, Usability, Performance, Evolvability & Portability	Development Schedule
Maintainer	Avoid low utility due to obsolescence; Cost-effective product support after development	Evolvability & Portability	Dependability
Developer	Avoid nonverifiable, inflexible, nonreusable product; Avoid the delay of product delivery and cost overrun.	Evolvability & Portability, Development Cost & Schedule, Reusability	Dependability, Interoperability, Usability, Performance
Customer	Avoid overrun budget and schedule; Avoid low utilization of the system	Development Cost & Schedule, Performance, Evolvability & Portability, Reusability	Dependability, Interoperability, Usability

Table 6. Stakeholder Roles / Quality Attribute Concerns Relationship

In the WinWin experiment results of SEE/SGS (Software Engineering Environment / Satellite Ground System), the profile analysis for the relationships between the stakeholders (i.e., User, Developer, and Customer) and the quality attributes (i.e., Interoperability, Usability, Evolvability & Portability, Development Cost & Schedule, and Reusability) is shown in Table 7. The profile was organized into the stakeholders' roles, the concerned quality attributes, their priorities, and the related win conditions.

In this project, the product was a tailored extension of a commercial SEE to support a family of SGS software systems. The customers would eventually use the SEE, so all stakeholders would be concerned about tool interoperability in the SEE. Also, the role of the SEE developer included the role of the maintainer as well. There were no win conditions about Dependability and Performance, given that these are less critical for SEE's.

Stakeholders / Quality Attribute	User		Customer		Developer	
	# of artifacts	Primary Concerns	# of artifacts	Primary Concerns	# of artifacts	Primary Concerns
Dependability	0	Yes	0		0	
Interoperability	1 High*	Yes	2 High		2 High	
Usability (Functionality)	5 High; 2 Medium	Yes	0		0	
Performance	0	Yes	0	Yes	0	
Evolvability & Portability	1 Medium	Yes	3 High	Yes	1 High	Yes
Cost & Schedule	0		4 High	Yes	0	Yes
Reusability	0		0	Yes	1 High	Yes

* The priority of win condition

Table 7. Profile Analysis Results

Thus, the proposed default set of relationships shown in Figure 9 is mostly the same, but somewhat different from those in Table 7, given the somewhat different usage of a SEE.

We concluded that the proposed default set of relationships shown in Figure 9 cannot be guaranteed to be applicable to all types of projects without changes. However, the proposed default set of relationships is still useful because it will assist the stakeholders in recognizing their default roles and responsibilities. The complexity of the conflict identification and resolution process can be reduced by not sending the unrelated and/or uninteresting quality-attribute conflict messages to the stakeholders who do not want to receive them. For the flexibility of the relationships between the stakeholders and the quality attributes, however, the model and/or the support system based on the relationships should have the capability to change the default set of the relationships from project to project.

5.3 Quality Attribute Strategies

A Quality Attribute Strategy is a design strategy for improving one or more quality attribute(s) in software systems. The general set of Quality Attribute Strategies (Table 8) is organized into the product and the process strategies. These strategies were compiled from the major existing studies of software quality metrics and methods: [Boehm et al., 73; Bowen et al., 1985; Chung et al., 1995; Deutsch-Willis, 1988; Dyson, 1991; Gilb, 1988; Gillies, 1992; Kahn-Keller, 1990; Kazman-Bass, 1994b; Lipow et al., 1977; McCall et al., 1977; Vincent et al., 1988; Schulmeyer-McManus, 1992]. For example, the product strategies for improving Dependability include Input Acceptability Checking, Program and Data Redundancy, Backup and Recovery, Monitoring and

Control, and Accuracy Optimization. The Process strategies for improving Dependability include Formal Specification and Verification, Failure Modes and Effects Analysis, and various Test strategies.

However, due to the side effects of improving a particular quality attribute, the Quality Attribute Strategies may have negative effects on some quality attributes.

For example, *Input Acceptability Checking* strategy applies to several Dependability sub-attributes, such as invalid data checking for Reliability and unauthorized-access checking for Security. *Input Acceptability Checking* also reinforces Interoperability via validity and access checking across the system interfaces. It reinforces Usability by providing rapid feedbacks on invalid user inputs. On the other hand, the activities for *Input Acceptability Checking* require additional code, memory, and execution cycles. Therefore, it may have a negative effect on Development Cost/Schedule and the Performance.

Table 9 shows the summary of some Quality Attribute Strategies to improve each quality attribute, including top-level assessments of their effect on other quality attributes. The complete set of the strategies will be formulated and analyzed in the Appendices.

	Product Strategies	Process Strategies
Dependability	Accuracy Optimization, Backup/ Recovery, Diagnostics, Error-reducing User Input/output, Fault-tolerance Functions, Input Acceptability Checking, Integrity Functions, Intrusion Detection & Handling, Layering, Modularity, Monitoring & Control, Redundancy	Failure Modes & Effects Analysis, Fault Tree Analysis, Formal Specification & Verification, Inspections, Penetration, Regression Test, Requirements/Design V & V, Stress Testing, Test Plans & Tools
Interoperability	Generality, Integrity Functions, Interface Specification, Layering, Modularity, Self-containedness	Interface Change Control, Interface Definition Tools, Interoperator Involvement, Specification Verification
Usability	Error-reducing User Input/output, Help/ explanation, Modularity, Navigation, Parametrization, UI Consistency, UI Flexibility, Undo, User-programmability, User-tailoring	Prototyping, Usage Monitoring & Analysis, User Engineering, User Interface Tools, User Involvement
Performance	Descoping, Domain Architecture-driven, Optimization (Code/ Algorithm), Platform-feature Exploitation	Benchmarking, Modeling, Performance Analysis, Prototyping, Simulation, Tuning, User Involvement
Adaptability (Evolvability / Portability)	Generality, Input Assertion/type Checking, Layering, Modularity, Parameterization, Self-containedness, Understandability, User-programmability, User-tailorability, Verifiability	Benchmarking, Maintainers & User Involvement, Portability Vector Specification, Prototyping, Requirement Growth Vector Specification & Verification
Development Cost / Schedule	Descoping, Domain Architecture-driven, Modularity, Reuse	Design To Cost/schedule, Early Error Elimination Tools And Techniques, Personnel/Management, Process Automation, Reuse-oriented Processes, User & Customer Involvement
Reusability	Domain Architecture-driven, Portability Functions	Domain Architecting, Reuser Involvement, Reuse Vector Specification & Verification
All of Above	Descoping, Domain Architecture-driven, Reuse (For Attributes Possessed By Reusable Assets)	Analysis, Continuous Process Improvement, Incentivization, Inspections, Personnel/Management Focus, Planning Focus, Requirement/ design V&V, Review Emphases, Tool Focus, Total Quality Management

Table 8. Quality Attribute Product and Process Strategies: General

Primary Attribute	Architecture Strategy	Other Attribute Reinforcement	Other Attribute Conflicts	Special Cases, Comments
Dependability	Input acceptability checking	Interoperability, Usability	Development Cost/ schedule, Performance	
	Redundancy		Development Cost/ schedule, Evolvability, Performance, Usability	
	Backup/recovery		Development Cost/ schedule, Evolvability, Performance	
	Monitoring & Control		Development Cost/ schedule, Performance	Performance reinforcement in long term via tuning
Interoperability	Input acceptability checking	Dependability, Usability	Development Cost/ schedule, Performance	
	Layering	Evolvability/ Portability, Reusability	Development Cost/ schedule, Performance	
Usability	Error-reducing user input/output	Dependability	Development Cost/ schedule, Performance	
	Input acceptability checking	Dependability, Interoperability	Development Cost/ schedule, Performance	
Performance	Architecture balance	Cost/Schedule		
	Domain architecture-driven	Cost/Schedule		
Evolvability/ Portability	Layering	Interoperability, Reusability	Development Cost/ schedule, Performance	
Cost/Schedule	Architecture balance	Performance		
	Domain architecture-driven	Performance		
Reusability	Domain architecture-driven	Interoperability, Reusability	Development Cost/ schedule, Performance	
	Layering	Interoperability, Evolvability/ Portability	Development Cost/ schedule, Performance	

Table 9. Quality Attribute Strategies and Relations: Architecture Strategies

Using the positive and negative relationships between the Quality Attribute Strategies and the quality attributes, the potential conflicts between Cost/Schedule (or Performance) and other quality attributes (e.g., Dependability, Interoperability, and Usability) could be deduced.

5.4 Architecture Strategies for Achieving Quality Attributes

An *Architecture Strategy* is a strategy for improving one (or more) quality attribute(s) of a software system by imposing a particular set of software architecture constraints. In the context of this dissertation, these terms are defined as follows:

- Strategy: a careful plan or method [Webster, 1993]
- Quality attributes of software: Dependability, Interoperability, Usability, Performance, Evolvability, Portability, Reusability, Development Affordability and Timeliness (i.e., Development Cost/Schedule)
- Software architecture constraints: constraints among a software system's components (e.g., program or data elements) and connectors (e.g., interfaces among the components)

In other words, an Architecture Strategy is a Quality Attribute Strategy which imposes software architecture constraints. An Architecture Strategy provides a formal structure for components, connectors, and their constraints. The formal structure helps people understand software attribute tradeoffs more fully.

5.4.1 Formalization of the "Architecture Strategies"

The formal structure (Figure 10) of Architecture Strategies is composed of i) a *definition* for each elementary strategy, ii) *preconditions* to check whether or not the environments or situations are candidates for applying the strategies, iii) *postconditions* to describe the results or actions after applying the strategies, and iv) *effects* on quality attributes with rationale.

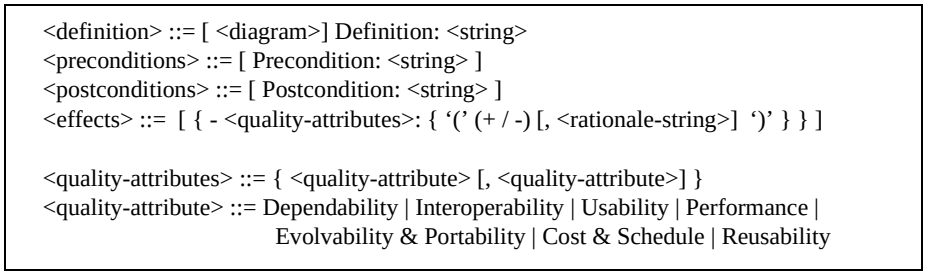
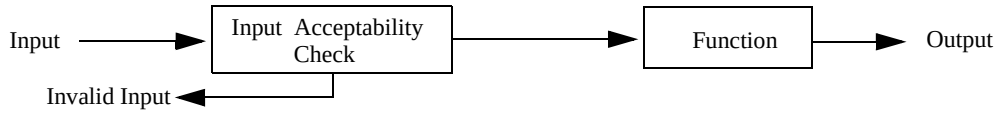


Figure 10. Structure of Architecture Strategies for Quality Attributes

Three examples of Architecture Strategies are shown in Figure 11. For example, the *preconditions* for *Input Acceptability Check* are sets of candidate inputs and acceptability criteria. The *postconditions* for the strategy are: "if valid, pass the input into the function; otherwise, indicate '*Invalid Input*' and exit". The *effect* on Dependability is positive, while the *effects* on Performance, Development Cost/Schedule, and Evolvability are negative.

Example 1. Input Acceptability Check:



Definition: An architectural composition that precedes a function by an acceptability check of its inputs

Preconditions:

Candidate inputs, acceptability criteria

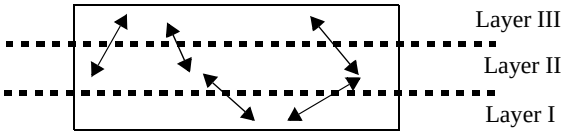
Postconditions:

If valid, pass input into the function, otherwise, indicate "Invalid Input" and exit.

Effects on quality attributes:

- Dependability: (+, unacceptable inputs filtered out)
- Performance (-, input-check requires resources)
- Development Cost, Schedule: (-, more to specify, develop, verify)
- Evolvability: (-, more to modify)

Example 2. Layering



Definition: A hierarchical architectural composition in which each layer can communicate only with the adjacent upwards or downwards layer

Preconditions:

Interface and protocol between a layer and an adjacent layer, request to pass data and/or control from layer to layer

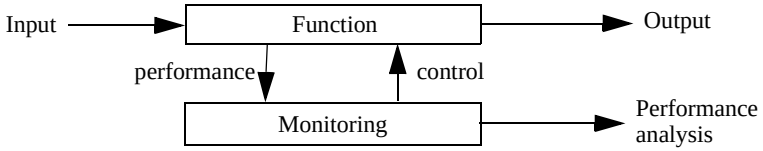
Postconditions:

Data and/or control passed from layer to layer, or notification of interface/protocol violation

Effects on quality attributes:

- Evolvability, Interoperability, Portability, Reusability: (+, hide sources of variation inside interface layers)
- Performance (-, need more interfaces, and data and/or control transfers, via protocol)
- Development Cost, Schedule: (-, more to specify, develop, verify)

Example 3. Monitoring & Control



Definition: An architectural composition that monitors the performance of function, controls the configuration or environment to stabilize the function (e.g., to avoid buffer overflows), and/or reports the result for subsequent performance analysis.

Preconditions:

Monitoring instrumentation, control limits and algorithms.

Postconditions:

If the function is stable, checks the performance and reports it, otherwise stabilizes the function by controlling the configuration or environment. May also report predicted future undesirable states.

Effects on quality attributes:

- Dependability: (+, avoids undesirable states)
- Performance: (-, needs additional processing in short term; +, improves performance in long term via system tuning
- Timeliness, affordability: (-, more to specify, develop, verify)

Figure 11. Three Examples of Architecture Strategies

5.4.2 Architecture Strategies and their Quality Attribute Tradeoffs

Based on the structure for the Architecture Strategies, Figure 12 shows an example of how to identify potential quality conflicts, help stakeholders understand why they conflict with each other, and support quality attribute tradeoff analysis for providing better ideas to resolve these conflicts.

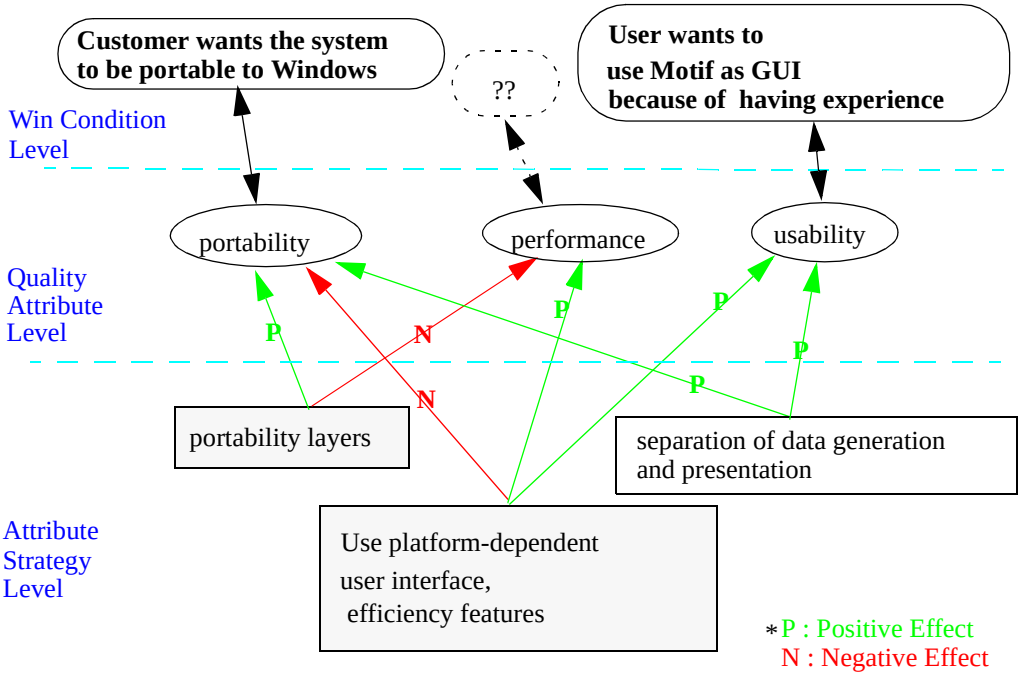


Figure 12. Quality Attribute Tradeoff Analysis

Associating a win condition with a quality attribute (say Q_1) triggers a search of the Architecture Strategies which have the positive and/or negative effects on Q_1. For example, the Portability attribute whose win condition is "portable to Windows" have positive effects on the *portability layers* and *separation of data generation and presentation* Attribute Strategies, but have negative effects on *the use of fast platform-dependent user interface features* Attribute Strategy.

The Architecture Strategies (e.g., *use of fast platform-dependent user interface features*) which are found to have negative effects on the associated quality attribute (e.g., portability) are used to identify potential conflicts with the other quality attributes (e.g., performance and usability) on which the searched Architecture Strategies have positive effects, or vice versa.

Stakeholders understand why portability and performance may conflict with each other and their tradeoff relationships because *the use of fast platform-dependent user interface features* can improve performance, but it may degrade portability.

Figure 13 shows a generalized algorithm for qualify conflict identification with the example shown in Figure 12.

Note that the algorithm shown in Figure 13 can identify potential attribute win conditions which did not exist in the current knowledge base, but are necessary. The algorithm used the information of the taxonomy links between win conditions and quality attribute taxonomy elements. If the conflict identified by positive-negative or negative-positive relationships contains a quality attribute which has no taxonomy link to a win condition, then the message of missing the win condition for the quality attribute is sent to directly-concerned stakeholders.

5.4.3 Elaboration of Architecture Strategies

In order to resolve the identified conflict by the algorithm, however, situation-specific information is necessary for the more detailed tradeoff analysis. For the

Algorithm: **Quality_Conflict_Identification(W_x)**

// Find a quality attribute which links to the win condition, W_x, via taxonomy links. And Initialize CONFLICT.
Find QA_x such that *taxo-link* (W_x,QA_x)
CONFLICT ← ∅

// Get Positive Architecture Strategeies (PAS) and negative Architecture Strategies (NAS)
PAS ← {AS_i | *positively-influences* (AS_i,QA_x) }
NAS ← {AS_i | *negatively-influences* (AS_i,QA_x) }

// Identify conflicts using positive-negative or negative-positive relationships.
For each AS_i in **PAS**
  CONFLICT ← **CONFLICT** ∪
    {(QA_x,QA_y, AS_i) | *negatively-influences* (AS_i,QA_y)}
For each AS_i in **NAS**
  CONFLICT ← **CONFLICT** ∪
    {(QA_x,QA_y, AS_i) | *positively-influences* (AS_i,QA_y)}

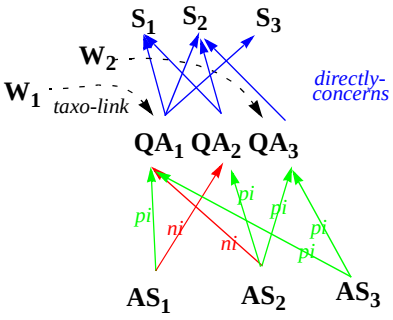
// Send conflict messages to the directly-concerned stakeholders
For each $CONFLICT_k$ (QA_x,QA_y, AS_i) in **CONFLICT**
  // Identify the directly-concerned stakeholders
  ST ← { S_i | *directly-concerns* (QA_x,S_i) ∨
      directly-concerns (QA_y,S_i) }
  // Check whether a win condition exist for QA_y
  If $ W_y such that *taxo_link*(W_y,QA_y)
    // Send a message of a potential conflict between QA_x and QA_y due to AS_i
    then send-message (**ST**, "Potential Conflict between W_x in QA_x and W_y in QA_y in terms of AS_i")
    // Send a message of potentially missing win condition, which may conflict a win condition in QA_y due to AS_i
    else send-message (**ST**, "Missing a Win Condition in QA_y; This Win Condition may conflict with W_x in QA_x in terms of AS_i")
EndFor

taxo-link: taxonomy link
pi : positively influences
ni : negatively influences

S_1: Customer; QA_1: Portability;
S_2: User; QA_2: Performance;
S_3: Developer; QA_3: Usability;

AS_1: Portability layers
AS_2: Use platform-dependent user interface, efficiency features
AS_3: separation of data generation and presentation

W_1: Customer wants the system to be portable to Windows
W_2: User wants to use Motif as GUI because of having experience



Input: Quality_Conflict_Identification(W_1)
Output:
  send_message({S_1, S_2, S_3},
    "Missing a Win Condition in QA_2; This Win Condition may conflict with W_1 in QA_1 in terms of AS_1")
  send_message({S_1, S_2, S_3},
    "Missing a Win Condition in QA_2; This Win Condition may conflict with W_1 in QA_1 in terms of AS_1")
  send_message({S_1, S_2, S_3},
    "Potential Conflict between W_1 in QA_1 and W_3 in QA_3 in terms of AS_2")

Figure 13. A Conflict Identification Algorithm with an Example

portability-performance conflict, for example, the information (e.g., how many platform-dependent user interface features there are, how much performance is needed for each feature, and which features are critical for portability) should be considered in determining the right balance in the portability and performance tradeoff analysis.

Thus, the following steps to elaborate the Strategy-Attribute Relations and Architecture Strategies would be helpful:

Step 1. Identify primitive Architecture Strategies. Table 10 summarizes a set of the Architecture Strategies. Whether there exist clear constraints for a software system's components and connectors among Product Quality Attribute Strategies shown in Table 8 determines the current working sets of the strategies.

Step 2. Categorize the *effect*s of the identified strategy on each of the other primary quality attributes as simply + or -. For any pair of strategies with the same pattern of +'s and -'s, combine them if they are sufficiently synonymous.

Step 3. Define the *preconditions* and *postconditions* involved in applying the Architecture Strategies. These sharpen the strategy definitions, help validate the + and - assignments, and help identify more complex interactions.

Step 4. Elaborate the more complex Strategy-Attribute Relations. For a particular quality attribute, both positive and negative effects may hold in different situations. In example 3 of Figure 11, the Monitoring and Control strategy improves Dependability at the cost of Performance in the near term (from point A to point B in Figure 14), but also provides data supporting long-term Performance improvement via tuning (point C).

Step 5. Formulate *options* to resolve the identified conflicts among quality attributes. Performance tuning is one such example.

Step 6. Update strategies based on experience.

	Architecture Strategies
Dependability	Assurance Monitoring & Control, Diagnostics, Fault-tolerance Functions, Input Acceptability Checking, Intrusion detection & handling, Redundancy
Interoperability	Layering
Usability	Error-reducing User Input/output
Performance	Architecture Balance, Performance Monitoring & Control, Pipelining
Adaptability (Evolvability / Portability)	Change-source Hiding, Input Assertion/type Checking, Layering
Reusability	Domain Architecture-driven

Table 10. Architecture Strategies

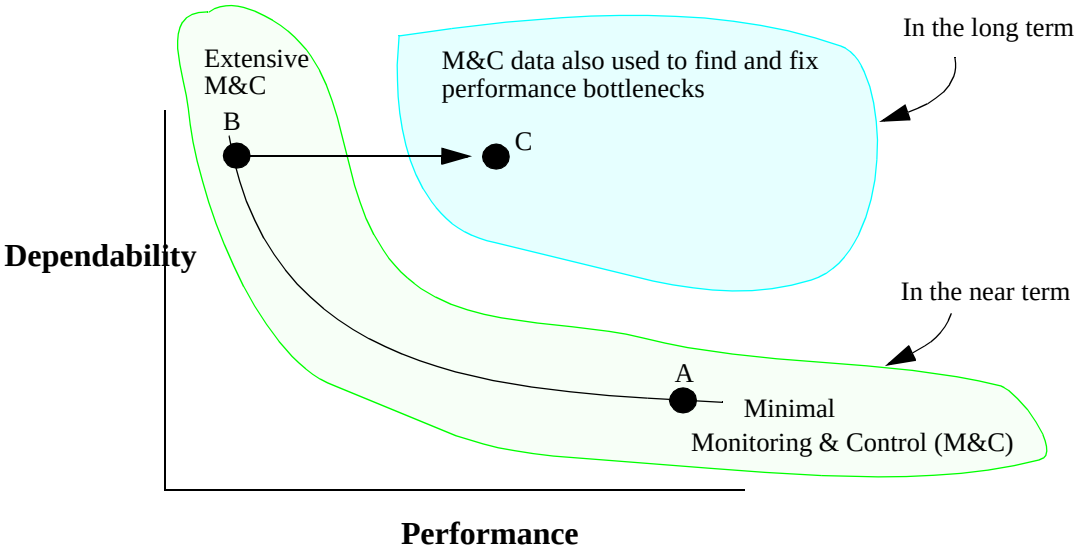


Figure 14. Performance/Dependability trades via Monitoring & Control strategy

6.0 Conflict Resolution Theories and Models for Quality Attributes

6.1 Option Creation Through Added Dimensions.

6.1.1 WinWin Conflict Resolution as the Problem Space View Model

Lee [Lee, 1996] developed a formal model for the WinWin requirements engineering process called the "*Problem Space View*", which defines a win condition as a constraint on the space R of all requirements specifications *r.* Each point *r* in R consists of a set of functional, infrastructure, and quality attribute specifications. In the model, a conflict is defined as a set of win conditions whose win regions have an empty intersection (the bottom space in Figure 15). She addressed that the conflict could be resolved by expanding stakeholders' win condition area (called "*satisfactory area*"). However, she didn't address the way of expanding their win conditions.

Based on the formal model, I propose a theory for resolving conflicts by option creation through added dimensions. The conflict in the *n* dimension space (the bottom space in Figure 15) can be resolved in the space of the $n+1^{st}$ dimension (the top space in Figure 15) by expanding stakeholders' win conditions due to the added dimension (called "*option strategy*").

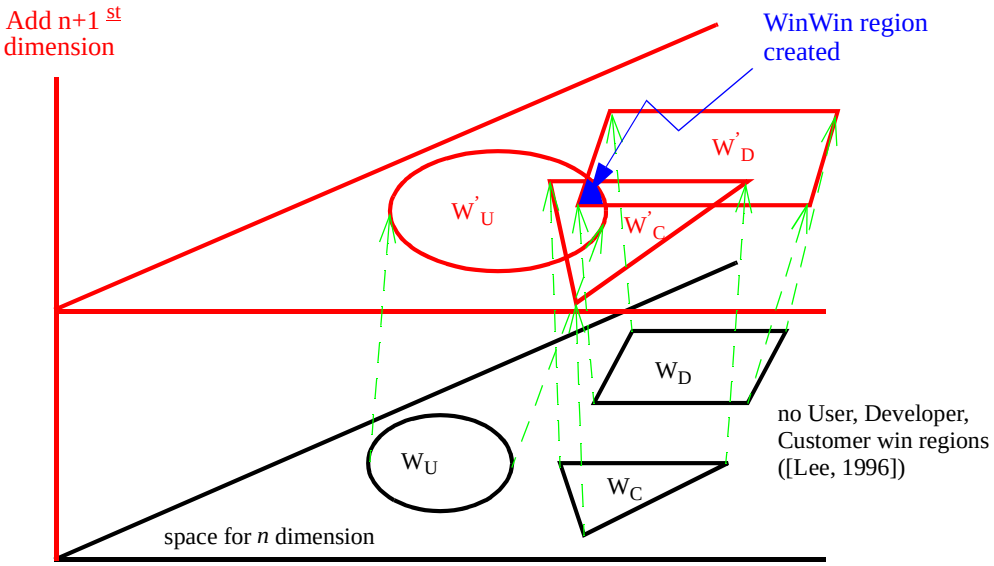


Figure 15. Conflict Resolution Through Added Dimensions

An example of a conflict situation in *n* dimension space is shown in Figure 16. The User's win condition, $W(U)_1$, consists of more than 15 functions, but the Customer's win condition, $W(C)_1$, is that the development cost should be less than $4M. The Developer's win condition, $W(D)_1$, is a reasonable expectation of work and reward (i.e., not too much work and not too little income) as estimated by a cost estimation model such as COCOMO [Boehm, 1981]. For the example, we assume for simplicity that each function costs $300K to develop. Figure 16 shows that there is no WinWin area to satisfy all stakeholders' constraints because the cost for implementing the 15 functions is estimated to be $4.5M.

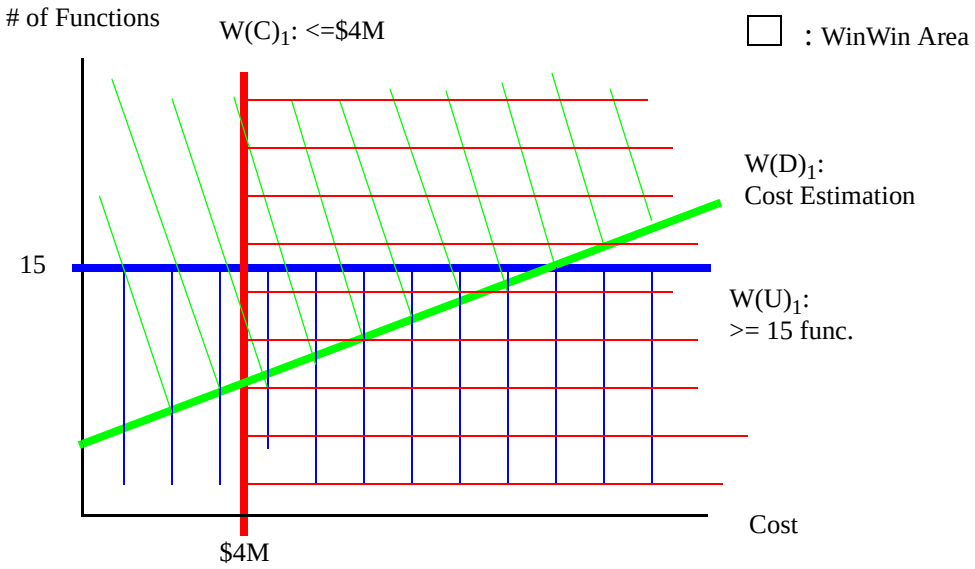


Figure 16. Conflict Situation in the Problem Space View Model

The following steps, which were used in solving the decision problem with constraints in [Boehm, 1981], represent the cost conflict situation more specifically:

1. Define objective:

   - Find the WinWin region (i.e., region which satisfies all constraint win conditions)

2. Define decision variables:

   - x_1: cost;
   - x_2: # of functions

3. Define constraints according to each win condition:

   - $g_1(x_1, x_2)$: x_1 <= $4M
   - $g_2(x_1, x_2)$: x_2 >= 15
   - $g_3(x_1, x_2)$: x_1 <= 300K * x_2 (= our assumption for simplicity)

4. Identify the WinWin region (the satisfactory area for all stakeholders):

    • No WinWin region (i.e., conflict)

5. Identify the WinWin point (the most satisfactory point for all stakeholders among the WinWin region) if the WinWin region exists.

6.1.2 Conflict Resolution Process by Option Creation through Added Dimensions

Figure 17 shows an example of resolving the cost conflict situation presented in section 6.1.1. The cost conflict situation shown in Figure 16 can be represented in the bottom space in Figure 17. The cost conflict can be resolved by creating an option, *reuse existing software assets which perform some of the 15 functions*, which is generated by an added dimension, "*reuse of software assets (%)*". The reuse of software assets can reduce development cost without reducing the number of functions the User wants to implement. This conflict resolution situation is shown in upper space in Figure 17. One of the assumptions for simplicity is that complete reuse saves the total development cost. Thus, reusing 3 functions (20% of 15 functions) saves $900K and reduces the cost to an affordable $3.6M.

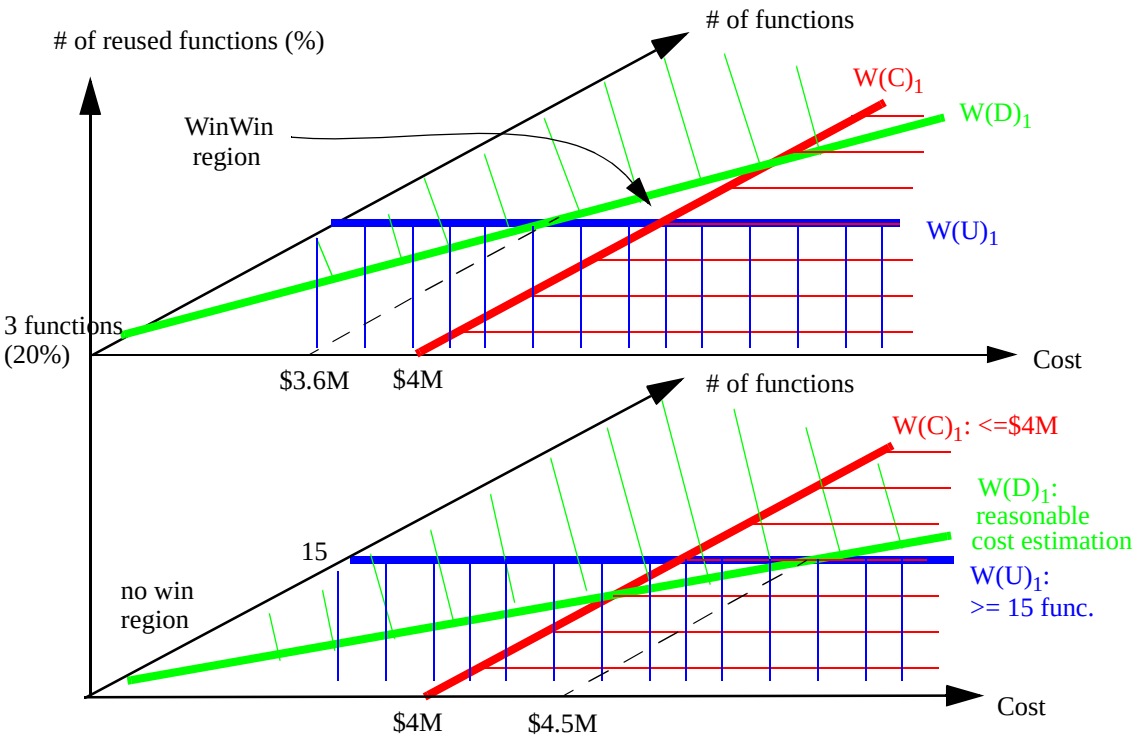


Figure 17. An Example of Cost Conflict Resolution Through Added Dimensions

Using the steps to represent cost conflict shown in section 6.1.1, the conflict resolution process by option creation through added dimension also can be represented more specifically by the following steps:

1. Define objective:

    • Find the WinWin region

2. Define decision variables:

    • x_1: cost

    • x_2: # of functions

3. Define constraints:

    - $g_1(x_1, x_2)$: x_1 <= \$4M
    - $g_2(x_1, x_2)$: x_2 >= 15
    - $g_3(x_1, x_2)$: x_1 <= \$300K * x_2

4. If there is no WinWin area (i.e., conflict), add an additional dimension, for example, x_3(= # functions covered by reuse of software assets).

    - $g_1(x_1, x_2, x_3)$: x_1 <= \$4M
    - $g_2(x_1, x_2, x_3)$: x_2 >= 15
    - $g_3'(x_1, x_2, x_3)$: x_1 <= \$300K * (x_2 - x_3)

5. Identify the WinWin region (the satisfactory area for all stakeholders):

    - x_1 <= \$4M; x_2 <= 15; 2 <= x_3 <= 3 (the blank area in Figure 17)

6. Identify the WinWin value (the most satisfactory point for all stakeholders among the WinWin region) if the WinWin region exists.

    - This step will be discussed in section 6.1.3.

Step 4 above (i.e., option creation process) can be elaborated upon in Figure 18. The input of the option creation process is a set of constraints (e.g., g_1, g_2, and g_3 shown in step 3) from win conditions, which have conflicts with each other. In other words, there is no requirements (i.e., no win-win region) which satisfy the set of constraints. If possible, the option creation process outputs a set of adjusted constraints (e.g., g_1, g_2, and g_3' shown in step 4) as a conflict resolution option after all potential

dimensions are applied into the conflicting set of constraints in order to create win-win region. Otherwise, an empty set is produced, which means that there exists no set of constraints for a win-win region.

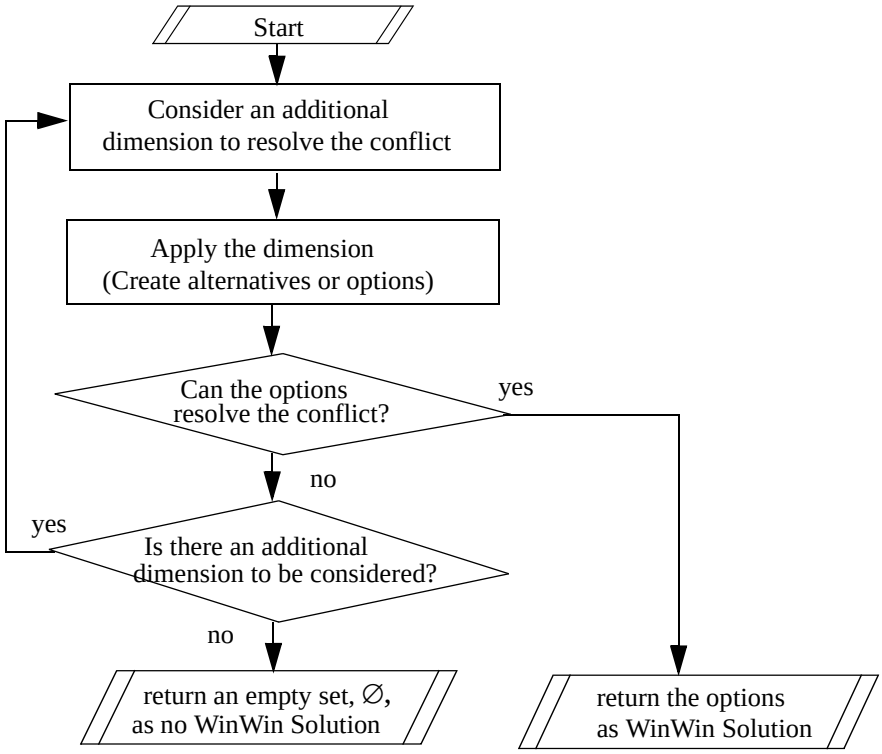


Figure 18. Overview of Conflict Resolution Process

The proposed dimensions depend on types of conflicts. Typically, there are proposed dimensions for a specific type of conflict. For example, *reducing/deferring functionality, reducing/deferring quality, relaxing schedule constraints, improving personnel capability, improving tools and platform, reusing software assets, and increasing budget* are typical means of resolving cost conflicts. It is worth while to formalize the dimensions (i.e., cost-resolution options), map them into a knowledge base, and make them available across multiple projects. These potential dimensions for cost

conflict resolution were formalized (section 6.2 and section 6.3). Also, a generalized tool based on the knowledge base of the formalized dimensions was developed (section 7.3).

A condition for applying the conflict resolution process shown in Figure 18 is that there exists "no win-win region" (i.e., conflict) which satisfies all stakeholders' constraints in terms of win conditions. Lee [Lee, 1996] proposed the formal notation for the win-win region.

$\mathbf{W_s = \{ x_1,...,x_n \mid U_S(x_1,...,x_n) > 0 \}}$ (which is adapted from [Lee 1996])
such that $x_1,...,x_n$: constraints (i.e., n-dimension),
S : stakeholders,
$U_S(x_1,...,x_n)$: stakeholder S's utility (must be > 0 for win)

Using the above formal notation and theory, the conditions for applying the conflict resolution process to enable higher-dimension win-win solutions are developed (Figure 19).

Condition-1, that the conflict cannot be resolved in existing n-dimension space, is a signal to consider using an additional dimension to resolve the conflict. Condition-2 investigates an additional dimension which can increase stakeholder's utility. If there is no such additional dimension, an empty set (i.e., no win-win solution) is returned as shown in Figure 18. In a USC-UCLA football game, for example, there is no consolation prize which makes loss of the game preferable. If there is such an additional dimension, Condition-3 can be considered to reduce win region gap by the utility added in the higher dimension. Simultaneously, Condition-4 should be considered to avoid reducing win regions for other stakeholders by the utility added in the higher dimension.

Condition-1: No win-win solution in existing n-dimensional space

$\nexists \quad x_1,...,x_n: U_S(x_1,...,x_n) > 0$, for all stakeholders, S

Condition-2: An additional dimension exists which provides added utility to stakeholders.

$\exists \quad S, x_d : U_S(x_1, ..., x_n, x_d) > U_S(x_1,...,x_n)$

Condition-3: The utility added in the higher dimension has the potential to bridge the win-region gap.

$\exists \quad S_0, x_1,...,x_n, x_d : U_{S0}(x_1, ..., x_n, x_d) > 0$

$U_S(x_1,...,x_n) > 0, S \neq S_0$

Condition-4: The extra dimension does not adversely reduce win regions for other stakeholders.

$\nexists \quad S_0, x_1, ..., x_n, x_d, S' : U_{S0}(x_1, ..., x_n, x_d) > 0$

$U_{S'}(x_1, ..., x_n, x_d) < 0$

Figure 19. Beginning of Theory: Conditions Enabling Higher-Dimension Win-Win Solutions

A more formalized algorithm of option creation through added dimension is shown in Figure 20. However, the algorithm is only applicable to following problems: i) how to determine the added dimensions for option creation, ii) how to get a set of constraints adjusted by a dimension value, iii) how to deal with concurrent process

(synchronization problem), and iv) what to do if all potential dimensions could not resolve the conflict.

6.1.3 Determining the WinWin Value

One of the problems in the conflict resolution process is how to determine a particular recommended WinWin value among the WinWin region. Unlike determining an optimal value in the classic decision problems [Boehm, 1981], each stakeholder may have different objective functions of their own, which make it difficult to determine a single agreeable WinWin value (i.e., the optimal value in [Boehm, 1981]) for all the stakeholders. For example, suppose that the stakeholders' objective functions shown in Figure 21 are the following:

- For User: To maximize the number of functions within the WinWin region
- For Customer: To minimize the development cost within the WinWin region
- For Developer: To maximize the development cost (i.e., income for Developer) and to minimize the number of functions (i.e., little work for Developer) concurrently.

Algorithm: **`WinWin_Option_Creation (CONST)`**

// Determine a set of dimensions which help conflict be resolved by relaxation of some constraints in CONST
DIM ← {d_j | d_j is a potential dimension to release some constraints in **CONST**}

// Consider each dimension in DIM
For each DIM_i in **DIM**

// Picp up a set of representive values in the considered dimension and save it into DV.
DV ← {DV_j | DV_j is a representive value of DIM_i}

// Consider each representive value in DV
For each DV_j in **DV**

// Adjust a set of constraints with the representive value, DV_j, and save it AdjustedCONST.
AdjustedCONST ← Adjust_Constraints (DV_j, **CONST**)

// Determine requirements which satisfy the adjusted constraints. Save them into AdjustedWWR If there is no such requirements (i.e., conflicts), the AdjustedWWR becomes a empty set, ∅.
AdjustedWWR ← {r_k | a requirement, r_k, satisfies **AdjustedCONST**}

// If there are requirements (i.e., WinWin option), then return the requirements as WinWin option and exit.
If **AdjustedWWR** ≠ ∅ then
return **AdjustedWWR**

EndFor

EndFor

// return an empty set (i.e., there is no WinWin option among inputed constraints, CONST).
return ∅

// return a set of constraints adjusted from a set of constraints, **CONST**, in a value of added dimension, DV_j
SubAlgorithm: **`Adjust_Constraints (DVj, CONST)`**

ReturnedCONST ← ∅
For each $CONST_i$ in **CONST**

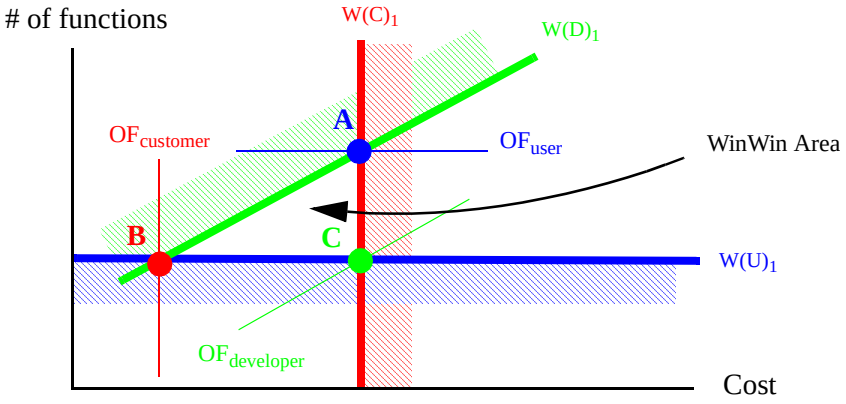
// If a constraint, $CONST_i$, is affected by a dimension value, DV_j, adjust the constraint with the value and add it into ReturnedCONST. For example, a constraint which was shown in the step 3 on page 59, $g_3(X_1,X_2)$: X_1 <= \$300K * X_2, was adjusted into $g_3'(X_1,X_2)$: X_1 <= \$300K * X_2 - \$25K * X_3 shown in step 4 on page 59, such that X_1 = development cost (\$), X_2 = # of functions, and X_3 = reuse of software (%).
If DV_j is a value of the dependent variable for $CONST_i$
AdjustedCONST ← Adjust $CONST_i$ by DV_j
ReturnedCONST ← **ReturnedCONST** ∪ {AdjustedCONST}

// If a constraint, $CONST_i$, is not affected by a dimension value, DV_j, add the constraint into ReturnedCONST without any change.
else
ReturnedCONST ← **ReturnedCONST** ∪ {$CONST_i$}

EndFor
return **ReturnedCONST**

Figure 20. An Algorithm of Conflict Resolution by Option Creation Through Added Dimensions

The potential WinWin value is point A for the User, point B for the Customer, and point C for the developer. It is difficult to determine a WinWin value which satisfies all stakeholders concurrently.



* OF: Objective Function; A,B,C: Optimal values for each stakeholder

Figure 21. Determining the WinWin Value

From the viewpoint of risk management, the potential optimal value is somewhere in the middle within the WinWin region rather than the edge of the WinWin region for the following reasons:

- The point A has a risk of cost overrun because of uncertainties of cost estimation.
- The point B has a risk of not using the software for users due to low capabilities of the software, and
- The point C has a risk of losing the contract for the next project if another vendor offers lower cost or more functionality

Another approach to determine the optimal WinWin value is the addition of more constraints, so that the WinWin region is reduced, and risk management techniques are applied to sharpen the WinWin region.

6.2 Relation to S-COST Resolution Strategies

S-COST is a knowledge-based tool that helps stakeholders analyze conflicts, draft, and negotiate options for resolving cost conflicts.

S-COST is a potential support tool for resolving cost conflict by option creation through added dimensions. For example, the cost conflict (e.g., cost overrun for implementing all proposed functions) shown in section 6.1 was resolved by option creation through an additional dimension (e.g., reuse of existing software which performs the functions). S-COST suggests the potential dimensions (called "S-COST Resolution Option Strategies) to resolve the such cost conflicts to stakeholders.

Table 11 shows the top-level option strategies for resolving cost conflicts. The strategies are primarily based on the analysis of the COCOMO cost drivers [Boehm, 1981] whose labels are shown in column 2 of Table 11.

- *Reduce/defer functionality.* This reduces cost by reducing the program (KDSI) and/or database (DATA) size, at least for the Initial Operational Capability (IOC).
- *Reduce/defer software quality.* This reduces cost by relaxing reliability (RELY) or performance (TIME) constraints, by forgoing the complexities (CPLX) of providing graceful degradation or information security, or by reducing documentation (DOCU).

- *Improve tools, techniques or platform.* This involves the use of a platform that is more powerful (TIME, STOR) or stable (VIRT); or via better software tools (TOOL).
- *Relax the delivery schedule constraint* (SCED).
- *Improve personnel capabilities.* This involves the use of more capable teams of analysts and programmers (ACAP, PCAP); stronger applications, platform, or language experience (AEXP, VEXP, LEXP), or equivalent but lower-cost personnel ($K/MM).
- *Reuse software assets.* This involves the reuse or adoption of more software assets (ADSI), with lower levels of design, code, or integration modification (DM, CM, IM).
- *Improve coordination of multiple project stakeholders as a team.* This involves synchronizing the project stakeholders by reconciliation of different objectives and culture and having experience in operating as a team (TEAM).
- *Architecture and risk resolution.* This reduces rework cost through risk assessment and control, and architecture thoroughness which includes verification of architectural specifications (RESL).
- *Improve process maturity level.* This reduces cost through SEI (Software Engineering Institute)'s CMM (Capability Maturity Model) (PMAT). Exercising this option involves choosing alternative suppliers, as process maturity cannot be increased instantaneously.

- *Improve precedentedness and development flexibility.* This reduces cost via improving organizational understanding of project objectives and experience in working with related software (PREC), or via eliminating the need for software conformance with pre-established requirements and with external interface specifications (FLEX).
- *Increase budget*. This can be justified if the current win condition budget is insufficient to generate a critical-mass competitive product, or if the return on investment (ROI) is sufficiently increased. Of course, this option strategy cannot be used if added funds are not available (These points illustrate the option strategy's Pros and Cons shown in columns 3 and 4 of Table 11)

S-COST uses the basic suggested S-COST Resolution Option Strategies as default to draft Option artifacts in WinWin for resolving the cost conflicts.

6.3 The Formalism of the "S-COST Resolution Strategies"

Table 11 shows the abstract level of suggestions for the option creation to resolve cost conflicts. However, in order to resolve the cost conflicts in a specific project situation, a more detailed and formalized structure for S-COST resolution option strategies is necessary. The formalized structure also helps stakeholders communicate with each other more effectively for achieving agreements.

Option Strategies	COCOMO Parameter	Pros	Cons
Reduce/defer functionality	KDSI, DATA	• Reduce cost, IOC, and schedule • Smaller product to maintain	• Capabilities unavailable to stakeholders • Need to pay later if deferred
Reduce/defer quality	RELY, CPLX, TIME, DOCU	• Reduce cost, schedule, and complexity	• Stakeholders lose quality capabilities
Improve tools, techniques, platform	TIME, STOR, VIRT, TOOL, SITE	• Reduce s/w cost and schedule • Improve maintainability and other qualities	• Increase tool, training, platform costs • Reducing tool, platform experience would increase s/w cost
Relax schedule constraint	SCED	• Reduce cost if schedule was tight	• Defer stakeholders use of product capabilities
Improve personnel capabilities	ACAP, PCAP, AEXP, VEXP, LEXP, $K/PM	• Reduce cost and schedule • Improve quality	• Projects losing better people will suffer • Potential staffing difficulties and delays • Increased cost/person-month unless low-cost outsourcing
Reuse software assets	ADSI, DM, CM, IM	• Reduce cost and schedule • May gain quality	• Stakeholders may lose quality capabilities • Risk of overestimating reuse
Improve coordination of teambuilding	TEAM	• Reduce cost and schedule by removing the inter-personnel overhead	• Uncontrollable for some situations
Architecture and risk resolution	RESL	• Reduce cost and schedule by avoiding rework	• Additional overhead for risk management is necessary.
Improve process maturity level	PMAT	• Reduce cost and schedule by removing the efforts for fixing errors • Improve quality	• Additional overhead for applying CMM is necessary
Improve precedentedness and development flexibility	PREC, FLEX	• Reduce cost and schedule by familiarity and flexibility of software development	• Uncontrollable for some situations
Increase budget	Revised win condition	• May enable product to reach competitive critical mass • May increase ROI	• Added funds may not be available

Table 11. Cost-Resolution Option Strategies

The proposed formal structure based on the COCOMO cost drivers is following:

```
Option-Strategy-Name (Module-Name,
    COCOMO cost driver,
    the value before the strategy is applied,
    the value after the strategy is applied,
    pros of the strategy,
    cons of the strategy,
    the reduced cost,
```

Each stakeholder suggests how much the COCOMO cost drivers for the Option Strategies should be changed (e.g., COCOMO cost driver, the value before and after the Strategies are applied). Given the information from stakeholders, S-COST produces the pros and cons of the Strategies using the knowledge base for the Option Strategies and the reduced cost and schedule using COCOMO. The knowledge base for suggesting the pros and cons of the Strategies has default knowledge, but it can be refined and situated from project to project.

In order to reduce the difference between the estimated development cost and the target development cost, several different strategies can be composed until the target cost is reached. For example, the following strategies can be composed to reduce $1.66M of the difference in an experimental project, STRIKEWARE, which will be explained in detail in section 7.3.3.

- Defer_functionality (SS/WB_Query/Display_(new), KDSI, 14000 SLOC, 8000 SLOC, “Reduce cost, IOC, and schedule; Smaller product to maintain”, “Capability unavailable to stakeholders; Need to pay later if deferred”, $438K, 0.46M)

- Defer_functionality (MDIF Priority Upgrades, KDSI, 26000 SLOC, 17000 SLOC, “Reduce cost, IOC, and schedule; Smaller product to maintain”, “Capability unavailable to stakeholders; Need to pay later if deferred”, $664K, 0.72M)
- Increase_budget (STRIKEWARE project, Budget, $5000K, $5379K, “May enable product to reach competitive critical mass; May increase ROI”, “Added funds may not be available”, -$379K, -0.42M)

6.4 Stakeholder/ S-COST Resolution Strategies Relationships

Like the Stakeholder/Quality Attribute relationship shown in Figure 9, understanding Stakeholder/Option_Strategy relationship is useful reducing the complexity of option negotiation.

For example, reducing reliability or performance may be acceptable options for some stakeholders but not for others. S-COST uses the Stakeholder/ Option_Strategy relationships in Figure 22 to notify the appropriate stakeholders of options which may have first-order consequences for them. For example, “Increase budget” can potentially affect any of the stakeholders by providing them with more capability, but the directly-concerned stakeholder is the Customer, who must find a way to justify and obtain the budget increase.

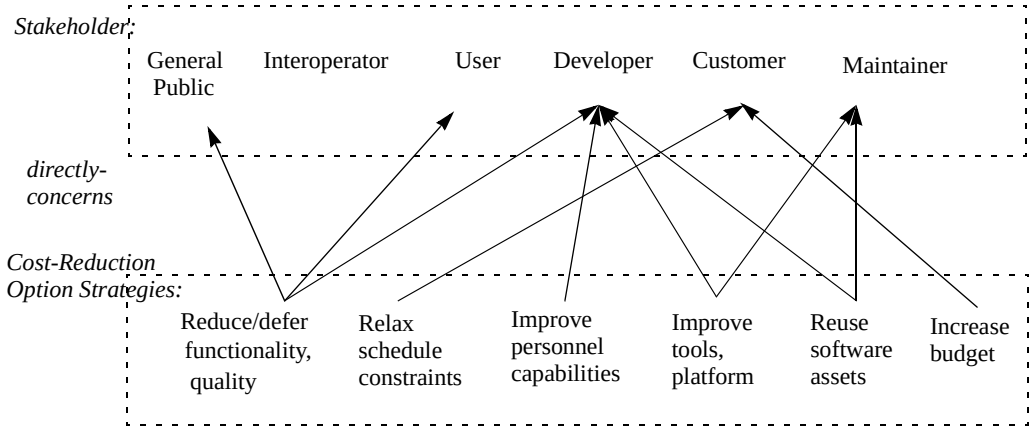


Figure 22. Stakeholder / Option_Strategy Relationships

Like Stakeholders' Roles & Responsibilities / Quality Attribute Concerns relationship shown in Table 6, S-COST also provides the Stakeholders' Roles & Responsibilities / Option Strategy Concerns relationship shown in Table 12 to rationalize the primary concerns on the S-COST Option Strategies. For example, one of the User's primary concerns on the S-COST Option Strategies is *Reduce/defer functionality and quality* because the User's roles and primary responsibilities are to execute cost-effective operational missions of the system. *Relax schedule constraints*, however, can be considered as a secondary concern because the strategy affects the delivery due date of the system to the User.

The primary concerns of a stakeholder are directly related to the stakeholder's roles and responsibilities. However, the secondary concerns are indirectly related to the stakeholder's roles and responsibilities. For example, *Relax schedule constraints* and *Increase budget* can be primary concerns for a Customer because the Customer's primary roles and responsibilities are avoiding overruns in the budget and schedule, but *Improve*

personnel capabilities, *Improve tools and platforms,* and *Reuse software assets* can be secondary concerns because the Customer does not take responsibilities for the problems (e.g, *Is a programmer having high capability available, Are tools or platforms available to reduce development cost, or Are there reusable software assets?)* even though these strategies could reduce budget and schedule indirectly.

There are no primary concerns for an Interoperator because the Interoperator's roles and responsibilities, *avoiding current and future interface problems between system and interoperating system*, are not directly related to the proposed cost resolution option strategies. However, the reduced quality by applying *Reduce/defer quality* strategy could make the interface problems more difficult. So the *Reduce/defer quality* strategy could be a secondary concern for the Interoperator.

However, the primary and secondary concerns are not absolute for all projects. There are some variations from project to project. Nevertheless, there are benefits for identifying the relationship between Stakeholders' Roles and Option Strategies. One of the benefits is to remind the stakeholders of their roles and responsibilities when they draft and negotiate cost resolution options. Another is to be able to negotiate more effective by identifying which concerns apply to which stakeholders.

Stakeholder	Roles and Primary Responsibilities	Cost Option Concerns	
		Primary	Secondary
General Public	Avoid adverse system side-effects: safety, security / privacy.	Reduce/defer quality	Reduce/defer functionality; Reuse software assets
Interoperator	Avoid current and future interface problems between system and interoperating system		Reduce/defer quality
User	Execute cost-effective operational missions	Reduce/defer functionality; Reduce/defer quality	Relax schedule constraints
Maintainer	Avoid low utility due to obsolescence; Cost-effective product support after development	Improve tools, platform; Reuse software assets	Reduce/defer quality; Relax schedule constraints
Developer	Avoid cost overrun for software development due to poor personnel capability and poor tool support; Avoid duplicated effort to the same function.	Reduce/defer functionality; Improve personnel capabilities; Improve tools, platform; Reuse software assets	Reduce/defer quality; Relax schedule constraints; Increase budget
Customer	Avoid overrun budget and schedule	Relax schedule constraints; Increase budget	Reduce/defer functionality; Reduce/defer quality; Improve personnel capabilities; Improve tools, platform; Reuse software assets

Table 12. Stakeholder Roles / Option Strategy Concerns Relationship

7.0 The Support Tools: QARCC and S-COST

7.1 Overview of the Support Tools

QARCC (Quality Attribute Risk and Conflict Consultant) is proposed as an aid for the identification of quality conflicts based on the models shown in section 5.0. S-COST (Software Cost Option Strategy Tool) is also proposed as an aid for resolving cost conflicts based on the models shown in section 6.0.

Figure 23 shows how these support tools can assist stakeholders in drafting Issues (by QARCC), Options (by S-COST: option generation phase), and Agreements (by S-COST: option negotiation phase) in the WinWin Negotiation Model shown in Figure 4.

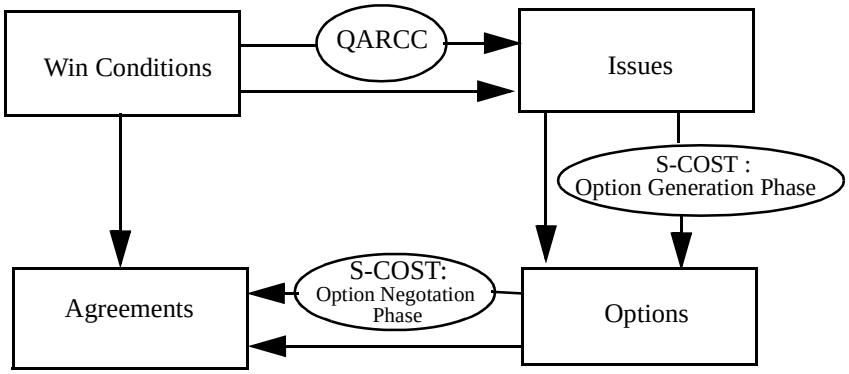


Figure 23. Overview of the Support Tools: QARCC & S-COST

7.2 A Top-level Support Tool: QARCC

7.2.1 Context

QARCC is a knowledge-based tool that assists stakeholders (e.g., users, developers, and customers) in the analysis of software requirements and the identification of quality conflicts among them.

QARCC operates in the context of the USC-CSE WinWin system, a groupware support system for determining software and system requirements as negotiated win conditions.

For each win condition of quality attributes surfaced by WinWin, QARCC identifies the architecture and process strategies for achieving the desired quality attribute based on the left-hand side of the knowledge base (Figure 8). For each strategy, it uses another part of its knowledge base to identify potential conflicts with other quality attributes that could arise if the strategy was employed. It then provides suggestions to stakeholders on these potential quality attribute conflicts.

7.2.2 Concept of Operation

Figure 24 shows the QARCC concept of operation for identifying potential quality-attribute conflicts, flagging them for affected stakeholders, and suggesting options for their resolution.

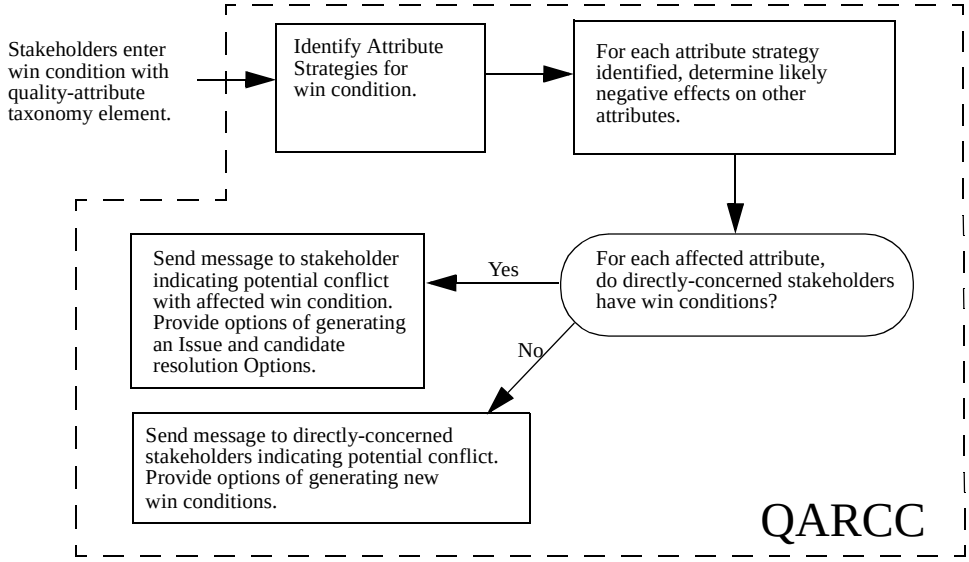


Figure 24. The QARCC Concept of Operation

QARCC is triggered by a stakeholder entering a new win condition with a quality-attribute taxonomy element (e.g., Portability in screen 1 of Figure 25). For this desired attribute, QARCC first considers its product and process strategies as given in Table 8 (e.g., Layering to achieve Portability). It then examines these strategies to search for potential conflicts with other attributes.

QARCC determines these potential conflicts from the portion of its knowledge base summarized in Table 9. For example, Layering produces likely conflicts with Cost/ Schedule and Performance. These are shown in the Potential Conflict List in screen 2 of Figure 25 (In the initial implementation, QARCC, Cost and Schedule were combined into Development Affordability, and Performance was called Efficiency).

QARCC then uses the relationships shown in Figure 9 to identify the stakeholders affected by these potential conflicts (Developer and Customer for Cost &

Schedule; User and Customer for Performance). For these stakeholders, QARCC pops up the *Conflict Advisor Note* window (screen 2) which shows a message to directly-concerned stakeholders indicating a list of potential conflicts with the new win condition in list form (Potential Conflict List shown in screen2). The list also enumerates the existing win conditions having one of the conflicted attributes in its Taxonomy Elements slot. If there are no existing win conditions for a conflicted attribute, a "Missing win condition" message is shown. For example, Development Cost has two existing win conditions, hohin-winc-5 and hohin-winc-9, whereas Dependability and Usability do not have any.

For existing affected win conditions, the stakeholder can select them with the mouse and then click on the *Create Issue* button to have QARCC draft an Issue artifact (screen 3). If no affected win conditions exist, the stakeholder can click on the *Create WinC* button to have QARCC draft a win condition artifact (screen 4).

An example of the draft material produced by QARCC is shown in the *Other's Comments* field of screen 3, which cautions the stakeholders that Affordability strategies such as reuse will conflict with the Portability win condition if the reused software is not portable.

By clicking the *Options* button at the bottom of screen 3, the stakeholder can have QARCC draft a set of candidate resolution Options (left window in screen 5). QARCC suggests six Options from its knowledge base: i) "Reduce or defer product functions"; ii) "Find, incorporate some relevant reusable software"; iii) "Find, engage expert performers"; iv) "Use design-to-cost process; Identify lower priority features to

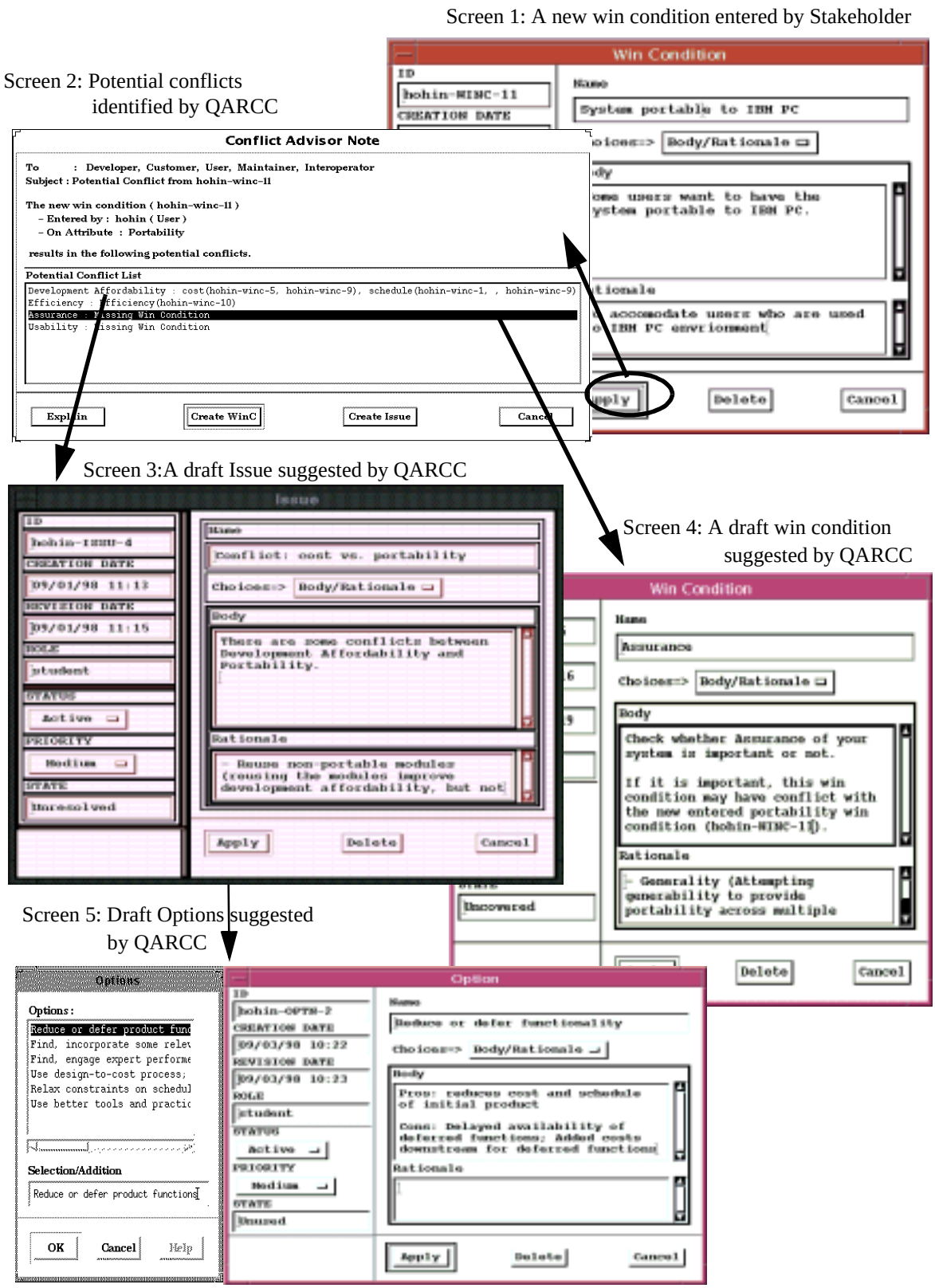


Figure 25. An Example of the Initial Implementation of QARCC

defer if necessary"; v) "Relax constraints on schedule, performance, hardware, and other attributes"; and vi) "Use better tools and practices" to resolve the conflict between Cost/ Schedule and Portability. As the Options are generalized, stakeholders can tailor them to their needs. QARCC also drafts pros and cons for the Options (right window in screen 5), helping the stakeholders to evaluate the Options and to converge on a mutually satisfactory (i.e., win-win) Option, which is adopted by an Agreement.

7.2.3 Experiment Results

7.2.3.1 Experiment Scenario

QARCC has been applied to several hypothetical projects, primarily in the area of Satellite Ground Stations. The experiment described here involved applying QARCC retroactively to the win conditions for a representative Software Engineering Environment (SEE) to support a Satellite Ground Station (SGS) product line.

The representative Developer was a workstation vendor's CASE division, the representative User was a large Aerospace Ground Systems Division, and the representative Customer was the hypothetical U.S. Space Systems and Operations Command.

The multi-stakeholder WinWin exercise generated 21 win conditions, including the following:

- SGS domain extensions to general SEE (SEE-GEN)
- SGS workload modeling, information flow simulation (SIMU)
- SGS-domain test simulators, test/debug tools (TEST)

- SGS workstation usage scenario generation (USAGE)
- SGS-domain data reduction and reporting (DR&R)
- Initial operational capability (IOC) cost below $7M and within 25 months
- Interoperable SEE functions and tools
- Low development risk; Low maintenance cost; easy to modify
- Commercializable middleware and commercially supported SEE to improve Evolvability
- Broadly applicable across product line to improve Evolvability

The main objective of the WinWin exercise was to determine the ability of WinWin to support renegotiation of a new win-win equilibrium solution once a new win condition was added to the base of 21 in-equilibrium win conditions. The new win condition, "Support the development of multi-mission satellite ground stations," caused a cost and schedule conflict with the previous equilibrium negotiated. After determining that WinWin could successfully support such a renegotiation [Boehm et al., 1995], we decided to apply QARCC to the body of win conditions to see how many potential conflicts it would identify.

First, we wanted to see if QARCC would identify the two conflicts used in the renegotiation process. These were conflicts of Cost/Schedule with Evolvability and Interoperability, which were used by the stakeholders to reject an option to recover cost and schedule by reusing some legacy software which was deficient in Evolvability and Interoperability. Second, we wanted to see if QARCC would surface other potential

conflicts, and if so, how many of them would have significant relevance to the satellite ground station system.

7.2.3.2 Results

The results are shown in Table 13 below. QARCC did find the two significant conflicts which surfaced in the WinWin exercise. In addition, it found eight more potential conflicts. Five of these were considered significant in the satellite ground station situation: conflicts of Cost/Schedule with Dependability, Performance, and Reusability; and conflicts of Interoperability and Evolvability with Performance. Three further potential conflicts were not considered significant: conflicts of Evolvability with Dependability and Usability, and a conflict of Cost/Schedule with Usability. These three "false alarm" situations are candidates for addition into the knowledge base, if the potential-conflict threshold for them was set too low for most other situations so that they would be more time-consuming than beneficial. Prioritizing stakeholders' interests in quality attributes can reduce the "false alarm" situations.

	Not Found by QARCC	**Found, Significant**	**Found, Insignificant**
Experiment 1: WinWin user exercise **WITHOUT QARCC**	0	2	0
Experiment2: WinWin user exercise **WITH QARCC**	0	2 + 5	3

Table 13. Conflicts Identified by QARCC

7.2.4 Lessons Learned

The primary conclusions from the initial QARCC experiment were:

- QARCC can help users, developers, customers, and other stakeholders to identify conflicts among their software quality requirements, and to identify additional potentially important quality requirements. In the experiment, QARCC found both of the quality conflicts previously identified, plus five others considered significant.
- QARCC needs further refinement to avoid overloading users with insignificant quality conflict suggestions. In the experiment, QARCC found three potential conflicts which were considered insignificant.

Two additional conclusions are derived from feedback based on demonstrations of QARCC to about 30 USC-CSE's industry and government Affiliates. There was a strong consensus that QARCC provided a useful framework for stakeholders to systematically identify software quality attribute conflicts, and that the semi-automated approach provided a good way to balance human skills and computer tools in addressing quality tradeoff issues.

7.3 A More Detailed Support Tool: S-COST

7.3.1 Context

S-COST is a knowledge-based tool that helps stakeholders (e.g., users, developers, and customers) analyze cost conflicts, and to draft and negotiate options for resolving cost conflicts. S-COST operates in the context of WinWin, QARCC, and COCOMO (COnstructive COst MOdel).

S-COST extends WinWin and complements QARCC by using an additional software cost knowledge base related to another component of WinWin: COCOMO. S-COST uses the COCOMO cost drivers (i.e., the parameters for adjusting the COCOMO model), cost estimates, and related experience to sharpen QARCC's identification of cost-conflict Issues. It also suggests in-depth cost-conflict resolution options, and provides option visualization and negotiation aids to help stakeholders resolve the cost-conflict Issues.

7.3.2 Concept of Operation

The S-COST concept of operation is shown in Figure 26. Using the WinWin system, stakeholders enter their new win conditions. These may involve functions, quality attribute goals or constraints. As shown in screen 1 of Figure 25, win condition schemas have attributes such as Priority and domain Taxonomy Elements. For win conditions with quality attribute and cost/schedule Taxonomy Elements, QARCC examines its architectural and process strategies (Table 8) to search for potential conflicts. For example, Layering the architecture to meet the Portability win condition in screen 1 of Figure 25

produces likely conflicts with Cost/Schedule and Performance (screen 2 of Figure 25; in the initial version of QARCC, Cost and Schedule were combined into Development Affordability, and Performance was called Efficiency). QARCC then generates an issue identifying this potential conflict for stakeholders to consider (screen 3 of Figure 25).

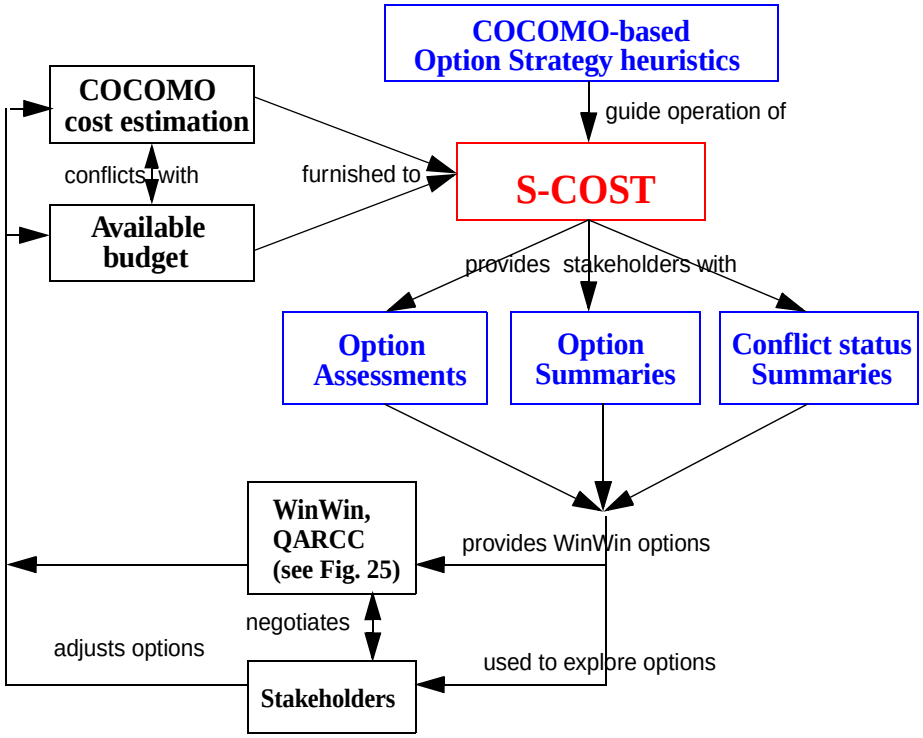


Figure 26. The S-COST Concept of Operation

Continuing with the scenario in Figure 26, once stakeholders are presented with a set of issues from QARCC involving available budget, they can then use COCOMO to analyze potential cost conflicts. If the COCOMO cost estimation conflicts with available budget, stakeholders enter this as a WinWin issue whose solution needs to be negotiated by the stakeholders.

As indicated in Figure 26, S-COST guided operation of COCOMO-based Option Strategy heuristics provides stakeholders with:

- Option Assessments: suggesting potential options for resolving cost issues,
- Option Summaries: providing a summary of which-option-strategy-can-reduce-how-much,
- Conflict status Summaries: providing a summary of other stakeholders' options to negotiate.

Based on the above capabilities, each stakeholder explores options to resolve cost conflicts and draft some WinWin options. Stakeholders negotiate their draft options in WinWin. After the stakeholders converge on a mutually satisfactory (win-win) combination of options, they draft a WinWin agreement schema, and follow WinWin's procedures for voting on and adopting the agreement.

7.3.3 Experiment Results

7.3.3.1 Overview of Experiment Scenario

The S-COST visualization and negotiation aids will be illustrated with respect to a satellite data processing scenario. In the scenario, the user, customer, and developer of a system called Strikeware have negotiated a $5 million, 16-month upgrade to add Satellite Surveillance data services to a Mission Data Integration Facility (MDIF). The Strikeware user has determined that it will be important to add weather data services to the MDIF upgrade. A COCOMO estimate of the resulting added software indicates a $6.66 M

cost and 17.6 month schedule, but the customer is strongly constrained to keep to the original $5M cost and 16 month schedule.

S-COST has several capabilities to help the stakeholders determine cost reduction options, visualize their impact on the problem situation, and negotiate a new win-win solution. For example, the Visualization window for option generation in Figure 27 shows the cost reduction target of $5M as a * mark. It uses data on the priorities of the stakeholders' functional module win conditions, and the corresponding COCOMO estimates of the module's cost contribution, to produce a display of module cost contributions by priority.

Using this display, the stakeholders could simply agree to drop or defer the lowest-priority modules until the cost target is reached. But there may be better options, such as splitting a module into higher and lower priority modules via the *Operations* button; or adjusting other cost drivers such as personnel capability and experience, improved tools, or software reuse via the *Resolution Strategies* button. Or, if justified and feasible, the customer could increase the budget, raising the target cost in the *Target Cost* field (Figure 27).

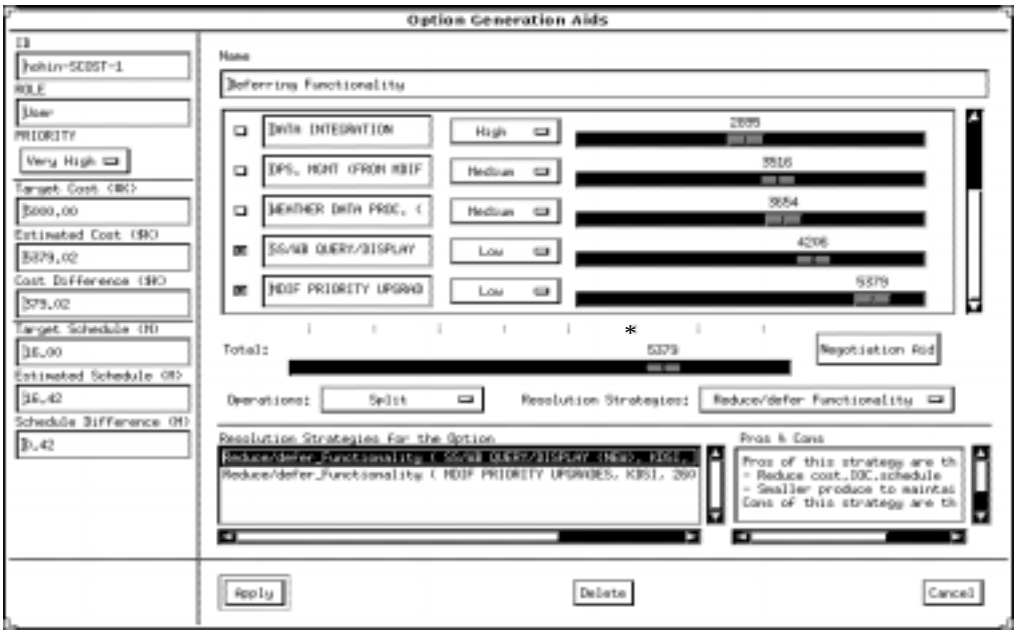


Figure 27. Visualization Window for Option Generation

7.3.3.2 Scenario for Option Generation

The S-COST Visualization window in Figure 27 has a number of option strategies and display aids for stakeholders. Some selected features are highlighted below.

After Function Elements (FEs) in the FE window (right top) are imported from COCOMO modules, they are sorted by the priority using “Sort-by-Priority”, one of the *Operations* buttons, based on the user-determined FEs. COCOMO-estimated cost and schedule appear in the left window, *Status Area*, along with User’s Id & Role, Priority of Option, and target cost & schedule. The *Operations* button is available to enable stakeholders to split, merge, insert, delete, and sort FE(s), as well as select_all, unselect_all, import, and export from/to COCOMO.

The *Strategies* button brings up a menu containing the cost resolution strategies described in Table 11. Each strategy has parameters which can be defined or adjusted once the strategy has been selected. Figure 28 shows an example of applying a "Reduce/defer functionality" *Strategy* option. Option Strategies are prepared to defer 6 KDSI of Query/Display (New) functionality and 9KDSI of MDIF Priority Upgrades functionality. The Pros & Cons area shows the potential positive and negative aspects of the option. If the stakeholder establishes this as an Option to be addressed in the WinWin system, the Pros & Cons will be included in the Option schema.

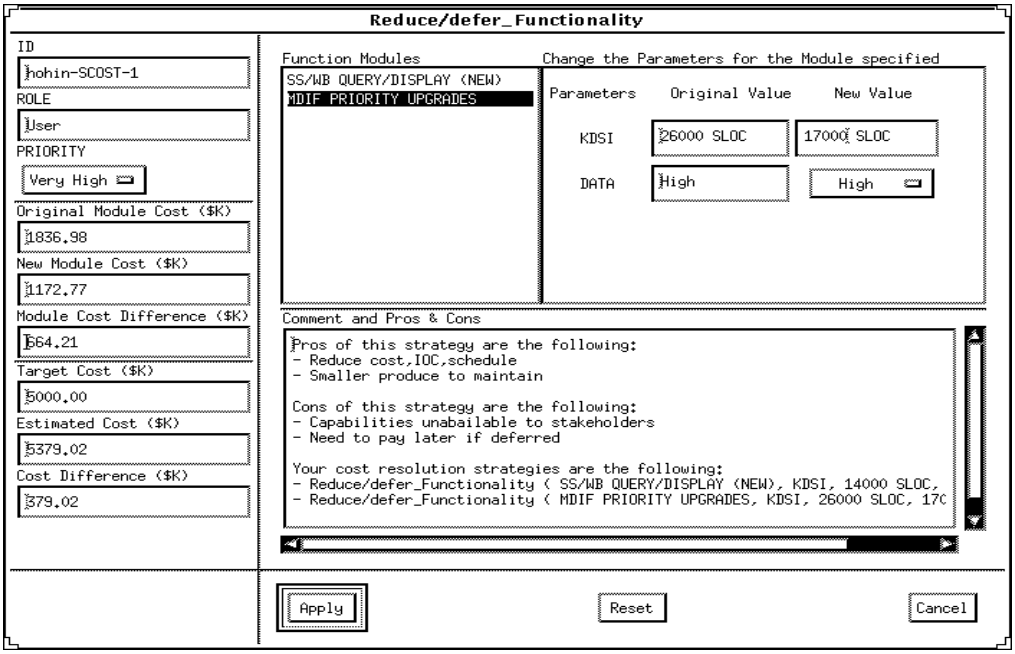


Figure 28. Aids for Applying Cost-Resolution Strategy

7.3.3.3 Scenario for Option Negotiation

Another visualization aid (obtained via the *Negotiation Aid* button in Figure 27) provides the Option Strategy list (Figure 29), which summarizes the status of negotiating a combination of Option Strategies suggested by the various stakeholders. The Options can be displayed in order of originating stakeholders, the Option Strategies' priority, or the type of the Option Strategy via the *Options* button. Stakeholders can revise their options after considering other stakeholders' strategies and their priorities. This helps stakeholders reach a win-win combination of Cost-Resolution Strategies.

The stakeholders continue to interact with S-COST and each other until they converge on a win-win cost reduction strategy with no win-lose side effects. At that point, the stakeholders can return to the WinWin system to draft, vote on, and adopt an Agreement resolving the Issue.

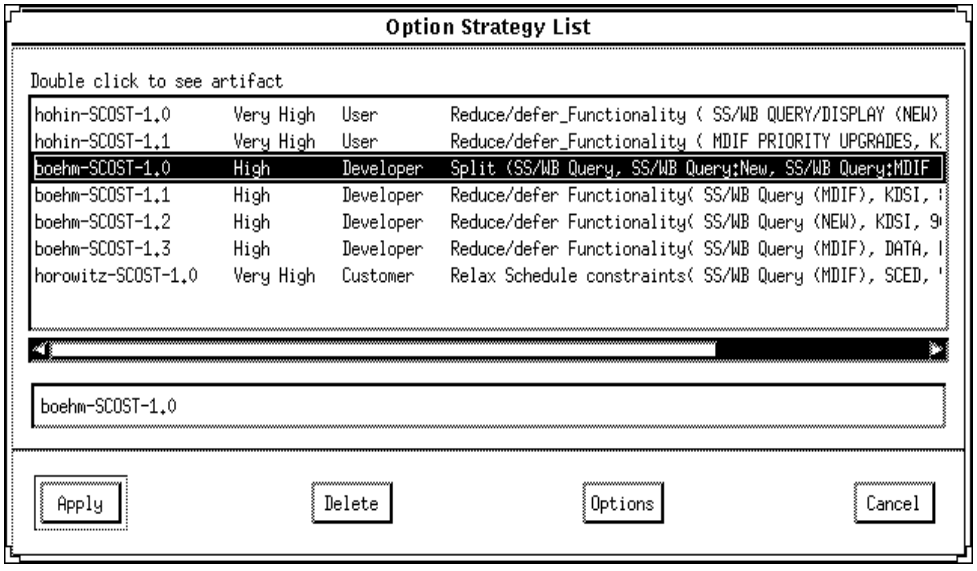


Figure 29. Visualization Window for Option Negotiation

7.3.3.4 Results

We have done a comparative analysis of the options surfaced by stakeholders in the initial WinWin Strikeware exercise and the options generated and analyzed by S-COST. S-COST provides a more thorough set of candidate cost-resolution options and analysis of their pros and cons. On the other hand, S-COST could not generate situation-specific options, such as the User deciding to break up the Query/Display module into higher and lower priority submodules.

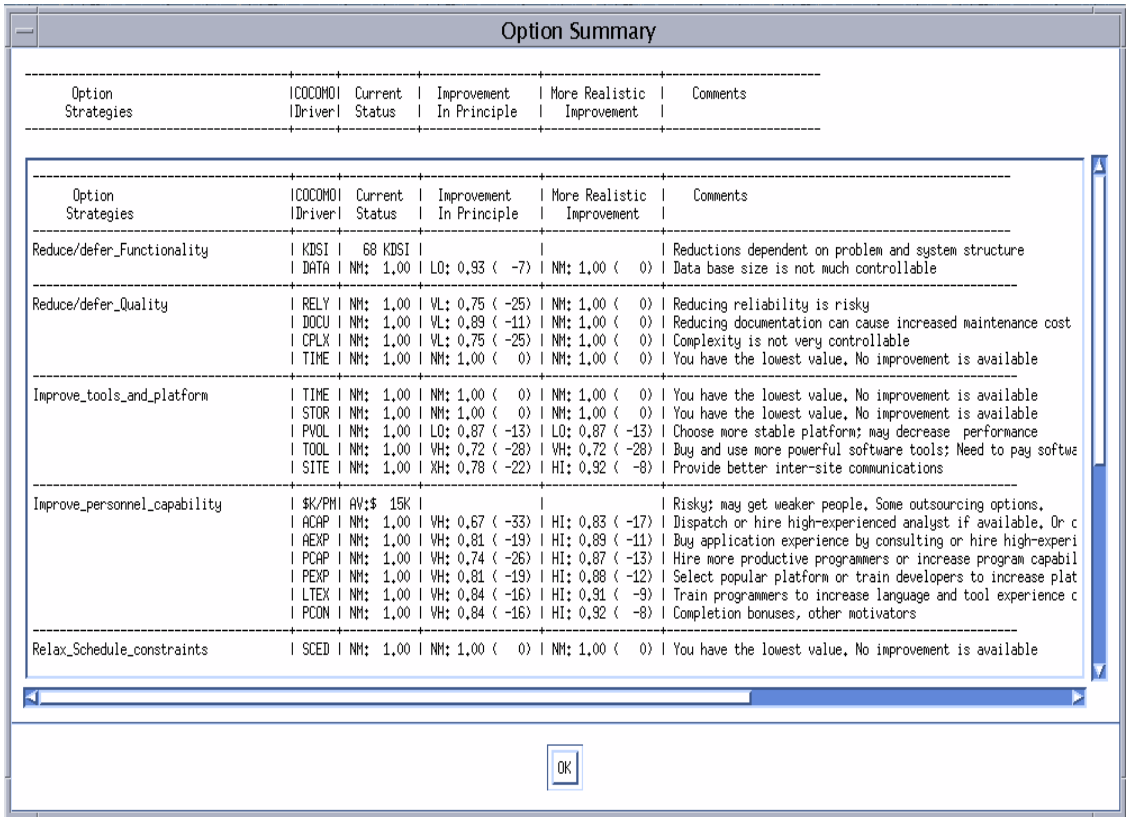
7.3.3.5 Tool Extension: Option Summary

One of the feedback from USC/CSE affiliates after S-COST demos is that some advice on "Which option strategy can reduce how much" (called "Option Summary") would be useful in the process of option generation.

Initially, the "option summary" feature was developed for the project having only one module as shown in Figure 30. The multiple-module version will be developed as a future work.

In the option summary window (Figure 30), the values of the three COCOMO cost drivers (named "Current Status", "Improvement In Principle", and "More Realistic Improvement") are shown with comments to provide a summary of which-option-strategy-can-reduce-how-much. For example, reduce/defer documentation (DOCU) can reduce documentation by 11% (shown in the parenthesis of the *Improvement-In-Principle* column) by changing NM (i.e., Nominal) shown in the *Current-Status* column to VL (i.e., Very Low) shown in the *Improvement-In-Principle* column, but a more realistic solution is

NM (shown in the *More-Realistic-Improvement* column) because "reducing documentation can cause increased maintenance cost" (shown in *Comments* column).



Option Strategies	COCOMO Driver	Current Status	Improvement In Principle	More Realistic Improvement	Comments
Reduce/defer_Functionality	KDSI	68 KDSI			Reductions dependent on problem and system structure
	DATA	NM: 1.00	LO: 0.93 (-7)	NM: 1.00 (0)	Data base size is not much controllable
Reduce/defer_Quality	RELY	NM: 1.00	VL: 0.75 (-25)	NM: 1.00 (0)	Reducing reliability is risky
	DOCU	NM: 1.00	VL: 0.89 (-11)	NM: 1.00 (0)	Reducing documentation can cause increased maintenance cost
	CPLX	NM: 1.00	VL: 0.75 (-25)	NM: 1.00 (0)	Complexity is not very controllable
	TIME	NM: 1.00	NM: 1.00 (0)	NM: 1.00 (0)	You have the lowest value. No improvement is available
Improve_tools_and_platform	TIME	NM: 1.00	NM: 1.00 (0)	NM: 1.00 (0)	You have the lowest value. No improvement is available
	STOR	NM: 1.00	NM: 1.00 (0)	NM: 1.00 (0)	You have the lowest value. No improvement is available
	PVOL	NM: 1.00	LO: 0.87 (-13)	LO: 0.87 (-13)	Choose more stable platform; may decrease performance
	TOOL	NM: 1.00	VH: 0.72 (-28)	VH: 0.72 (-28)	Buy and use more powerful software tools; Need to pay softwa
	SITE	NM: 1.00	XH: 0.78 (-22)	HI: 0.92 (-8)	Provide better inter-site communications
Improve_personnel_capability	$K/PM	AV:$ 15K			Risky; may get weaker people. Some outsourcing options.
	ACAP	NM: 1.00	VH: 0.67 (-33)	HI: 0.83 (-17)	Dispatch or hire high-experienced analyst if available. Or c
	AEXP	NM: 1.00	VH: 0.81 (-19)	HI: 0.89 (-11)	Buy application experience by consulting or hire high-experi
	PCAP	NM: 1.00	VH: 0.74 (-26)	HI: 0.87 (-13)	Hire more productive programmers or increase program capabil
	PEXP	NM: 1.00	VH: 0.81 (-19)	HI: 0.88 (-12)	Select popular platform or train developers to increase plat
	LTEX	NM: 1.00	VH: 0.84 (-16)	HI: 0.91 (-9)	Train programmers to increase language and tool experience c
	PCON	NM: 1.00	VH: 0.84 (-16)	HI: 0.92 (-8)	Completion bonuses, other motivators
Relax_Schedule_constraints	SCED	NM: 1.00	NM: 1.00 (0)	NM: 1.00 (0)	You have the lowest value. No improvement is available

Figure 30. Visualization Window for Option Summary

Because *Current Status* in Execution Time Constraint (TIME) and Main Storage Constraint (STOR) had the same value as *Improvement-In-Principle*, no improvement was available because the *Current Status* had the lowest value.

Required Development Schedule (SCED) has the same lowest value (i.e., the value of *Improvement-In-Principle*) from Nominal (NM) to Very High (VH). In Figure 30,

Nominal is shown as the value of *Improvement-In-Principle* due to the limitation of column space.

The value of Program size (e.g., KDSI and ADSI) was not shown in the columns of *Improvement-In-Principle* and *More-Realistic-Improvement* because the advice is useless without domain and/or environment knowledge.

The "option summary" feature gives stakeholders a general indication of which option strategies are most effective to resolve cost conflicts.

7.3.4 Lessons Learned

Based on the strengths and limitations of these automated approaches, we conclude that S-COST's resulting semi-automated approach is stronger than a heavily manual approach or a heavily automated approach

The option Summary feature is also based on a semi-automated approach. It does not tell stakeholders which strategies they should apply automatically. In order to get the right answer when using the heavily automated approach, complicated inputs such as domain knowledge, environment factors, and personal priority are necessary. With the semi-automated approach, however, additional inputs are not required. This makes the relative effectiveness of each strategy more clear to the users. The USC/CSE's industry and government affiliates showed very positive feedback during demos of the Option Summary feature.

Another feedback from USC/CSE affiliates was regarding the use of S-COST as a standalone tool rather than a dependent tool of WinWin. An example of the S-COST

standalone use is a training tool for COCOMO. Novice software engineers may not understand which “improvements in principle” are realistic. However, S-COST provides guidance on realistic cost-resolution option strategies so that the novices can apply COCOMO more effectively.

8.0 Results of the Analysis of the Experimental Data and Survey

8.1 Results of the Analysis of the WinWin Data of CS577a

The University of Southern California / Center for Software Engineering (USC/CSE) developed 15 multimedia digital library software systems with input from the USC library staff (as customers and users) and graduate students enrolled in CSCI 577a, a software engineering class (as developers), during the 1996-97 semester [Egyed-Boehm, 1997].

The library projects dealt with diverse data, including medieval manuscripts, technical reports, corporate business information, and stereoscopic slides. Each project had its desired capabilities, and unique constraints. The 86 graduate students in the class, broken up into 15 teams (5 or 6 students per team), formulated operational concepts, requirements specifications, architectures, prototypes, life cycle plans, and integrating rationale for the proposed capabilities of 15 USC's Library Information Systems during the 11-week semester. Table 14 shows the topic list of the 15 systems.

Altogether, 12 project topics were chosen for this experiment, six of which were continued during the following semester. The medieval manuscripts team could not be evaluated because their electronic data were missing. Teams 3 and 4, 5 and 9, and 7 and 10 played a special role because they worked on the same problem sets. See Table 15 for more detail on a sample of these projects.

Having real customers with real problems forced the students to deal with a number of real world characteristics (e.g., fuzzy requirements, availability of resources, personnel turnover, and conflicts).

Team	Topic	Continued
1	Stereoscopic Slides	
2	Latin American Pamphlets	Yes
3	EDGAR Corporate Data	
4	EDGAR Corporate Data	Yes
5	Hancock Image Archives	
6	ITV Material	
7	Technical Reports	
8	CNTV Moving Image Archives	Yes
9	Hancock Image Archives	Yes
10	Technical Reports	Yes
11	Maps	
12	Searchable Archives for Images	
13	Korean-American Museum	
14	Planning Documents	
15	Medieval Manuscripts	Yes

Table 14. Library Project Topics

Before the application systems were developed, the WinWin system was used to determine the negotiated requirements. The WinWin repository provided not only the artifact data but also the negotiation process data. This section summarizes the results of the data analysis as a means to understand the conflict identification and resolution process. The data analysis for the conflict identification and resolution process can be

classified into three concerns: (i) analysis of conflict identification and the resolution process; (ii) analysis of the roles & relationships between stakeholders and artifacts; and (iii) analysis of the effectiveness of QARCC and S-COST.

Problem # and Topic	Author and Title	Problem Statement
Problem #2: Hancock Image Archives	Jean Crampon, Hancock Library of Biology and Oceanography	There is a substantial collection of photographs, slides, and films in some of the Library's archival collections. As an example of the type of materials available, I would like to suggest using the archival collections of the Hancock Library of Biology and Oceanography to see if better access could be designed. Material from this collection is used by both scholars on campus and worldwide. Most of the Hancock materials are still under copyright, but the copyright is owned by USC in most cases.
Problem #9: EDGAR Corporate Data	Caroline Sisneros, Crocker Business Library	Increasingly the government is using the WWW as a tool for dissemination of information. Two much-used sites are the Edgar Database of Corporate Information (http://www.sec.gov/edgarhp.htm) and the Bureau of the Census (http://www.census.gov). Part of the problem is that some of the information (particularly that at the EDGAR site) in only available as ASCII files. For information that is textual in nature, while the files can be cleaned up, formatting of statistical tables is often lost in downloading, e-mailing, or transferring to statistical programs. And while this information is useful for the typical library researcher, who usually have a very distinct information need, the investment in what it would take to put this information is a usable format is often too much trouble.
Problem Set #13: CNTV Moving Image Archives	Sandra Joy Lee, Moving Image Archives, School of Cinema/ TV	The USC Moving Image Archives houses USC student film and video productions dating from the1930s to current productions in the School of Cinema-Television. Moving image materials in multiple formats, specialized viewing equipment, limited storage space, and complex access needs create challenges that may be solved with new computer technologies. Fifteen movie clips (.mov format), each approximately 45 minutes in length, over 100 digital film stills (.gif format), and textual descriptions of the films will be made available to students wishing to explore this project.

Table 15. Examples of Library Multimedia Problem Statements

8.1.1 Analysis of Conflict Identification and the Resolution Process

[Egyed-Boehm, 1997] analyzed the general requirement negotiation patterns for the multimedia library systems. They tested certain hypotheses to identify the general negotiation patterns, which were based on the following information: (i) the WinWin artifacts, the system log data (e.g., system login time and date, (ii) the project duration in terms of days), and (iii) people data (e.g., team grading, industry experience, and English proficiency). They did not, however, analyze the quality-conflict negotiation patterns.

8.1.1.1 Analysis of Quality Issues

The following quality-issue hypotheses, adopted from the general hypotheses in [Egyed-Boehm, 1997], were tested by the WinWin artifact data of the multimedia library systems to analyze the quality-conflict negotiation process.

Hypothesis 1: Most quality-attribute win conditions will be noncontroversial.

Since a win condition is seen as the goal space in which a stakeholder expresses his/her desires of the proposed application system and an issue is seen as a conflict between two or more contradictory goals, less than half (i.e., 45%) of all goals (e.g., functional, quality, and infrastructure goals) caused conflicts (Table 16).

However, the quality win conditions were involved in somewhat more conflicts (49%) than the general win conditions (45%), including functional and infrastructure win conditions. The difference is not large, but it suggests that quality attributes are somewhat more likely to require negotiation.

Hypothesis 2: Most quality issues will be straightforward to resolve.

The number of options per issue is, in many cases, an indication of the complexity of the issue. Of all issues, 66 % had only one option. Only 31% of all general issues had multiple (i.e., more than one) options. Among the issues having multiple options, 50% of them had only two options. Thus, most issues were quite straightforward to resolve.

Condition	**Number of Artifacts**
Win Conditions involved in issues	232/513 (45%)
Quality Win Conditions involved in issues	118/240 (49%)
The Number of issues having **NO** option	4/176 (2 %)
The Number of issues having **ONE** option	117/176 (66 %)
The Number of issues having **MULTIPLE** options	55/176 (31 %)
The Number of **Quality** issues having **NO** option	4/102 (4 %)
The Number of **Quality** issues having **ONE** option	67/102 (66 %)
The Number of **Quality** issues having **MULTIPLE** options	31/102 (30 %)

Table 16. Analysis Result of the Analysis of the WinWin Artifacts

The quality issues were also quite straightforward to resolve. Of the quality issues, 66% had only one option. Only 30% of the quality issues had multiple options.

Among the issues having no option, 75% were unresolved issues (i.e., issues which did not have any further consideration into options or agreements). 25% were “short-cut” issues (i.e., issues which were directly resolved by agreements without drafting options).

8.1.1.2 Analysis of Quality-Conflict Issues

A quality-conflict issue is a quality issue which contains at least one conflict between one quality attribute and another. Among the 102 quality issues (Table 16), there were 61 quality-conflict issues. The other 41 quality issues were non-conflict-quality issues (i.e., issues which dealt with how to improve a specific quality, but the improvement of the specific quality did not adversely reduce other qualities).

The number of options per issue also were analyzed to identify quality-conflict negotiation process patterns. The number of quality-conflict issues having one option was 39 (64% of all quality-conflict issues) and the number of quality-conflict issues having multiple (i.e., more than one) options was 19 (31%). These findings are shown in Table 17. The quality-conflict issues, like the quality issues, were straightforward in terms of their resolution.

Condition	**Number of Artifacts**
The Number of **Quality-Conflict** issues having **NO** option	3/61 (5 %)
The Number of **Quality-Conflict** issues having **ONE** option	39/61 (64 %)
The Number of **Quality-Conflict** issues having **MULTIPLE** options	19/61 (31 %)

Table 17. Analysis Results of the Analysis of the Quality-Conflict Issues

After the quality-conflict issues **having only one option** were analyzed, the following negotiation patterns were identified:

- ***Directly Accepting***: A quality-conflict issue is resolved by directly accepting its only option to an agreement without semantically changing the option.
- ***Adapting***: A quality-conflict issue is resolved by adapting its only option to an agreement with semantically changing the option.
- ***Decomposing***: A quality-conflict issue is resolved by decomposing its only option to multiple (i.e., more than one) agreements.
- ***Contradictorily Accepting***: A quality-conflict issue is resolved by accepting its only option to an agreement, but the agreement is semantically opposite to the option.

After the quality-conflict issues **having multiple options** were analyzed, the following negotiation patterns were identified:

- ***Electing***: A quality-conflict issue is resolved by electing the best option(s) among the multiple proposed options for the issue.
- ***Merging***: A quality-conflict issue is resolved by merging the multiple proposed options into an agreement.
- ***Accepting all***: A quality-conflict issue is resolved by accepting all options for the issue via multiple agreements.

Hypothesis 3 [Negotiation Pattern Analysis I]: Among the quality-conflict issues having only one option, the number of the quality-conflict issues resolved by *directly accepting* options will be greater than the number of the issues resolved by *adapting options*.

The negotiation patterns for the quality-conflict issues having one option are shown in Table 18. The number of the issues resolved by the *Directly Accepting* pattern (59% of all quality-conflict issues) is greater than the number of the issues resolved by the *Adapting* pattern (36%).

This difference appears strong, but due to the small sample size is not statistically significant. The hypothesis (t = 1.090 with 14 degrees of freedom; two-tailed P value = 0.2940) is rejected because the mean difference (= -0.6000) between the two patterns is considered not significant with 95% confidence interval (= -1.788 to 0.5882). In general, the differences found for the other hypotheses are strongly suggestive, but not statistically significant due to the small sample size and the variability across applications and team styles.

Negotiation Patterns for Quality-Conflict Issues Having One option	**Number of Artifacts**
Accepting an option **directly** to an agreement without changing the option semantically	23 / 39 (59 %)
Adapting an option to an agreement with changing the option semantically	14 / 39 (36 %)
Decomposing an option to multiple agreements	1 / 39 (3 %)
Accepting an option **contradictorily** to an agreement	1 / 39 (3 %)

Table 18. Negotiation Patterns for Quality-Conflict Issues Having One Option

Each team, however, has different preferred patterns. For example, more than 75% of the quality-conflict issues resolved by *Directly Accepting* patterns were done by Teams 2, 3, 5, and 7, whereas 75% of the quality-conflict issues resolved by *Adapting* patterns were done by teams 1, 10, and 15.

Both *Decomposing* and *Contradictorily Accepting* patterns were rare (3%). A *Contradictorily Accepting* pattern (i.e., an option and its agreement are semantically contradictory to each other) looks odd, but it reduced negotiation efforts by simply drafting a contradictory option rather than by drafting two options, which are contradictory to each other, and electing the opposite option among the two options. For example, a tradeoff issue between the use of high-resolution images and its process time was resolved by *contradictorily accepting* a high-resolution-image-usage-and-slow-process-time agreement from a low-resolution-image-usage-and-fast-process-time option.

Hypothesis 4 [Negotiation Pattern Analysis II]: Among the quality-conflict issues having multiple options, the number of the quality-conflict issues resolved by electing the best option(s) will be greater than the number of the issues resolved by merging the multiple options or accepting all the multiple options.

The negotiation patterns for the quality-conflict issues having multiple options are shown in Table 19. The number of the issues having the *Electing-the-best* pattern (42%) is greater than the number of the issues having the *Merging* pattern (26%) or the *Accepting-All* pattern (32%).

Negotiation Patterns for Quality-Conflict Issues Having Multiple Options	Number of Artifacts
Electing the best option(s) among the proposed multiple options	8 / 19 (42 %)
Merging the multiple options into an agreement	5 / 19 (26 %)
Accepting all the multiple options into multiple agreements	6 / 19 (32 %)

Table 19. Negotiation Patterns for Quality-Conflict Issues Having Multiple Options

Among the eight issues having the *Electing-the-best* pattern, seven were resolved to an agreement by electing only one option as the best, and the remaining one issue was resolved to two agreements by electing two options as the best. All issues having *Merging* patterns were resolved to an agreement and all issues having *Accepting-All* patterns were resolved to multiple agreements.

Of the issues, 63% having the *Electing-the-best* pattern and 60% of the issues having the *Accepting-All* pattern were accepted without semantically changing the options. Of course, all issues having the *Merging* pattern were accepted with changing the options.

The negotiation patterns of quality-conflict issues having multiple options depend on how to draft the resolution options. The *Merging* and *Accepting-All* pattern had "*Non-Exclusive-Or*" options (i.e., all of the options can be accepted at the same time). For example, "make server interoperable" and "make clients interoperable" can be accepted all at the same time. The *Electing* pattern, however, had "*Exclusive-Or*" options (i.e., only one options can be accepted among the proposed options because of their compatibility).

For example, “less fast and high resolution” and “faster and low resolution” can not be accepted all at the same time. Only one of them can be accepted.

Hypothesis 5: Most of the quality-conflict issues will be resolved without comments.

Eighty percent of all issues and 84% of the quality-conflict issues were resolved without comments.

The comments on quality-conflict issues were used (i) to add, estimate, and elaborate on some constraints (60% of quality-conflict issues); (ii) to express “agree/ disagree” (20%); (iii) to clarify ambiguity (10%); or (iv) to explore potential options (10%).

Artifact Type	**Total**	**With Comments**	**Without Comments**
All issues	176	36 (20 %)	140 (80 %)
Quality-Conflict issues	61	10 (16 %)	51 (84 %)
All options	250	26 (10 %)	224 (90 %)
Quality-Conflict options	74	2 (3%)	72 (97 %)

Table 20. Results of the WinWin Artifacts

Hypothesis 6: Most of the quality-conflict resolution options will be adapted to agreements without comments

Ninety percent of all options and 97% of the quality-conflict options were resolved without comments (Table 20). All comments for the quality-conflict options were used to supplement and elaborate on the options.

8.1.2 Analysis of the Stakeholders' Roles and their Relationships to Artifacts

The stakeholders did not participate equally throughout the conflict resolution process. The users and customers participated more strongly at the early stages of the process, whereas the developers and the customers were more involved later. The following hypotheses elaborate the stakeholders' roles and their relationships to the WinWin artifacts.

Hypothesis 7: The primary-concerned relationship between stakeholders and quality attributes shown in Figure 9 will hold for the digital library student projects

The proposed default set of relationships shown in Figure 9 were slightly different from the relationships shown in the multimedia library application systems (Figure 31).

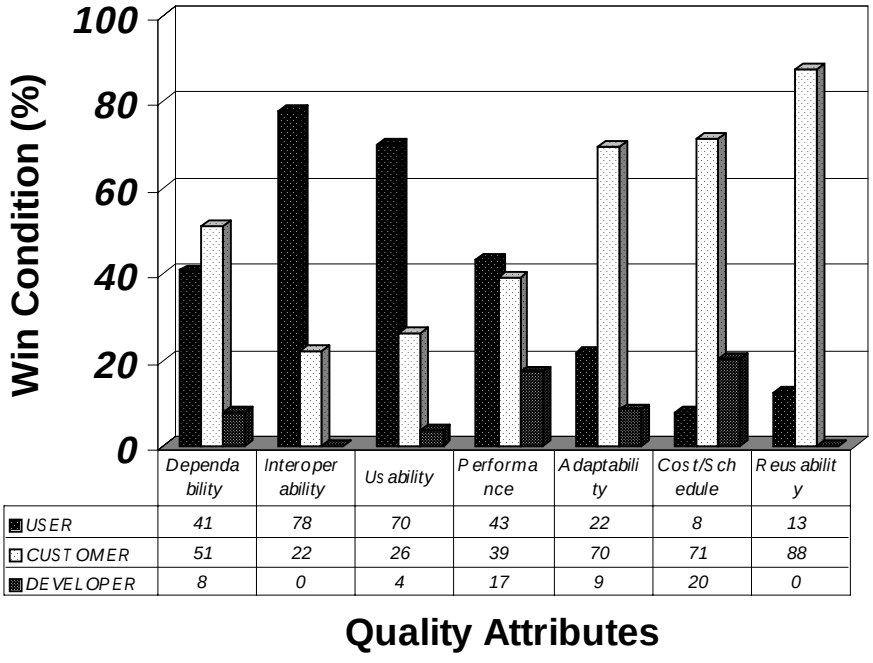


Figure 31. Results of the Win Condition Analysis for the Stakeholders' Role in Quality Requiremnets

With a 19% threshold, a new diagram of the primary-concerned relationships between stakeholders and quality attributes can be developed (Figure 32).

The difference shown in Figure 32 indicates that the customers are interested in all quality attributes, including Dependability, Interoperability, and Usability, which were missed in Figure 9. Another difference is that the developers did not sufficiently draft quality-attribute related win conditions. The developers' concerns about Evolvability/ portability and Reusability were not strong. This was probably because the student teams would not be around to evolve or reuse the software. However, the developers raised many issues related to quality attributes (more than 50% for all quality attributes).

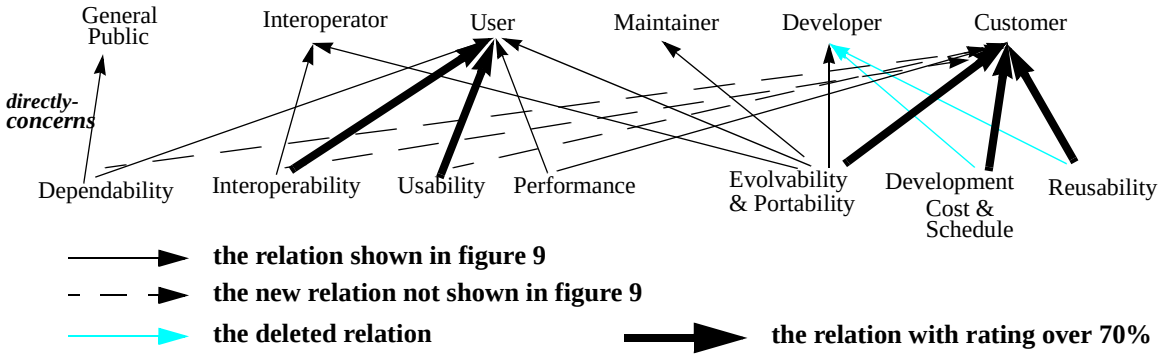
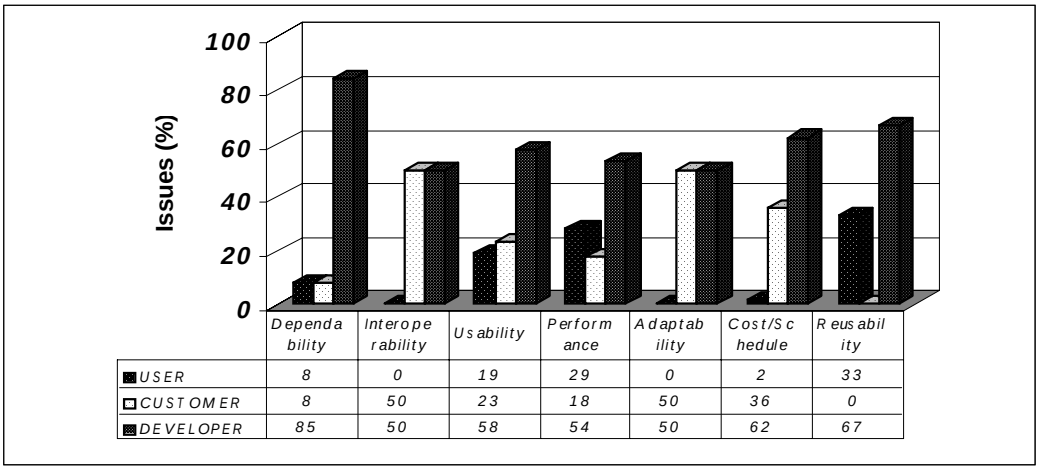
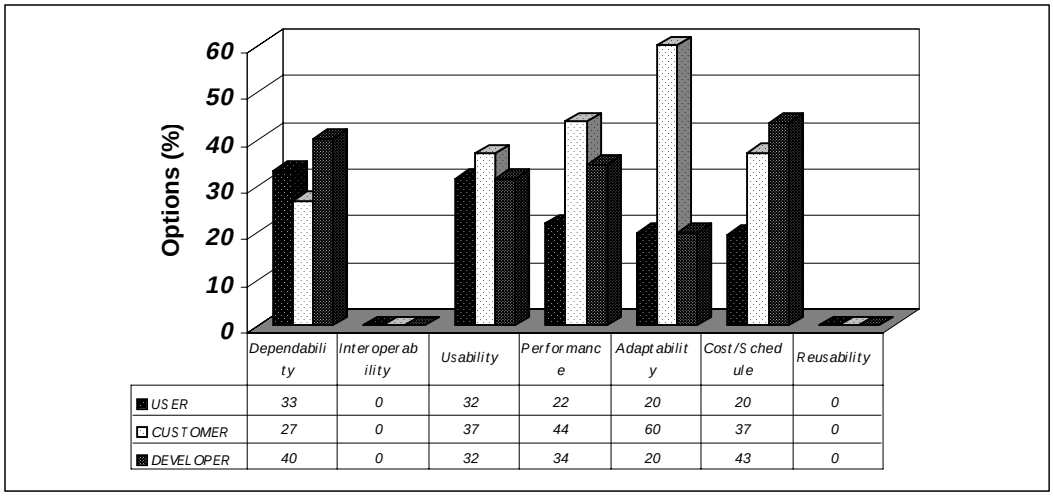


Figure 32. Mapping of the Common Stakeholders' Primary Concerns onto Quality Attributes

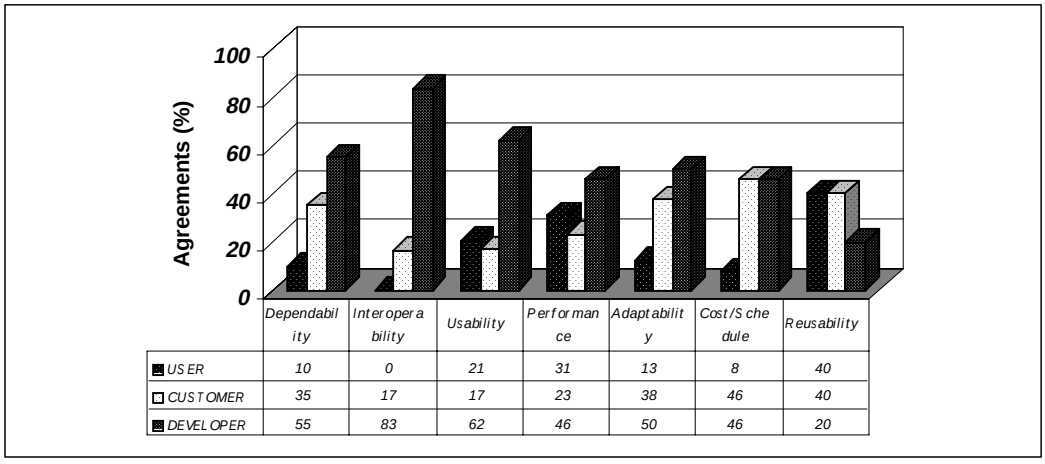
Results of the analysis of issues, options, and agreements for the stakeholders' role are shown in Figure 33. Unlike win conditions, developer raised more quality issues and agreements than other stakeholders. User's activity for issues, options, and agreements was significantly reduced.



	Dependability	Interoperability	Usability	Performance	Adaptability	Cost/Schedule	Reusability
USER	8	0	19	29	0	2	33
CUSTOMER	8	50	23	18	50	36	0
DEVELOPER	85	50	58	54	50	62	67



	Dependability	Interoperability	Usability	Performance	Adaptability	Cost/Schedule	Reusability
USER	33	0	32	22	20	20	0
CUSTOMER	27	0	37	44	60	37	0
DEVELOPER	40	0	32	34	20	43	0



	Dependability	Interoperability	Usability	Performance	Adaptability	Cost/Schedule	Reusability
USER	10	0	21	31	13	8	40
CUSTOMER	35	17	17	23	38	46	40
DEVELOPER	55	83	62	46	50	46	20

Figure 33. Results of the Analysis of Issues, Options, and Agreements for the Stakeholders' Role

Hypothesis 8: In quality requirements, users would be more active in identifying win conditions, but less active in identifying issues, options, and agreements.

Among the quality-attribute artifacts users drafted, the number of win conditions was greater than the combined number of issues, options, and agreements (Table 21 and Figure 34). Users concentrated on drafting on their desires (i.e., win conditions) rather than drafting issues, options, or agreements.

Hypothesis 9: In quality requirements, customers would be more active in identifying win conditions, but less active in identifying issues, options, and agreements.

Among the quality-attribute artifacts customers drafted, the number of win conditions (46% of all quality artifacts) was much greater than the number of issues (13%), the number of options (18%), or the number of agreements (24%).

Hypothesis 10: In quality requirements, developers would be more active in identifying issues and agreements, but less active in identifying win conditions and options.

Among the quality-attribute artifacts developers drafted, the number of issues and agreements was much greater than the number of win conditions and the number of options. Developers were more interested in identifying conflicts (i.e., issues) and commitments for their resolution (i.e., agreements).

Figure 34 is a graph based on the number of quality-attribute artifacts shown in Table 21. Users and customers were more active in identifying win conditions (about 50% of their activities), but less active in identifying issues, options, and agreements (less than 20% of their attributes except for developers' drafting agreements). However, developers were more active in identifying issues and agreements (more than 30% of their activities), but less active in identifying issues and options (less than 20%).

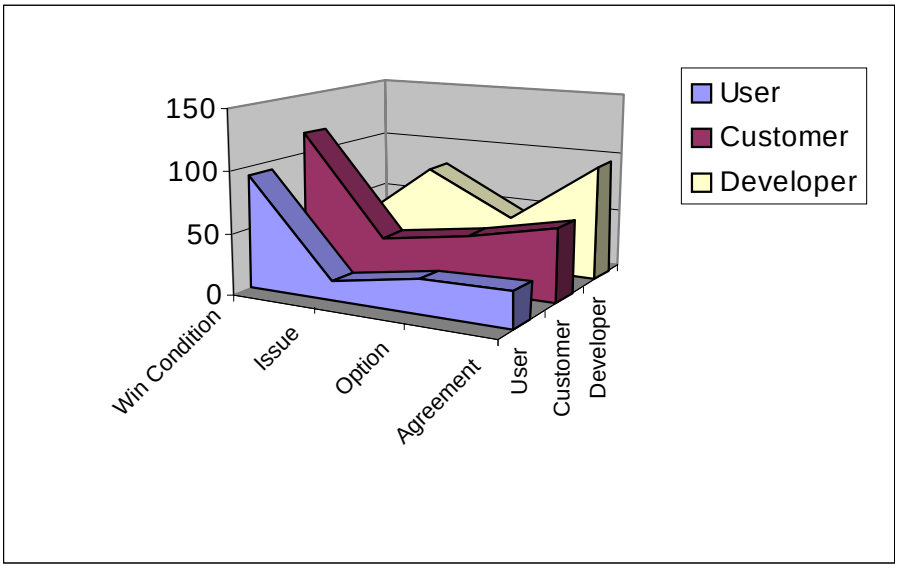


Figure 34. Analysis Graph of Quality Artifacts

	Win Conditions	Issues	Options	Agreements	TOTAL
User	94 (55%)	16 (10%)	28 (17%)	30 (18%)	168 (100%)
Customer	117 (46%)	34 (13%)	45 (18%)	61 (23%)	257 (100%)
Developer	26 (11%)	80 (33%)	44 (18%)	96 (38%)	246 (100%)

Table 21. Results of the Analysis of the Quality Artifacts

Figure 35 is a graph based on the number of all artifacts (Table 22) including infrastructure, domain, and quality-attribute requirements. Like the analysis of the quality-attribute artifacts, users and customers were more active in identifying win conditions (more or less 50% of their activities), but less active in identifying issues, options, and agreements (less than 20% for issues and options, but about 30% for agreements). Users and customers were more active in identifying agreements of all artifacts (about 30%) than in identifying agreements of the quality-attribute artifacts (about 20%).

Developers showed more focus on identifying agreements of all artifacts (about 40%), but showed indiscriminately less focus on identifying win conditions, issues, and options (about 20%). In the quality-attribute analysis, issues were 33%. This implies that developers played an more important role to identify the quality-attribute issues rather than other issues.

	Win Conditions	**Issues**	**Options**	**Agreements**	**TOTAL**
User	203 (52%)	29 (7%)	61 (15%)	101 (26%)	394 (100%)
Customer	226 (42%)	52 (10%)	93 (17%)	168 (31%)	539 (100%)
Developer	84 (18%)	95 (20%)	96 (21%)	192 (41%)	467 (100%)

Table 22. Results of the Analysis of all Artifacts

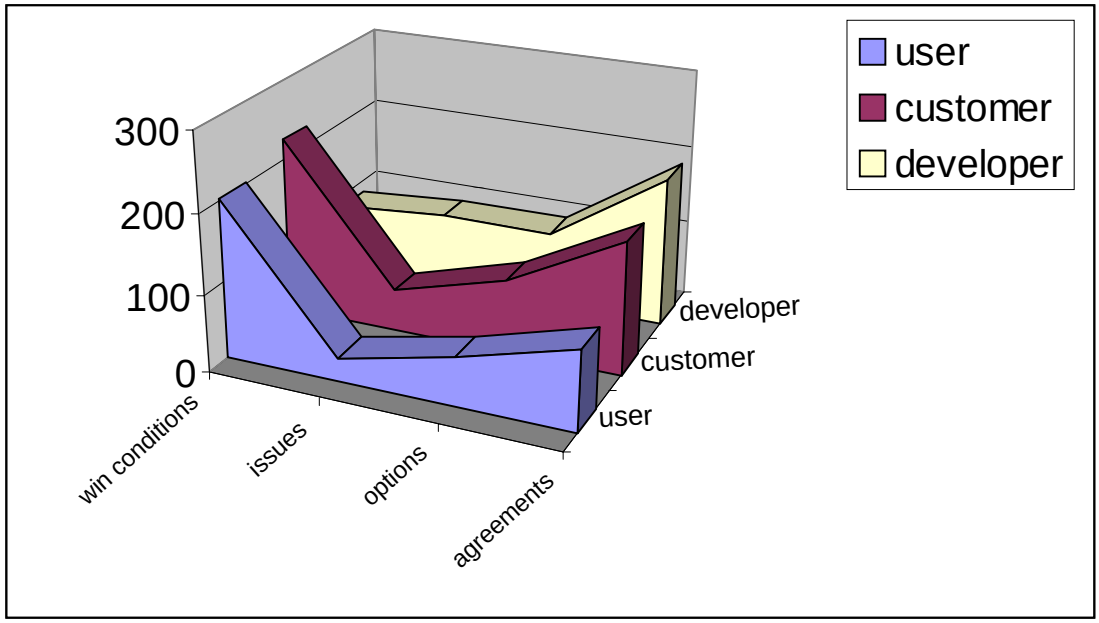


Figure 35. Analysis Graph of all Artifacts

8.1.3 Analysis of the Effectiveness of QARCC and S-COST

Hypothesis 11 [Effectiveness of the QARCC model and tool]: The number of quality-conflict issues raised by QARCC is much greater than the number of quality-conflict issues raised by the students.

The quality-conflict issues which QARCC could potentially identify, based on its knowledge base of Quality Attribute Strategies, are shown in Table 23. This means that QARCC could help the students identify, at most, 70 issues per team. The students without QARCC identified only four issues per team by summing up the average number of quality-conflict issues per team, as shown in Table 24.

However, all 70 potential issues suggested by QARCC are not significant. The students need to filter out insignificant suggestions by QARCC. To estimate the minimum number of significant suggestions by QARCC, the frequency of Quality Attribute Strategies in the quality-conflict issues raised by the students was analyzed (Table 25). We can assume that the significant issues can be identified by at least one team. Then, at least six significant issues could be identified using non-compound Quality Attribute Strategies (e.g., QAS ID# shown in Appendix B: 2, 7, 10, 17, 18 and 26), and several issues based on compound Quality Attribute Strategies can be identified by QARCC.

For Dependability

1[a]:Accuracy optimization, -C
2: Backup/recovery, -A, -C, -P
6: Diagnostics, -C, -P
8: Error-reducing user input/output, Input acceptability checking, Input assertion/type checking, -A, -P
9: Fault-tolerance functions, -C, -P
12:Integrity functions, -C, -P
13:Interface specification, -C
15:Modularity, -C
16:Monitoring & Control, -C, -P
22:Redundancy, -A, -C, -I, -P
24:UI consistency, -C
27:Undo, -C
30:Verifiability, -C, -P
31:Visibility, -C

For Interoperability

4: Change-source Hiding, -C
10:Generality, -C, -P
13:Interface specification, -C
14:Layering, -C, -P
15:Modularity, -C
19:Parametrization, -C
21:Portability, -C, -P
24:UI consistency, -C
25:Understandability, -C

For Usability

8: Error-reducing user input/output, Input acceptability checking, Input assertion/type checking, -A, -P
11:Help/explanation, -C
17:Navigation, -C
24:UI consistency, -C
25:UI flexibility, -C, -P
27:Undo, -C
28: User-programmability, -C
29:User-tailorability, -C

For Reusability

4: Change-source Hiding, -C
13:Interface specification, -C
14:Layering, -C, -P
19:Parameterization, -C
24:UI consistency, -C
26:Understandability, -C

For Adaptaility (Evolvability / Portability)

4: Change-source Hiding, -C
5: Descoping, -U
10:Generality, -C, -P
13:Interface specification, -C
14:Layering, -C, -P
16:Modularity, -C
19:Parameterization, -C
21:Portability, -C, -P
23:Self-containedness, -C
24:UI consistency, -C
26:Understandability, -C

For Cost / Schedule

5: Descoping, -U

For Performance

1: Accuracy optimization, -C
3: Buy faster hardware, -C
16:Monitoring & Control, -C
18:Optimization, -C, -A
20:Platform-feature exploitation, -C, -A, -I

	D	I	U	R	A	C	P
D		22			2, 8, 22	1[a], 2, 6, 9, 12, 13, 15, 16, 22, 24, 27, 30, 31	2, 6, 8, 9, 12, 16, 22, 30
I						4, 10, 13, 14, 15, 19, 21, 24, 26	10, 14, 20, 21
U					5, 8	5, 11, 17, 24, 25, 27, 28, 29	8, 25
R						4, 13, 14, 19, 24, 26	14
A						4, 10, 13, 14, 16, 19, 21, 23, 24, 26	10, 14, 18, 20, 21
C							1, 3, 16, 18, 20
P							

Table 23. Potential Quality-Conflict Issues Identified by QARCC

a. The ID number of Quality Attribute Strategies in Appendix B (Quality Attribute Strategies)

	D	I	U	R	A	C	P
D						0.27 (4[a])	0.07 (1)
I						0.13 (2)	
U						1.2 (18)	0.87 (13)
R						0.27 (4)	
A						0.13 (2)	0.13 (2)
C						0.07 (1)	0.87 (13)
P							0.07 (1)

Table 24. The Average Number of Quality-Conflict Issues per Student Team

a. The total number of quality-conflict issues in all 15 teams.

These findings imply that knowledge based tools, such QARCC, are useful due to their ability to capture the expertise and to make it available on a broad basis.

Though the results of this analysis, five new strategies (e.g., buy more hardware for availability, training, make module changeable or reusable, copyright), which did not previously exist in the QARCC knowledge base, were identified.

It should be noted, however, that about 80% of the issues identified by the students also can be identified by QARCC.

	Quality Attribute Strategy	Strategy Frequency in all 15 teams	Total
Identified Strategies by QARCC	Backup/Recover	2	48 (79 %)
	Generality	2	
	Help/Explanation	2	
	Descoping	28	
	Buy faster hardware	10	
	Platform-feature exploitation	1	
	Compound Strategies	3	
New Strategies (Not Identified by QARCC)	Buy more hardware for availability	1	9 (15 %)
	Training (System Usage)	3	
	Make modules more changeable	1	
	Make modules more reusable	3	
	Copyright	1	
Missing, Contaminated, or ambiguous cases		4	4 (6%)
Total		61	61 (100 %)

Table 25. Frequency Analysis of Quality Attribute Strategies

Hypothesis 12 [Effectiveness of the S-COST model and tool]: The number of cost-conflict-resolution options in the S-COST knowledge base is much greater than the number of cost-conflict-resolution options the students raised.

Among 61 quality-conflict issues, 31 were cost-conflict issues (e.g., budget or schedule overrun issues). S-COST could help the students to resolve these 31 cost-conflict issues by suggesting potential cost-conflict-resolution options.

The number of the options which S-COST could potentially suggest is 11 per team, as seen in Table 11. However, the average number of options the students drafted in a project is approximately two (31 strategies / 15 teams).

Again, all 11 strategies may not be applied because of the significance of the strategies. For example, the *Relax schedule constraint* may be not allowed due to the limitation of the class schedule (i.e., the class should finish by the end of the semester).

We can assume that a strategy drafted by at least one team is significant. Then, at least five significant options could be drafted using non-compound Cost-Resolution Option Strategies (e.g., ID#: 1, 2, 3, 6, 11 shown in Table 26) and several options could be drafted using the compound strategies.

Of the options drafted by the students, 97% can be drafted by S-COST. This implies that the S-COST Cost-Resolution Option Strategies covered the option space well. Only one strategy (i.e., Buy information) that the students identified was missing.

Note that 71% of the options were based on the *Reduce/Defer functionality* strategy. This implies that the students who had situations where there was a high degree of functionality combined with a tight class schedule and a small supporting budget didn't

have any other options except of the *Reduce/Defer functionality* option. Another implication is that the librarians could not provide more options (e.g., buy new tools or reuse COTS components) because they didn't have any budgets for the projects. On the other hand, discussion between the students and the librarians may not be recorded into WinWin due to input barriers (e.g., availability of computer facilities during the discussion, unwillingness of the librarians' computer use because of their unfamiliarity), although the conclusion usually is.

S-COST Cost-Resolution Option Strategies

1: Reduce/defer functionality
2: Reduce/defer software quality
3: Improve tools, techniques or platforms
4: Relax the delivery schedule constraint
5: Improve personnel capabilities
6: Reuse software assets
7: Improve coordination of multiple project stakeholders as a team
8: Architecture and risk resolution
9: Improve process maturity level
10: Improve precedentedness and development flexibility
11: Increase budget

	Cost-Resolution Option Strategy	**Strategy Frequency in all 15 teams**	**Total**
Identified Strategies by S-COST	Reduce/Defer functionality	22	30 (97 %)
	Reduce/Defer quality	1	
	Improve tools, techniques, and platform	2	
	Reuse software assets	3	
	Increase budget	1	
	Composition	1	
New Strategies (Not Identified by S-COST)	Buy Information	1	1 (3 %)
Total		31	31 (100 %)

Table 26. Frequency Analysis of Quality Attribute Strategies

8.1.4 Lessons Learned

The primary conclusions from the analysis of the WinWin data of CS577a were:

- The negotiation process for the quality-attribute conflict resolution is not much different from that for the general conflict resolution (e.g., issues were straightforward to resolve).
- The differences found for hypotheses are strongly suggestive, but not statistically significant due to the small sample size and the variability across applications and team styles.
- The primary-concerned relationship between stakeholders' roles and quality attributes in the digital library student projects is slightly different from that of the SEE/SGS (Software Engineering Environment / Satellite Ground System) project which is one of hypothetical, but representative projects. For example, the relationship from developers to reusability was eliminated in the student projects because the reusability of codes the students made was not of concern in the class, as is the cased with commercial companies.
- The data analysis showed the possibility that QARCC and S-COST help stakeholders consider additional issues and options. The students drafted issues using 6 quality attribute strategies among 41 strategies and drafted options using 5 cost-resolution option strategies among 12 strategies. On the other hand, the students suggested 5 quality attribute strategies out of 41 strategies to identify quality-attribute conflicts and suggested 1 option strategy out of 12

strategies to resolve the cost conflicts. They are considered to add into the knowledge base of QARCC and S-COST.

8.2 Survey Results of the Relative Criticality of Attribute Conflicts

This survey was performed to investigate the relative criticality of the conflicts among software quality attributes such as Dependability, Interoperability, Usability, Performance, Evolvability & Portability (i.e., Adaptability), Cost & Schedule, and Reusability. Each quality attribute can be considered as top-level quality attributes which has associated with more detailed-level quality attributes. For example, Dependability, a top-level quality, could have association with Reliability/Accuracy, Correctness, Availability/Survivability, Integrity, Security/Privacy, and Safety, more detailed-level quality attributes.

The survey form is shown in the next page. The participators in this survey are Art Davis (NG - Northrop Grumman), Steven Moore (RES - Raytheon Electronic Systems), Allan Willey (Motorola), Yeondae Chung (SERI - System Engineering Research Institute, Korea), Mary Hesselgrave (Bell Labs/Lucent), Fred Cummins (EDS - Electronic Data System), Gary Thomas (RES - Raytheon Electronic Systems). They ranked the relative criticality of the attribute conflicts on a scale of 0 (generally insignificant) to 10 (generally critical).

INSTRUCTION: Rank the relative criticality of the following attribute conflicts on a scale of 0 (generally insignificant) to 10 (generally critical). Try to consider your organization's overall range of software applications.

Your Organization: _____
Type of your application: _____
Your Name, email, and Phone # :_____

	Depend-ability	Interopera-bility	Usability	Perfor-mance	Evolvabil-ity/Porta-bility	Cost/ Schedule	Reusability
Dependability							
Interoperability							
Usability							
Performance							
Evolvability/ Portability							
Cost/schedule							
Reusability							

Do you have any special comments? Which situations or cases are top-level critical conflicts among quality attributes?
(e.g., __Dependability_ vs ___performance___ : critical for security protection, real-time fault tolerance)

_____ vs _____ :

_____ vs _____ :

_____ vs _____ :

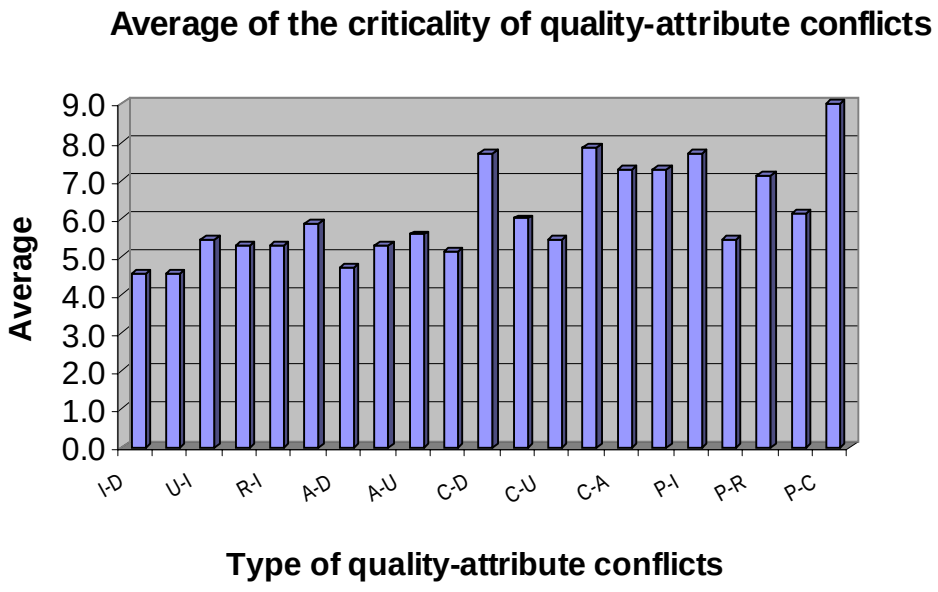
_____ vs _____ :

cc: If you have more, please use the back side of this sheet.

The survey results are in the following:

	NG	RES	Motorola	SERI	Bell Lab	EDS	RES	AVG	STD
I-D	2	5	8	1	2	8	6	4.6	2.9
U-D	4	5	8	7	1	2	5	4.6	2.5
U-I	3	7	9	8	0	5	6	5.4	3.1
R-D	5	8	7	6	2	2	7	5.3	2.4
R-I	4	10	7	8	0	2	6	5.3	3.5
R-U	4	10	5	7	4	4	7	5.9	2.3
A-D	6	4	2	5	7	3	6	4.7	1.8
A-I	3	8	8	9	0	2	7	5.3	3.5
A-U	5	7	8	8	2	3	6	5.6	2.4
A-R	2	10	7	8	0	1	8	5.1	4.0
C-D	8	5	9	8	8	8	8	7.7	1.3
C-I	5	5	5	5	6	8	8	6.0	1.4
C-U	5	4	5	6	3	6	9	5.4	1.9
C-R	3	10	7	8	8	10	9	7.9	2.4
C-A	5	10	7	5	7	8	9	7.3	1.9
P-D	8	10	5	6	8	7	7	7.3	1.6
P-I	3	10	5	9	7	10	10	7.7	2.8
P-U	4	8	5	8	0	4	9	5.4	3.2
P-R	3	8	7	8	8	8	8	7.1	1.9
P-A	7	5	3	7	7	6	8	6.1	1.7
P-C	8	10	7	9	9	10	10	9.0	1.2
AVERAGE	4.6	7.6	6.4	7.0	4.2	5.6	7.6		
STD	1.9	2.3	1.9	1.9	3.4	3.0	1.4		

The bar chart of the average of the criticality of quality attributes is shown in the following figure:



Another view of the criticality is the following:

	D	I	U	R	A	C	P
D				•		●	●
I			•	•	•	•	●
U				•	•	•	•
R						●	●
A						●	•
C							⬤
P							

(⬤ : Average rating 9 on scale of 10; ● : Average rating 7-8; • : Average rating 5-7)
(D: Dependability; I: Interoperability, U: Usability; P: Performance;
A: Adaptability; C: Cost/Schedule; R: Reusability)

Higher average point means more significant conflicts among quality attributes. The initial analysis results are in the following:

- Most Significant Conflict (over 9): P-C
- Significant Conflicts (over 7): A-P, I-P, A-C, P-C, E-C, P-R, C-R
- Less Significant Conflicts (over 5): I-U, U-P, I-E, U-E, P-E, I-C, U-C, A-R, I-R, U-R, E-R
- Insignificant Conflicts (below 5): A-I, A-U, A-E

Higher Standard Deviation (STD) means less converging on the significance of the quality conflicts among the participators. Thus, the quality conflicts which have lower STD could have a meaning in most situations.

- Lowest STD of the Conflict (below 1.2): P-C
- Lower STD of the Conflicts (below 2.0): A-P, A-E, P-E, U-C, A-C, E-C, P-R
- Higher STD of the Conflicts (over 3.0): I-U, U-P, I-E, I-R, E-R

The primary conclusion from the survey results of the relative criticality of attribute conflicts were:

- The conflict between Performance and Cost/Schedule was the most important conflict based on average and STD information.
- The conflicts not involved in Cost/Schedule and Performance were less important (i.e., low rating).
- Compared with the average number of quality-attribute conflict issues in the digital library projects (Table 24), the table of the criticality showed that the conflicts between Usability and Cost/Schedule and between Usability and Performance were less important. However, both indicated that the conflict between Performance and Cost/Schedule was one of most important conflicts.

9.0 Summary of Key Contributions

- Models for identifying quality conflicts and resolving cost conflicts were developed, assisting stakeholders to systematically analyze relationships among quality attributes, identify the potential quality conflicts, create possible resolution options, and negotiate the drafted options. In particular,
  - The Stakeholder/Quality Attribute relationship model and the Stakeholder/ Option Strategy relation model were developed to reduce the complexity of the conflict identification and resolution process by sending conflict messages only to the interested stakeholders. Draft forms were developed for aid in negotiating the identified conflicts.
  - Quality Attribute Strategies were developed which refined the relationships among quality attributes.
  - Architecture Strategies were developed and formalized to provide advice about quality conflict identification and resolution using software architecture concepts and terms
  - S-COST Resolution Option Strategies were developed and formalized to resolve cost conflicts by option creation through added dimensions.
- Prototype support systems for identifying quality conflicts by QARCC and resolving cost conflicts by S-COST have been developed to scale up the conflict identification and resolution process in the WinWin system and to supplement stakeholders' expertise in conflict identification and resolution. In particular,

- QARCC has been developed as the support system for quality conflict identification.
- S-COST has been developed as the support system for cost conflict resolution (i.e., option generation and option negotiation). It can also operate as a COCOMO II adjunct independently of WinWin.

- Analyses of alternative approaches to automated conflict detection and resolution were performed, providing insights on which types of approaches were more tractable (model-based, domain-based, keyword-based, semiautomated) and which were less tractable (domain-independent, natural language-based, fully automated, fully manual).
- Some initial theories for identifying quality conflicts and resolving cost conflicts (i.e., create resolution options and negotiate them for agreements) were developed and then have enabled us to draw some insights on what conflicts there are and how conflicts can be resolved. In particular,
  - An example for creating options through added dimension was developed, which provides an initial theoretical base for the S-COST Resolution Option Strategy model.

10.0 Future Extensions

There are many useful extensions which should be made in our models. They can be broken down into three categories: those that are related to the underlying models for the conflict identification and resolution (in section 10.1), those that are related to the support tools for the conflict identification and resolution (in section 10.2), those that are related to the theories (in section 10.3).

10.1 Extensions to the Models for Conflict Identification and Resolution

Table 27 shows the current status and the extension of the models for conflict identification and resolution.

10.1.1 Elaboration of Situation-Specific Architecture Strategies

The steps to further define Strategy-Attribute relations and Architecture Strategies was proposed in section 5.4. Based on these steps, I plan to develop situation-specific set of Architecture Strategies.

10.1.2 Elaboration of Situation-Specific S-COST Option Strategies

The Stakeholder / Cost_Resolution_Strategies shown in Figure 22 and Stakeholder_Roles / Option_Strategy_Concern relationship shown in Table 12 can be refined and customized according to a specific domain.

What I've done	What I plan to do
QARCC knowledge-base structure has been developed • Stakeholder/Quality Attribute Relationship model and its profile analysis • Hierarchy of Quality Attributes • Quality Attribute Strategies (Product and Process strategies) • Some Architecture Strategies and their formalism	Elaborate situation-specific Architecture Strategies (section 10.1.1) • Apply the elaboration steps shown in section 5.4.2 into several domains
Validate the generality of the Stakeholder/Quality Attribute Relationship by analyzing the profiles of more projects such as 15 WinWin exercises in cs577a class	
S-COST knowledge-base structure has been developed • Stakeholder/Option Strategy Relation model • S-COST Resolution Option Strategies and their formalism	Elaborate situation-specific S-COST Resolution Option Strategies (section 10.1.2) • Customize the relations between Stakeholders and the S-COST Resolution Option Strategies into a specific domain • Customize Stakeholder Roles / Option Strategy Concern relationship
Perform the profile analysis of S-COST like that of QARCC.	

Table 27. Current Status and the Extension of the Models

10.2 Extensions to the Tools and General Approaches

Table 28 shows the current status and the extension of the models for the conflict identification and resolution

10.2.1 Generalization of the QARCC Capabilities

The current QARCC system does not allow the QARCC users to insert, delete, and change elements of its knowledge bases (e.g., Quality Attribute Strategies, Strategy-Attribute Relations). The next version of QARCC (called, "QARCC-3") can have these

capabilities. However, consistency problems could arise due to the manual alteration of the knowledge base. The balance of the generality and maturity of knowledge bases can be determined from experiment results.

10.2.2 Generalization of the S-COST Capabilities

The S-COST capabilities can be generalized by allowing S-COST users to insert, delete, and change its knowledge bases (e.g., S-COST Strategies, Stakeholder/ Option Strategies Relationship). In the USC-CSE annual research reviews, such modifications were suggested by the affiliates to generalize the knowledge base.

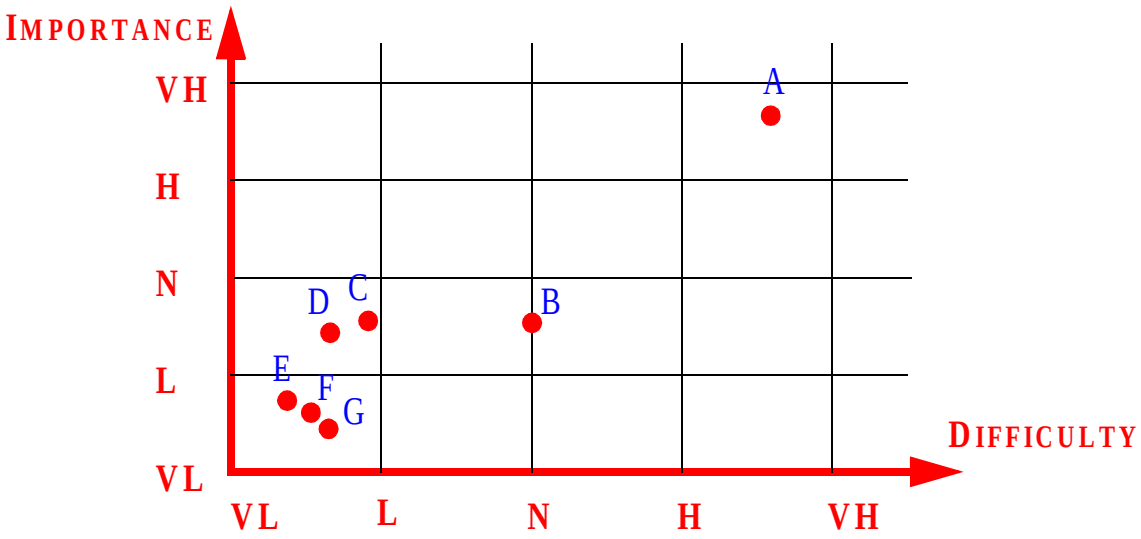
<table>
<tr><th>What I’ve done</th><th>What I plan to do</th></tr>
<tr><td>The following basic QARCC (QARCC 1.0) capabilities have been implemented:
• Operation on the context of the initial WinWin system (tooltalk version)
• Identifying the potential quality conflicts among win conditions (Its focus is to identify the top-level 7 quality attributes).
• Drafting win condition and Issues artifacts in QARCC (QARCC provide the advice about the potential conflicts in the artifacts)</td><td rowspan="2">The following more upgraded QARCC (QARCC 3.0) capabilities will be implemented:
• All capabilities of QARCC 2.0
• Generalization of the capabilities (section 10.2.1)
- Insert, change, and delete of quality attributes from stakeholders
- Insert, change, and delete of Quality Attribute Strategies and Architecture Strategies with its structured knowledge field-out form
- Conflict Identification by group-to-group of win condition and other artifacts</td></tr>
<tr><td>The following upgraded QARCC (QARCC 2.0) capabilities have been implemented:
• Operation on the context of WinWin 1.0 (RPC version)
• All capabilities of QARCC 1.0
• New UI (which enable stakeholders to navigate the win conditions associated with the conflicted quality attributes)
• Selection of the interesting quality attributes for each stakeholder
• Sending the potential conflict messages to the interested stakeholders</td></tr>
<tr><td>The following basic S-COST (S-COST 1.0) capabilities have been implemented:
• Drafting Option based on the S-COST Resolution Option Strategies
• Visualization of the option generation
• Visualization of the option negotiation
• Import and export COCOMO files</td><td rowspan="2">Extending S-COST to provide schedule improvement advice via CORADMO (COnstructive Rapid Application Development MOdel)

Tightly integrating S-COST with WinWin and COCOMO (i.e., automatically transfer data between S-COST and WinWin or COCOMO)

Extending better visualization aids (e.g., fancy 3D graphic)</td></tr>
<tr><td>The following basic S-COST (S-COST 2.0) capabilities have been implemented:
• Implementation of the Option Summary algorithm and system
The following upgraded S-COST (S-COST 3.0) capabilities have been implemented:
• Implementation of the Stakeholder/Option Strategy Relation model
• Generalization of the capabilities (section 10.2.2)
- Insert, change, delete, save, load, import and export of the S-COST Resolution Option Strategies with its structured knowledge field-out form
- Insert, change, and delete of Stakeholders</td></tr>
</table>

Table 28. Current Status and the Extension of the Support Systems

The survey results of research plans by 30 USC/CSE affiliate industries are shown in Figure 36.



A: Schedule Tradeoff Analysis capability*

B: Situation-specific Strategies

C: Utility Functions: undo, redo, copy, cut, paste, snapshot

D: Tightly-integration with WinWin and COCOMO

E: Better visualization aids (fancy graphic)

F: Support for other cost estimation tools

G: Advice for a best set of option strategies

Figure 36. Survey Results of the S-COST future work

* Note that CORADMO (COnstructive Rapid Application Development MOdel) makes the capability not so difficult.

10.3 Extensions to the Theories for Conflict Identification and Resolution

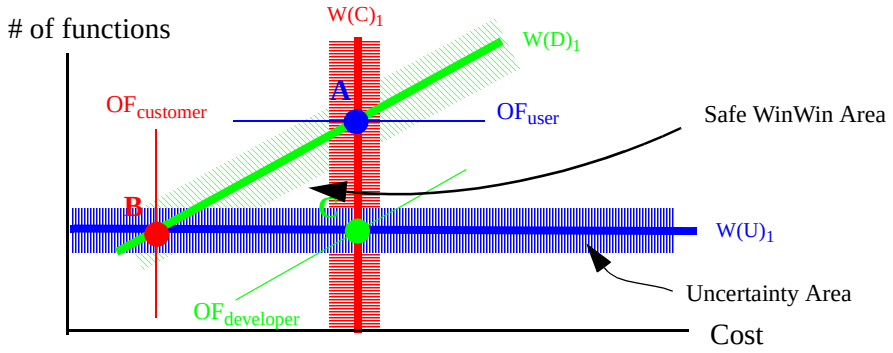
Table 29 shows the current status and the extension of the theories for the conflict identification and resolution.

What I've done	What I plan to do
An example for option creation through added dimensions has been developed • The conflict resolution process (for *n* dimension conflicts) has been proposed. • Algorithm to determine the existence of the WinWin solution.	Refine a general algorithm to resolve cost conflict by option creation through added dimensions. Refine the algorithm for determining the WinWin value. The criteria for determining the value are the following (section 10.3.1): • Risk management factors • Uncertainty factors
Validate the theories through the experiment exercises of their models and support systems. If the theories are not useful, refine or discard them.	

Table 29. Current Status and the Extension of the Theory

10.3.1 Refinements in Determining the WinWin Value

As the constraints from win conditions are not guaranteed to be unchangeable in any circumstance, the solid lines shown in Figure 37 are extended into the uncertainty band. The WinWin value can be determined in the Safe WinWin area (i.e., the WinWin area which does not contain the uncertainty band). The safe WinWin area can be called the risk free area from a risk management perspective. A risk-avoidance algorithm (e.g., which risks are considered to be significant in the WinWin area, how they can be avoided, and which value is safest in the WinWin area) is important future work.



* OF: Objective Function; A,B,C: Optimal values for each stakeholder

Figure 37. Determining the WinWin Value with Uncertainty Factors

Part III: References and Appendices

A list of references used for this thesis is given, as well as appendices describing Quality Attributes and Quality Attribute Strategies.

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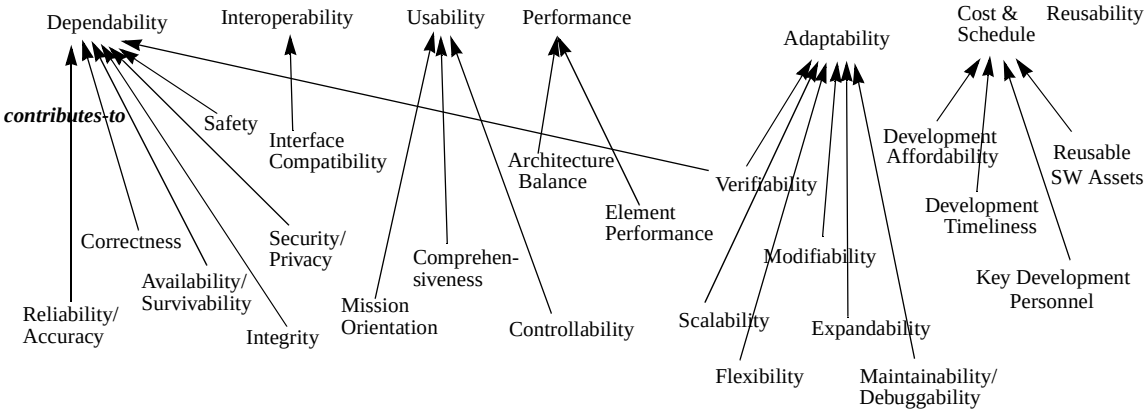
12.0 Appendix A: Quality Attributes [1]



12.1 Dependability

Dependability is defined as “that property of a computer system such that reliance can justifiably be placed on the service it delivers” [Laprie, 1992]. Depending on the intended application of the system dependability is usually expressed as a number of inter-dependent properties such as reliability, maintainability and safety. It refers to a broad notion of what has historically been referred to as “fault tolerance”, “reliability”, or “robustness”.

1. Main References: [Bowen et al., 1985], [Boehm et al., 1973], [Dyson, 1991], [Lipow et al.,1977], [McCall et al., 1977], [Murine, 1994], [Schulmeyer-McManus, 1992], [Deutsch-Willis, 1988], [IEEE, 1991]

12.1.1 Reliability/Accuracy

Reliability is defined by the ability of a system or component to perform its required functions under stated conditions for a specified period of time [IEEE, 1991].

- Accuracy: (1) A qualitative assessment of correctness, or freedom from error; (2) A quantitative measure of the magnitude of error [IEEE, 1991].
  - Accuracy checklist (AC.1) [Bowen et al., 1985; Dyson, 1991; Murine, 1994]
    - Is-there (accuracy rqmts, for all applicable functions)
    - Is-there (quantitative accuracy rqmts for input/output variables of each applicable function)
    - Is-there (quantitative accuracy rqmts for the constants of each applicable function)
    - Support (enough precision of existing math library routines for accuracy objectives)
- Anomaly Management: Anything observed in the documentation or operation of software that deviates from expectations based on previously verified software products or reference documents [IEEE, 1991].
  - Error tolerance/control (AM.1) [Bowen et al., 1985; Dyson, 1991; Murine, 1994]
    - #[1] (instances of centrally controlled concurrent processing) / # (instances of concurrent processing)
    - # (recognized error conditions required recovery or repair) / # (error conditions)
  - Improper input data (AM.2)
    - Is-there (error tolerances for all external input data (e.g., range of numerical values, legal combinations of alphanumeric values))
  - Computational failures (AM.3)
    - Is-there (rqmts for detection of recovery from all computational failures)
  - Hardware faults (AM.4)
    - Is-there (rqmts to recover from all detected hardware faults (e.g., power failure, clock interrupt))
  - Device errors (AM.5)
    - Is-there (rqmts to recover from all I/O device errors)
  - Communication errors (AM.6)
    - Is-there (rqmts to recover from all communication transmission errors)
  - Node/communication failures (AM.7)
    - Is-there (rqmts to recover from all failures to communicate with other nodes or other systems)

1. "The number of"

- Simplicity: The degree to which a system or component has a design and implementation that is straightforward and easy to understand [IEEE, 1991].

  - Design structure (SI.1(10)) [Bowen et al., 1985; Dyson, 1991; Murine, 1994]

    Is-there (diagrams identify all formats in a standard fashion)
    Is-there (rqmt for programming standard)
  - Structured language or preprocessor (SI.2(1))

    Is-there (rqmt to use a structured language or preprocessor to implement the software)
  - Data and control flow complexity (SI.3(1))
  - Coding simplicity (SI.4(14))

    Is-there (rqmt for a programming standard)
  - Specificity (SI.5(3))
  - Halsteed's level of difficulty measure (SI.6(1))

12.1.2 Correctness

Correctness is defined by: (1) The degree to which a system or component is free from faults in its specification, design, and implementation; (2) The degree to which software, documentation, or other items meet specified requirements; (3) The degree to which software, documentation, or other items meet user needs and expectations, whether specified or not [IEEE, 1991].

- Completeness: Those characteristics of software which provide full implementation of the functions required [Bowen et al., 1985; Schulmeyer-McManus, 1992].

  - Completeness checklist (CP.1(11)) [Bowen et al., 1985; Dyson, 1991; Murine, 1994]

    Clearly-define (I/O, processing)
    # (documented data reference with source, meaning and format) / # (data reference)
    All-referred (all defined functions (i.e., documented with source, meaning, format))
    Allocate (all defined functions, configuration items (i.e., CSCI's, HWCI's))
    Define (all referenced functions (i.e., documented with I/O, processing rqmts))
    Describe (processing flows (algorithms) and all decision points (condition stmts) in the flows for all functions)

- Consistency: The degree of uniformity, standardization, and freedom from contradiction among the documents or parts of a system or component [IEEE, 1991].

  - Procedure consistency (CS.1(5)) [Bowen et al., 1985; Dyson, 1991; Murine, 1994]

    Is-there (rqmt to standardize all design representations (e.g., control flow, data flow))

    Is-there (rqmt to standardize the calling sequence protocol between software units)

    Is-there (rqmt to standardize the external I/O protocol and format for all software units)

    Is-there (rqmt to standardize error handling for all software units)

    Use (a single, unique name for all references to the same function)

  - Data consistency (CS.2(6))

    Is-there (rqmt to standardize all data representation in the design)

    Is-there (rqmt to standardize the naming of all data)

    Is-there (rqmt to standardize the definition and use of global variables)

    Is-there (rqmt to establish consistency and concurrence of multiple copies of the same software or database version)

    Is-there (rqmt to verify consistency and concurrence of multiple copies of the same software or database version)

    Use (a single, unique name for all references to the same data)

- Traceability: (1) The degree to which a relationship can be established between two or more products of the development process, especially products having a predecessor-successor or master-subordinate relationship to one another; for example, the degree to which the requirements and design of a given software component match; (2) The degree to which each element in a software development product established its reason for existing; for example, the degree to which each element in a bubble chart references the requirement that it satisfied [IEEE, 1991].

  - Cross reference (TC.1(2))

12.1.3 Survivability/Availability

The concern with survivability is that software continue to perform (e.g., in a degraded mode) even when a portion of the system has failed.

- Anomaly Management (See section 12.1.1)

- Autonomy: Those characteristics of software which determine its non-dependency on interfaces and functions [Bowen et al., 1985; Dyson, 1991].
  - Interface complexity (AU.1(14)) [Bowen et al., 1985; Dyson, 1991; Murine, 1994]
    - Partitioned (all processes and functions to be logically complete and self-contained to minimize interface complexity)
  - Self-sufficiency (AU.2(2))
    - Is-there (rqmt for each operational CPU/system to have a separate power source)
    - Is-there (rqmt for the executive software to perform testing of its own operation and of the communication links, memory devices, and peripheral devices)
- Distributedness: Those characteristics of software which determine the degree to which software functions are geographically or logically separated within the system [Bowen et al., 1985; Dyson, 1991].
  - Design structure (DI.1(9)) [Bowen et al., 1985; Dyson, 1991; Murine, 1994]
    - Provide (graphic portrayal (e.g., figures, diagrams, tables) to identify all s/w functions and functional interfaces)
    - Provide (graphic portrayal to identify all different types of system-level information and the information flow within the system)
    - Is-there (rqmt for the organization and distribution of information within the system (e.g., information distributed across nodes or among storage devices))
    - Is-there (rqmt for file/library accessibility from each node)
    - Is-there (rqmt for providing alternate processing sources within the system (e.g., multiple processors, alternate node))
    - Is-there (rqmt to distribute all mission-critical functions over redundant elements or nodes)
    - Is-there (rqmt to distribute control functions across different nodes/elements so as to ensure system operation under anomalous conditions)
    - Is-there (rqmt for implementing functions across several physical structures (i.e., function and physical structure are not necessarily the same))
- Modularity: The degree to which a system or computer program is composed of discrete components such that a change to one component has minimal impact on other components [IEEE, 1991].
  - Modular implementation (MO.1(1)) [Bowen et al., 1985; Dyson, 1991; Murine, 1994]
    - Is-there (rqmt to develop all software functions and software elements according to structured design techniques (e.g., top-down design))
  - Modular design (MO.2(8))
    - Is-there (rqmt regarding the relationships among software entities (e.g., rqmts to minimize content, common and external coupling among software entities))

Is-there (rqmt regarding the relationships between the elements within software entities (e.g., all software entities are required to reflect an average cohesion value of 0.6 or greater))

- Reconfigurability: Those characteristics of software which provide for continuity of system operation when one or more processors, storage units, or communication links fails [Bowen et al., 1985; Dyson, 1991].

  - Restructure checklist (RE.1(4)) [Bowen et al., 1985; Dyson, 1991; Murine, 1994]

    Is-there (rqmt to ensure communication paths to all remaining nodes/communication links in the event of a failure of one node/link)

    Is-there (rqmt for maintaining the integrity of all data values following the occurrence of anomalous conditions)

    Is-there (rqmt to enable all disconnected nodes to rejoin the network after recovery, such that the processing functions of the system are not interrupted)

    Is-there (rqmt to replicate all critical data in the system at two or more distinct nodes)

12.1.4 Integrity

Integrity is defined by the degree to which a system or component prevents unauthorized access to, or modification of, computer programs or data [IEEE, 1991].

- System Accessibility: Those characteristics of software which provide for control and audit of access to the software and data [Bowen et al., 1985].

  - Access control (SS.1(4)) [Bowen et al., 1985; Dyson, 1991; Murine, 1994]

    Is-there (rqmt to control user input/output access in the system (e.g., login name and password))

    Is-there (rqmt to control data access in the system)

    Is-there (rqmt to control the scope of task operations during execution (e.g., privileged cmds))

    Is-there (rqmt to control access to the network)

  - Access audit (SS.2(4))

    Is-there (rqmt to record and report all access to the system (e.g., record terminal and processor linkage, data file access, and jobs run information))

    Is-there (rqmt to immediately indicate and identify all access violations)

    Is-there (rqmt to isolate I/O functions from computational functions)

12.1.5 Verifiability

Verifiability deals with software design characteristics affecting the effort to verify software operation and performance [Bowen et al., 1985; Dyson, 1991].

- Simplicity (see section 12.1.1 Reliability)

- Modularity (see section 12.1.3 Survivability/Availability)

- Self-Descriptiveness: Those characteristics of software which provide explanation of the implementation of functions [Bowen et al., 1985; Schulmeyer-McManus, 1992].

  - Quality of comments (SD.1(1)) [Bowen et al., 1985; Dyson, 1991; Murine, 1994]
  - Effectiveness of comments (SD.2(8))

    Standardize (each unit prologue with unit's function, author, version number, version date, inputs, outputs, algorithms, assumptions and limitations)

    Standardize (the identification and placement of comments in the unit)
  - Descriptiveness of language (SD.3(6))

    Standardize (format for the structure of units)

- Visibility: Those characteristics of software which provide status monitoring of the development and operation [Bowen et al., 1985; Dyson, 1991].

  - Unit testing (VS.1 (2)) [Bowen et al., 1985; Dyson, 1991; Murine, 1994]
  - Integration testing (VS.2 (1))
  - CSCI testing (VS.3 (3))

12.2 Interoperability

Interoperability is defined by the ability of two or more systems or components to exchange information and to use the information that has been exchanged [IEEE, 1991].

- Modularity (see section 12.1.3 Survivability/Availability)

- Commonality: Those characteristics of software which provide for the use of interface standards for protocols, routines, and data representations [Bowen et al., 1985; Dyson, 1991].

- Communications commonality (CL.1 (14)) [Bowen et al., 1985; Dyson, 1991; Murine, 1994]

  Is-there (rqmt for communication with other systems)

  Is-there (rqmt for a protocol standard to control all network communication)

  Standardize (network processing control using the network protocol standard)

  Standardize (user session control using the network protocol standard)

  Standardize (communication routing using the network protocol standard)

  Standardize (uniform message handling (e.g., synchronization, message decoding) using the network protocol standard)

  1 / # (input functions from other systems)

  1 / # (output functions from other systems)

- Data commonality (CL.2 (8))

  Is-there (rqmts for a standard to establish common representations of data for uniform communication with other system)

  1/ #(functions performed data translations)

  Is-there (rqmts to receive all input data from other systems in common formats)

  1 / (1 + #(different formats used for input data from other systems))

  Is-there (rqmts to output all data to other systems in common formats)

  1 / (1 + #(different formats used for output data from other systems))

- Common vocabulary (CL.3 (1))

  Is-there (a common technical vocabulary with equivalent definitions for this system and all interoperating systems)

- Functional Overlap: Those characteristics of software which provide common functions to both systems [Bowen et al., 1985; Dyson, 1991].

  - Function overlap checklist (FO.1 (4)) [Bowen et al., 1985; Dyson, 1991; Murine, 1994]

    1 - (#(duplicated functions in interoperating system) / #(functions))

- Independence: Those characteristics of software which determine its non-dependency on software environment (computing system, operating system, utilities, input-output routines, libraries) [Bowen et al., 1985; Dyson, 1991].

  - Software independence function system (ID.1 (3)) [Bowen et al., 1985; Dyson, 1991; Murine, 1994]

    Is-there (rqmts to use a standard subset of the implementation language)

    Establish (a standard subset of the implementation language for coding)

  - Machine independence (ID.2 (4))

    Support (same version and dialect of the implementation language on other machines)

- System/Interface Compatibility: Those characteristics of software which provide the hardware, software, and communication compatibility of two systems [Bowen et al., 1985; Dyson, 1991].

  - Communication compatibility (SY.1 (4)) [Bowen et al., 1985; Dyson, 1991; Murine, 1994]

    Is-there (rqmts for the I/O transmission rates of this system to be the same as the interoperating system)

    Is-there (rqmts for this system to use the same communication protocol as the interoperating system)

    Is-there (rqmts for common interpretation of the content in all messages sent from and received by this system and by the interoperating system)

    Is-there (rqmts for this system to use the same structure and sequence for message contents as the interoperating system)

  - Data compatibility (SY.2 (3))

    Is-there (rqmts for this system to use the same data format as the interoperating system)

    Is-there (rqmts for this system to establish the same data base structure as the interoperating system)

    Is-there (rqmts for this system to provide the same data base access techniques as the interoperating system)

  - Hardware compatibility (SY.3 (6))

    Is-there (rqmts for this system to use the same word length as the interoperating system)

    Is-there (rqmts for this system to use the same interrupt structure as the interoperating system)

    Is-there (rqmts for this system to use the same instruction set as the interoperating system)

  - Software compatibility (SY.4 (3))

    Is-there (rqmts for this system to use the same source code language as the interoperating system)

    Is-there (rqmts for this system to use the same supporting software as the interoperating system)

  - Document for other system (SY.5 (1))

    Is-there (documentation for interoperability rqmts with the interoperating systems)

12.3 Usability

Usability is defined by the ease with which a user can learn to operate, prepare inputs for, and interpret outputs of a system or component [IEEE, 1991].

- Operability (Mission orientation, Controllability): Those characteristics of software which determine operations and procedures concerned with operation of software [Schulmeyer-McManus, 1992] and which provide useful inputs and outputs which can be assimilated [Bowen et al., 1985].

- Operability checklist (OP.1 (16)) [Bowen et al., 1985; Dyson, 1991; Murine, 1994]

  Is-there (error reporting)

  Is-there (specification of response for errors)

  Is-there (interrupt capability by operator (e.g., stop, save and enter data, continue processing))

  1/ (1 + #(operations performed by the operator for a typical mission/job))

  Is-there (rqmts to specify the procedures for setting up a mission/job and completing it)

  Is-there (rqmts to maintain a hard copy log of all operator interactions with the system)

  Is-there (rqmts to provide simple and consistent operator messages and require simple and consistent operator responses)

  Is-there (rqmts to report all access violations to the operator)

  Is-there (rqmts specifying the appropriate responses for all access violation)

  Is-there (rqmts to provide the operator/user the capability to obtain specific system (or network) resource status information and to reallocation resources)

  Is-there (rqmts to provide the operator/user the capability to manipulate data regardless of the data's location in the system)

  Is-there (rqmts to make system implementation details transparent to the user (e.g., the user can access a file without knowing its location in the system)

- User input communicativeness (OP.2 (6))

  #(input parameters with default values) / #(input parameters)

  Is-there (rqmts to enable the user to review and modify all input data prior to execution)

  Is-there (rqmts to terminate all user-input data by explicitly defined logical end of input)

  Is-there (rqmts to provide the user options for input media (e.g., terminal, tape drive))

- User output communicativeness (OP.3 (8))

  Is-there (rqmts to provide the user with output control (e.g., output media, output format, amount of output))

  Is-there (rqmts for all outputs to the user to have unique, descriptive labels for identifying data)

  Is-there (rqmts for all error messages to clearly identify the nature of the error to the user)

  Is-there (rqmts to provide the user with options for output media)

  Is-there (rqmts to establish a standard (common) user command language for network information and data access)

- Training (Comprehensiveness): Those characteristics of software which provide transition from current operation and provide initial familiarization [Bowen et al., 1985; Schulmeyer-McManus, 1992].

  - Training checklist (TN.1 (4)) [Bowen et al., 1985; Dyson, 1991; Murine, 1994]

    Is-there (rqmts to provide lesson plans and training materials for operators, and users, and maintainers of the system)

    Is-there (rqmts to provide realistic simulation exercises for the system)

    Is-there (rqmts to provide "help" information and diagnostic information for the operator, end user, and maintainer of the system)

    Is-there (rqmts to provide selectable levels of aid and guidance for system users of different degrees of expertise)

12.4 Performance (Efficiency)

Performance is defined by the degree to which a system or component accomplishes its designated functions within given constraints, such as speed, accuracy, or memory usage [IEEE, 1991]. Efficiency is defined by the degree to which a system or component performs its designated functions with minimum consumption of resources [IEEE, 1991].

- Communication Efficiency (of Element Performance): Those characteristics of software which provide for minimum utilization of communication resources in performing functions [Bowen et al., 1985; Dyson, 1991].
  - Communication effectiveness measure (EC.1 (1)) [Bowen et al., 1985; Dyson, 1991; Murine, 1994]
    Is-there (performance rqmts and limitations for system communication efficiency)
- Processing Efficiency (of Element Performance): Those characteristics of software which provide for minimum utilization of processing resources in performing functions [Bowen et al., 1985; Dyson, 1991].
  - Processing effectiveness measure (EP.1 (6)) [Bowen et al., 1985; Dyson, 1991; Murine, 1994]
    Is-there (rqmt for processing efficiency (e.g., flow time for process, execution time))
    Is-there (rqmt to use an optimizing compiler or to code in assembly language to optimize processing efficiency)
    Is-there (rqmt for no overlays in memory management of the system)
  - Data usage effectiveness measure (EP.2 (7))
    Is-there (rqmt for efficiently storing data)
    Is-there (variable initialization when the variable is declared)
- Storage Efficiency (of Element Performance): Those characteristics of software which provide for minimum utilization of storage resources in performing functions [Bowen et al., 1985; Dyson, 1991].

- Storage effectiveness measure (ES.1 (8)) [Bowen et al., 1985; Dyson, 1991; Murine, 1994]

  Is-there (rqmt for storing data to efficiently utilize primary and secondary storage)
  Is-there (virtual storage)
  Is-there (dynamic reallocation of physical memory space during execution)
  Is-there (rqmt to use an optimizing compiler or to code in assembly language to optimize storage efficiency)

12.5 Adaptability

Adaptability is defined by the ease with which a system or component can be modified for use in applications or environments other than those for which it was specifically designed [IEEE, 1991].

- Simplicity (see section 12.1.1 Reliability/Accuracy)
- Modularity (see section 12.1.3 Survivability/Availability)
- Self-Descriptiveness (see section 12.1.5 Verifiability)

12.5.1 **Verifiability** (see section 12.1.5 Verifiability)

12.5.2 Flexibility

Flexibility is defined by the easy with which a system or component can be modified for use in applications or environments other than those for which it was specifically designed [IEEE, 1991].

- Generality: (1) The degree to which a system or component performs a broad range of functions [IEEE, 1991]. (2) Those attributes of the software that provide breadth to the functions performed [Schulmeyer-McManus, 1992].

  - Unit references (GE.1 (1)) [Bowen et al., 1985; Dyson, 1991; Murine, 1994]
  - Unit implementation (GE.2 (4))

12.5.3 Expandability

Expandability is defined by the easy with which a system or component can be modified to increase its storage or functional capability [IEEE, 1991].

- Generality (see section 12.5.2 Flexibility)

- Augmentability: Those characteristics of software which provide for expansion of capability for functions and data [Bowen et al., 1985; Dyson, 1991].

  - Data storage expansion (AT.1 (3)) [Bowen et al., 1985; Dyson, 1991; Murine, 1994]

    Is-there (rqmt for spare memory storage capacity)

    Is-there (rqmt for spare auxiliary storage capacity)

  - Computation extensibility (AT.2 (3))

    Is-there (rqmt for spare processing capacity (time))

  - Channel extensibility (AT.3 (2))

    Is-there (rqmt for spare I/O channel capacity (time))

    Is-there (rqmt for spare communication channel capacity (time))

  - Design extensibility (AT.4 (3))

    Is-there (rqmt for interface compatibility among all the processors, communication links, memory devices, and peripherals)

    Document (the results of any previous engineering studies such as tradeoff studies, feasibility studies, risk analyses, and requirements definitions)

    Document (new or emerging software-related disciplines which may affect the scope of the software requirements or the software implementation techniques)

- Virtuality: Those characteristics of software which present a system that does not require user knowledge of the physical, logical, or topological characteristics [Bowen et al., 1985; Dyson, 1991].

  - System data independence (VR.1 (1)) [Bowen et al., 1985; Dyson, 1991; Murine, 1994]

    Is-there (rqmt to make system implementation details transparent to the user (e.g., the user can create a file without specifying its location in the system/network))

12.5.4 Maintainability/Debuggability

Maintainability is defined by: (1) The easy with which a software system or component can be modified to correct faults, improve performance or other attributes, or adapt to a changed environment; (2) The easy with which a hardware system or component can be retained in, or restored to, a state in which it can perform its required functions [IEEE, 1991].

- Visibility (see section 12.1.5 Verifiability)

- Consistency: The degree of uniformity, standardization, and freedom from contradiction among the documents or parts of a system or component [IEEE, 1991].

  - Procedure consistency (CS.1 (5)) [Bowen et al., 1985; Dyson, 1991; Murine, 1994]

    Standardize (the calling sequence protocol between software units)
    Standardize (all design representation (e.g., representations for control flow, data flow))
    Standardize (external I/O protocol, format)
    Standardize (error handling)
    Is-there (a single, unique name to the same functions referred)

  - Data consistency (CS.2 (6))

    Standardize (all data representation in the design)
    Standardize (definition and use of global variables)
    Is-there (rqmts to establish consistency and concurrency of multiple copies of the same software or data base version)
    Is-there (rqmts to verify consistency and concurrency of multiple copies of the same software or data base version)
    Is-there (a single, unique name to the same data referred)

12.6 Development Cost and Schedule

The cost and schedule for developing the software including design, coding, and testing.

12.7 Reusability

Reusability is the degree to which a software module or other work product can be used in more than one computer program or software system [IEEE, 1991].

- Simplicity (see section 12.1.1 Reliability/Accuracy)
- Modularity (see section 12.1.3 Survivability/Availability)
- Self-Descriptiveness (see section 12.1.5 Verifiability)
- Independence (see section 12.2 Interoperability)
- Generality (see section 12.5.2 Flexibility)
- Application Independence: Those characteristics of software which provide full implementation of the function required [Bowen et al., 1985].
  - Database management implementation independence (AP.1 (1)) [Bowen et al., 1985; Dyson, 1991; Murine, 1994]

    Is-there (rqmts to limit specific references to the data base management scheme)
  - Data structure (AP.2 (4))

    Standardize (commenting all global data within a software unit to show where data is derived, the data's compositions, and how the data is used)

    Standardize (commenting all parameter input/output and local variables within a software unit which includes requirements identifying the data's composition and use)
  - Architecture standardization (AP.3 (2))

    Is-there (rqmts to localize specific references to computer architecture (e.g., specific device references localized to the executive rather than the application software))
  - Microcode independence (AP.4 (1))

    Is-there (rqmts to avoid or to limit the use of microcode instruction statements)
  - Functional independence (AP.5 (3))

    Is-there (rqmts to develop functional processing algorithms such that they are not unique to this system's application)

- Document Accessibility: Those characteristics of software which provide for easy access to software and selective use of its components [Bowen et al., 1985; Dyson, 1991].
  - Access to document (DO.1 (1)) [Bowen et al., 1985; Dyson, 1991; Murine, 1994]
    Access (current versions of all software documentation)
  - Well-structural document (DO.2 (8))
    Specify (all documentation, clearly and simply such that procedures, functions, algorithms can be easily understood)
    Specify (control and data flow with graphic portrayal, clearly)
    Is-there (indexing scheme for all documents)
    Is-there (separated volumes or separations within a single volume based on system functions)
    Is-there (comprehensive descriptions of all system/software functions)
- Functional Scope: Those characteristics of software which provide commonality of functions among applications [Bowen et al., 1985; Dyson, 1991].
  - Functional specificity (FS.1(2)) [Bowen et al., 1985; Dyson, 1991; Murine, 1994]
  - Functional commonality (FS.2(6))
    Is-there (rqmts to construct functions in such a way to facilitate their use in other similar system applications)
    Document (specific use and limitations of the data)
    Document (input/output formats)
    Document (outputs as to the specific use and interpretation of the data)
  - Functional selective usability (FS.3(3))
    Is-there (rqmts to provide the user options for computation and output (e.g., selection of type of coordinate system, output media, format))
    Is-there (rqmts to enable modification of the resources allocated to functions (e.g., changing the amount of memory work space for a function))
- System Clarity: Those characteristics of software which provide for clear description of program structure in a non-complex and understandable manner [Bowen et al., 1985; Dyson, 1991].
  - Interface complexity (ST.1 (6)) [Bowen et al., 1985; Dyson, 1991; Murine, 1994]
  - Program flow complexity (ST.2 (5))
  - Application functional complexity (ST.3 (6))
    Is-there (rqmts to isolate I/O functions from computational function)

- Communication complexity (ST.4 (5))
- Structure clarity (ST.5 (4))

13.0 Appendix B: Quality Attribute Strategies (QAS)

QAS 1. Accuracy Engineering

Definition:

- Adjust and balance the accuracy of inputs and outputs of each component in the system based on required and desired accuracy criteria.

Preconditions:

- Required and desired accuracy level, measure of accuracy, criteria for the optimum state of accuracy

Postconditions (Suggestions for achieving relevant quality attributes or their results):

- Get efficient and accurate outputs of the system with reasonable resources.

Effects on quality attributes:

- Dependability: (+, more accurate with available resources)
- Performance (+, more efficient by removing heavy processing for unnecessary component accuracy in the system viewpoint)
- Cost, Schedule: (-, more to specify, develop, and verify)

QAS 2. Backup/Recovery (see appendix 14.0)

QAS 3. Buy Faster Hardware (see appendix 14.0)

QAS 4. Change-source Hiding (see appendix 14.0)

QAS 5. Descoping

Definition:

- Reduce or defer the number of components or their quality.

Preconditions:

- Prioritize the components or quality based on their importance.
- Identify dependencies of the components

Postconditions (Suggestions for achieving relevant quality attributes or their results):

- Capabilities unavailable to stakeholders
- Need to pay later if deferred

Effects on quality attributes:

- Adaptability: (+, easy to maintain unless adaptability features descoped)
- Usability: (-, capabilities unavailable to users)
- Cost, Schedule: (+, reduce development cost and schedule; -, increase maintenance cost)

QAS 6. Diagnostics (see appendix 14.0)

QAS 7. Domain architecture-driven (see appendix 14.0)

QAS 8. Error-reducing user input/output, Input Checking, Input assertion/type checking (see appendix 14.0)

QAS 9. Fault-tolerance functions (see appendix 14.0)

QAS 10. Generality

Definition:

- Units of software are general if they provide a service for more than one function, that is, if two or more software components request them.

Preconditions:

- A primitive function that can have many uses, general unit interface.

Postconditions:

- Use object managers wherever possible
- Avoid mixing input, processing, and output in one unit.
- Parameterize limits on input data structure size and data item values

Effects on quality attributes:

- Adaptability, Interoperability (+, more flexible to be modifiable, portable, or interoperable)

- Performance (-, may need additional codes to generalize)
- Cost, Schedule: (-, more to specify, develop, and verify)

QAS 11. Help/explanation

Definition:
- Messages or message windows for helping tool users with operation.

Preconditions:
- Description of functions; User guide for the functions or programs

Postconditions (Suggestions for achieving relevant quality attributes or their results):
- Reduce the tool learning efforts (e.g., cost and schedule)

Effects on quality attributes:
- Usability: (+, easier to use the tool)
- Cost, Schedule: (-, more to specify, develop, and verify)

QAS 12. Integrity functions

Definition:
- Integrity means that the user is reasonably certain that software and data are not being tampered with or stolen

Preconditions:
- Access violation codes and policy (e.g., improper access logging causes automatic disconnection)

Postconditions (Suggestions for achieving relevant quality attributes or their results):
- Limit user access by user identification and passwords
- Control data access by authorization tables
- Control the scope of task operations during execution
- Control network access by authorization tables
- Keep logs of all system accesses
- Output alerts in case of access violations
- Allow only valid data-base operations
- Monitor data bases to ensure that they are valid
- Design in the ability to disconnect any interfacing system
- Password-protect files from unauthorized access
- Disallow unauthorized modifications to software
- Protect against loss of services by inadvertent actions
- Disallow bypass of security features

Effects on quality attributes:
- Dependability: (+, avoids undesirable states)
- Performance (-, needs additional processing to check or verify user accesses)
- Cost, Schedule: (-, more to specify, develop, and verify)

QAS 13. Interface specification

Definition:
- Specification of the interface with formal or informal description

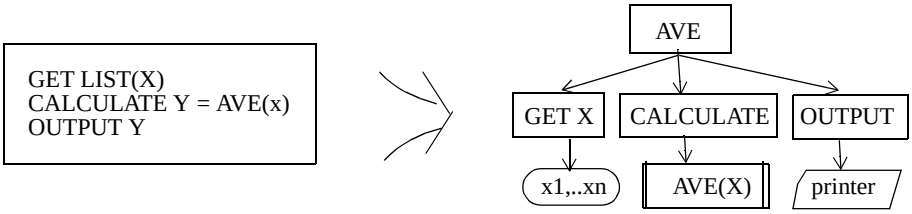
Preconditions:
- Description language for interface

Postconditions:
- Identify the mismatching interfaces
- Understand interactions among components better

Effects on quality attributes:
- Adaptability, Interoperability, Dependability, Reusability: (+, clearer to understand interfaces)
- Cost, Schedule: (-, more to specify, develop, and verify)

QAS 14. Layering (see appendix 14.0)

QAS 15. Modularity



Definition:
- Software is modular if it is designed and implemented with all of the modern techniques that lead to an orderly, cohesive component structure with optimum coupling.

Preconditions:
- Definition of optimum coupling; compatible design units

Postconditions (Suggestions for achieving relevant quality attributes or their results):
- Maximize the cohesion of units
- Minimize the complexity and volume in unit coupling
- Separate each unit into a specification, declaration, and execution part.
- Use a structured design and testing technique.
- Make a design unit have a single processing objective.

Effects on quality attributes:
- Dependability, Adaptability, Interoperability: (+, easy to trace and understand components)
- Cost, Schedule: (-, more to specify, develop, and verify)

QAS 16. Monitoring & Control (see appendix 14.0)

QAS 17. Navigation

Definition:
- The system has a capability of browsing from one place to another

Preconditions:
- Navigation method, algorithm, or graphic representation

Postconditions (Suggestions for achieving relevant quality attributes or their results):
- Navigate the system through “Zoom In/ Zoom Out”;

Effects on quality attributes:
- Usability (+, Users can get an easy access of what they want)
- Cost, Schedule: (-, more to specify, develop, and verify)

QAS 18. Optimization

Definition:
- Optimization of used memory, size of program, execution time

Preconditions:
- Optimization algorithm for memory, disk space, and execution time.

Postconditions:
- Use optimization compiler
- Tradeoffs may exist among components (e.g., disk space vs. execution time)

Effects on quality attributes:
- Adaptability: (-, difficult to change codes with sustaining the optimum state)
- Performance (+, fast due to optimization of memory, disk space, and execution time)
- Cost, Schedule: (-, more to specify, develop, and verify)

QAS 19. Parametrization (see appendix 14.0)

QAS 20. Platform-feature exploitation

Definition:
- Take advantage of features of the platform

Preconditions:
- Feature list; conditions for applying the useful features into your application

Postconditions (Suggestions for achieving relevant quality attributes or their results):
- Use and maximize the usefulness of system features.

Effects on quality attributes:
- Adaptability, Interoperability: (-, due to incompatible features across multiple platforms)
- Performance (+, platform-oriented instruction can reduce the overhead of generality)
- Cost, Schedule: (-, need the knowledge of platform-feature; +, if programmer knows about a platform well)

QAS 21. Portability functions

Definition:
- Portability means that the software may be used on several different operating systems or computers

Preconditions:
- General mechanism to support different platforms or environments

Postconditions (Suggestions for achieving relevant quality attributes or their results):
- Increase the system modularity
- Increase independency among modules
- Increase self-descriptiveness of modules

Effects on quality attributes:
- Adaptability, Interoperability: (+, easy to port)
- Performance (-, needs additional processing to generalize modules)
- Cost, Schedule: (-, more to specify, develop, and verify)

QAS 22. Redundancy (see appendix 14.0)

QAS 23. Self-containedness

Definition:
- Software is self-containedness if it includes tools, data bases, and procedures when the software is delivered, so that the software works fine in any circumstance.

Preconditions:
- The contained software should not be too big and portable to general platform

Postconditions (Suggestions for achieving relevant quality attributes or their results):
- Make it a library functions

Effects on quality attributes:
- Adaptability: (+, easy to port)
- Cost, Schedule: (-, more to specify, develop, and verify)

QAS 24. UI consistency

Definition:
- UI is consistent when the same standards are used throughout the design and implementation of UI, for example, when one can be assured that the data name “x” in one screen refers to the same item “x” referred to another screen.To achieve consistency, it is necessary to establish standards before the design and implementation effort begins and to ensure that the standards are uniformly enforced.

Preconditions (Components):
- Consistency rules; more general and standard representation/formats

Postconditions (Suggestions for achieving relevant quality attributes or their results):
- Standardize the data representation format
- Standardize the design representation
- Standardize data and functions naming
- Standardize global data definition and use
- Standardize interunit communication protocols
- Standardize input/output (I/O) protocol and formats
- Standardize error-handling functions and protocols
- Use a single, unique name for each data item and function
- Ensure consistency of multiple versions of data bases

Effects on quality attributes:
- Usability: (+, easy to learn due to standardization)
- Adaptability, Interoperability, Reusability: (+, if standard may be easy to port and modify across platforms)

- Dependability: (+, easy to reduce errors due to standardization)
- Cost, Schedule: (-, more to specify, develop, and verify)

QAS 25. UI flexibility

Definition:
- UI flexibility means that the software is readily adaptable, via a user interface or change of data, to a wide range of different environments without immediately resorting to expendability-type changes.

Preconditions:
- Support the commonality and consistency across difference platforms

Postconditions (Suggestions for achieving relevant quality attributes or their results):
- Make program organization general enough.
- Separate common modules with unique ones for different platforms and environments

Effects on quality attributes:
- Usability: (+, support various user needs)
- Performance (-, needs additional processing to support the variety of UI)
- Cost, Schedule: (-, more to specify, develop, and verify)

QAS 26. Understandability (Self-descriptiveness)

Definition:
- Software is understandable if a reader of the design or source code can easily understand how a function has been implemented, that is, if the software is a self-documented description of itself.

Preconditions:
- comments included in the code with their effectiveness

Postconditions:
- Document the results of decisions in design representations
- Identify external interfaces in design representations
- Establish standards for writing unit prologues, commenting, and structuring code
- Follow established unit standards
- Establish and follow standards for global data commenting
- Provide comments for all decision points and transfers of control
- Use a higher order language (HOL) wherever possible
- Provide comments for all nonstandard HOL statements
- Provide comments for all data item attributes(e.g., range and accuracy)
- Provide comments on the ranges of values and defaults for all unit inputs
- Logically block and indent code
- Do not overload the meanings of keywords in the programming language
- Describe the purpose or intent of the code in code comments
- Describe the properties of data items in the names of the data item

Effects on quality attributes:
- Adaptability, Interoperability, Reusability: (+, easy to understand; fast to modify)
- Performance (depend on)
- Cost, Schedule: (-, more to specify, develop, and verify)

QAS 27. Undo

Definition:
- Back to the original state as if a command wasn’t executed

Preconditions:
- The results of the command should be recoverable

Postconditions (Suggestions for achieving relevant quality attributes or their results):
- Use log or status files

Effects on quality attributes:
- Dependability: (+, avoids undesirable states)
- Usability: (+, avoid unnecessary actions to go back to the original state)
- Cost, Schedule: (-, more to specify, develop, and verify)

QAS 28. User-programmability

Definition:
- The system has capabilities for interpreting or compiling programs to customize user interfaces or functions.

Preconditions:
- Clear, simple, but general enough to program the capabilities
- Primitive instruction/command set

Postconditions (Suggestions for achieving relevant quality attributes or their results):
- Decide which capabilities the users may want
- Error checking / Debugger would be helpful

Effects on quality attributes:
- Usability: (+, support user flexibility)
- Performance (depend on)
- Cost, Schedule: (-, more to specify, develop, and verify)

QAS 29. User-tailorability

Definition:
- The system has capabilities for determining User's preferences (e.g., font, color, view, window size and position) and environments (e.g., directory, default file, environment variables).

Preconditions:
- Preferences and environments preserved in this application

Postconditions (Suggestions for achieving relevant quality attributes or their results):
- Make the system more general by choosing the options from the users.
- Provide a default set.

Effects on quality attributes:
- Usability: (+, support user preferences)
- Cost, Schedule: (-, more to specify, develop, and verify)

QAS 30. Verifiability

Definition:
- Verifiability means that it is simple to certify that the software is correct.

Preconditions:
- Automatic self-testing; a library of standard test programs.

Postconditions (Suggestions for achieving relevant quality attributes or their results):
- Certify that the software is correct (by black-box and/or white-box tests, or theory proving techniques)

Effects on quality attributes:
- Dependability: (+, avoids undesirable states)
- Performance (-, needs additional processing)
- Cost, Schedule: (-, more to specify, develop, and verify)

QAS 31. Visibility

Definition:
- Software is visible if there is insight into its progress as regards coding and testing. Insight is gained through objective evidence of the correct functioning of the software during execution, primarily through the thoroughness of testing and the success of the test results.
- Visibility is equally applicable to both initial development and maintenance changes. It is added to the software by embedding self-testing in the code and through completeness of software testing procedures.

Preconditions (Components, Conditions for being applicable):
- Testing objective, criteria, drivers, and evaluation; The software should be testable and its result interpretable.

Postconditions (Detailed actions for achieving the above strategy):
- Provide tests for all software performance requirements
- Design test scenarios to maximize the number of units tested
- Document inputs and outputs for performance test cases
- Provide tests for all unit-to-unit interface
- Provide tests for all parameters in each unit interface
- Provide test for all execution paths in each unit
- Add monitors to detect intermittent errors and marginal performance
- Add built-in test software to isolate defective components

Effects on quality attributes:

- Dependability: (+, avoids undesirable states)
- Cost, Schedule: (-, more to specify, develop, and verify)

14.0 Appendix C: Architecture Strategies (AS)

14.1 List of Architecture Strategies

AS 1. Backup/Recovery

Definition:
- Additional resources or duplicate copies of data on different storage media for emergency purposes.

Preconditions:
- Backup file list and backup policy (e.g., backup frequency)

Postconditions (Type of Backup/Recovery):
- Full Backup/Recovery: Back up or recover all selected files.
- Differential Backup/Recovery: Back up or recover selected files that have been changed. This is used when only the latest version of a file is required.
- Incremental Backup/Recovery: Back up or recover selected files that have been changed, but if a file has been changed for the second or subsequent time since the last full backup, the file doesn't replace the already-backed-up file, rather it is appended to the backup medium. This is used when each revision of a file must be maintained.
- Delta Backup/Recovery: Similar to an incremental backup/recover, but back up or recover only the actual data in the selected files that has changed, not the files themselves.

Effects on quality attributes:
- Dependability: (+, avoid loss of important data or resources by backup/recovery)
- Performance, Adaptability: (-, need additional processing resources for backup)
- Cost, Schedule: (-, more to specify, develop, and verify)

AS 2. Buy Faster Hardware

Definition:
- The hardware which has fast CPU time, disk access time, instruction execution time, bandwidth

Preconditions:
- Cost effectiveness; good ROI (Return On Investment)

Postconditions:
- Faster CPU, faster disk access, faster bandwidth

Effects on quality attributes:
- Performance (+, can execute an instruction faster than ever)
- Cost, Schedule: (-, hardware cost)

AS 3. Change-source Hiding

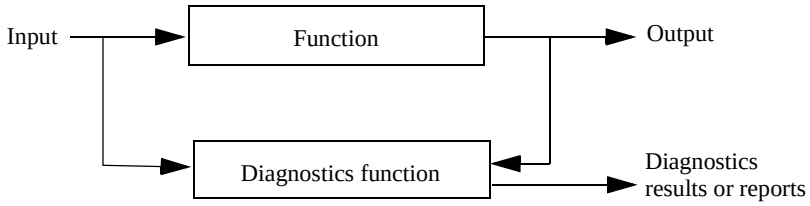
Definition:
- A technique that sources of change are hidden within module

Preconditions:
- Identify sources of change

Postconditions (Suggestions for achieving relevant quality attributes or their results):
- Sources of change hidden within module

Effects on quality attributes:
- Adaptability, Interoperability, Reusability: (+, the change does not affect module interface)
- Cost, Schedule: (-, more to specify, develop, and verify; +: less rework)

AS 4. Diagnostics



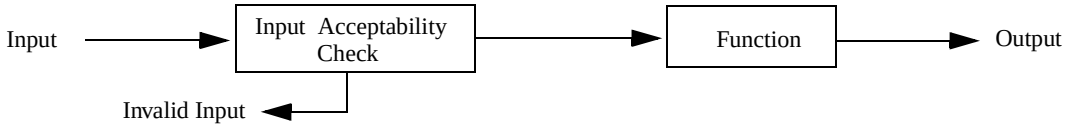
Definition:
- An architectural composition diagnosing that the function is running well

Preconditions:
- Diagnostics criteria and algorithms

Postconditions:
- Diagnose what's wrong and report it.

Effects on quality attributes:
- Dependability: (+, avoids undesirable states)
- Performance: (-, needs additional processing)
- Cost, Schedule: (-, more to specify, develop, and verify; +, less debugging, rework)

AS 5. Error-reducing user input/output, Input Checking, Input assertion/type checking



Definition:
- An architectural composition that precedes a function by an acceptability check of its inputs

Preconditions:
- Candidate inputs, acceptability criteria

Postconditions:
- If valid, pass input into the Function, otherwise, indicate "Invalid Input" and exit.

Domain Independent Effects on quality attributes[1]:
- Dependability: (+, unacceptable inputs filtered out)
- Usability: (+, fast revision for the invalid input)
- Adaptability: (-, more efforts to extend the functions)
- Performance: (-, needs more execution time)

AS 6. Fault-tolerance functions

Definition:
- It is defined as the ability of a system to respond gracefully to an unexpected hardware or software failure. There are many levels of fault tolerance, the lowest being the ability to continue operation in the event of a power failure. Many fault-tolerant computer systems mirror all operations -- that is, every operation is performed on two or more duplicate systems, so if one fails the other can take over[2].

Preconditions:
- fault detection algorithms

Postconditions (Suggestions for achieving relevant quality attributes or their results):
- Recover a failed system due to hardware or software errors such as power failure, hardware component failure (e.g., clock interrupts, I/O device errors), arithmetic faults, and network or communication errors
- Prevent invalid input errors (e.g, wrong range of input, different input type) before the errors cause whole

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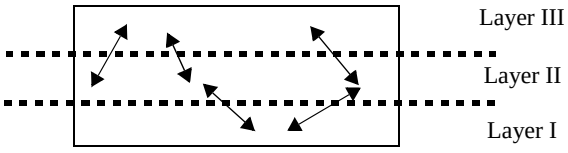
1. The detailed analysis of conditions under which these will be problems is available in appendix 14.2.
2. PC Webopaedia Definition and Links, 1997, http://www.pcwebopedia.com

system clash.
- Use alternatives or redundant resources (e.g., another hardware or software components) when errors occur
- Avoid the propagation of failures resulting from errors

Effects on quality attributes:
- Dependability: (+, avoids undesirable states)
- Performance (-, need additional processing to avoid failures)
- Cost, Schedule: (-, more to specify, develop, and verify)

AS 7. Layering



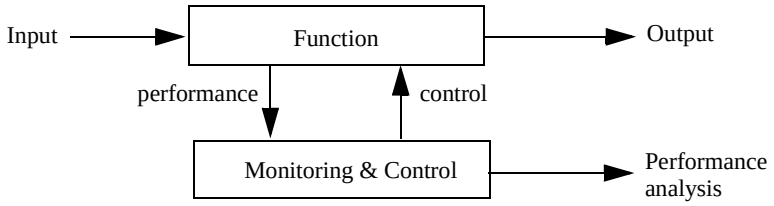
Definition:
- A hierarchical architectural composition in which each layer can communicate only with the adjacent upwards or downwards layer

Preconditions:
- Interface and protocol between a layer and an adjacent layer, request to pass data and/or control from layer to layer

Postconditions:
- Data and/or control passed from layer to layer, or notification of interface/protocol violation

Effects on quality attributes[1]:
- Adaptability, Interoperability, Reusability: (+, hide sources of variation inside interface layers)
- Performance (-, need more interfaces, and data and/or control transfers, via protocol)
- Cost, Schedule: (-, more to specify, develop, and verify)

AS 8. Monitoring & Control for Performance (or for Assurance)



Definition:
- An architectural composition that 1) monitors the performance (or dependability) of a function, 2) controls configuration or environment to stabilize the function (e.g., to avoid buffer overflows), and 3) reports results of subsequent performance (or dependability) analysis.

Preconditions:
- Monitoring instrumentation, control limits and algorithms.

Postconditions:
- If the function is stable, check the performance and report it. Otherwise, it stabilizes the function by controlling the configuration or environment.

Effects on quality attributes:
- Dependability: (+, avoids undesirable states)
- Performance: (-, needs additional processing in short term; +, improves performance in long term via system tuning)
- Cost, Schedule: (-, more to specify, develop, and verify)

AS 9. Parametrization

Definition:

---

1. The detailed analysis of conditions under which these will be problems is available in appendix 14.2.

- A parameter-driven program solves a problem that is partially or entirely described by the values (i.e., parameters) that are entered at the time the program is loaded.

Preconditions:

- Well-defined parameters for good interfaces

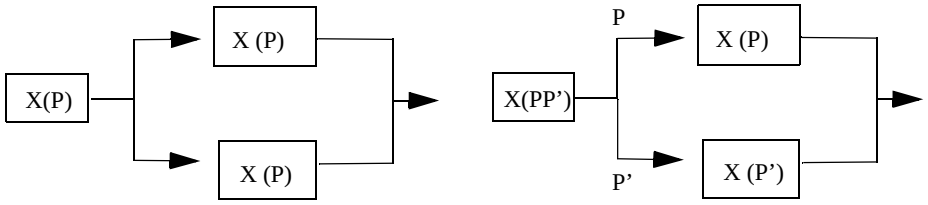
Postconditions (Suggestions for achieving relevant quality attributes or their results):

- Parameter-driven software is widely used when a program or an object is called for and loaded by another program or object rather than by the user.

Effects on quality attributes:

- Adaptability, Interoperability, Reusability: (+, provide good interfaces)
- Cost, Schedule: (-, more to specify, develop, and verify)

AS 10. Redundancy



(a) Redundancy for Dependability (by duplicating and executing the same function)

(b) Redundancy for Performance (by dividing a function into multiple components and executing them simultaneously)

Definition:

- An architectural composition that replicates components or data

Preconditions:

- Redundant components or data
- Redundant policy (e.g., disk array policy for duplicating data across disks)
- The amount of redundancy in a system

Postconditions (Suggestions for achieving relevant quality attributes or their results):

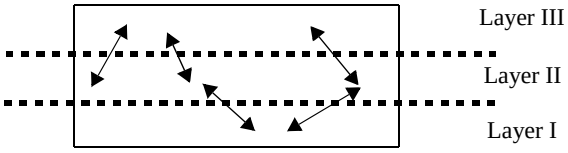
- Increase parallelism by dividing a single function among several components in diagram (a)
- Increase redundancy by performing the same operation across several components in diagram (b)
- Tradeoffs between Performance and Dependability

Effects on quality attributes:

- Dependability: (+, the failure of a single duplicated component may not cause the entire operation to fail in diagram (a); -, the failure of any of the parallel components may cause the entire operation to fail in diagram (b))
- Performance: (+, may increase throughput by parallelism in diagram (b))
- Adaptability (-, needs additional efforts to modify)
- Cost, Schedule: (-, more to specify, develop, and verify)

14.2 Examples of Elaboration of Architecture Strategies

Example 1.Layering



Definition:

- A hierarchical architectural composition in which each layer can communicate only with the adjacent upwards or downwards layer

Preconditions:

- Interface and protocol between a layer and an adjacent layer
- Request to pass data and/or control from layer to layer

Postconditions:

- Data and/or control passed from layer to layer
- Notification of interface/protocol violation

Effects on quality attributes:

- Evolvability, Interoperability, Portability, Reusability: (+, hide sources of variation inside interface layers)
- Performance (-, need more interfaces, and data and/or control transfers, via protocol)

--> However, it is possible that passing data and/or control may not reduce performance in case of transferring the pointer of data buffer rather than data itself.

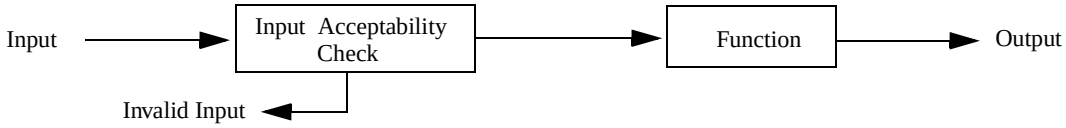
--> If each layer is implemented at different sites or processors (i.e., the data transfer via network is needed), the data volume is the key factor to determine Performance.

* (Data transfer time from one layer to its adjacent layer) $\propto$ (frequency of data transfer) * (the number of transaction per each data transfer) * (transfer time per each transaction per data per routing) * (data size) * (number of routing per each transaction per data)
* Performance $\propto$ (the number of layer which is affected by data transfer) * (data transfer time from one layer to adjacent layer) = $\sum$ ($layer_i$)(data transfer $time_i$)
* The transfer-time delay (due to network bottleneck) is propagated from the bottom layer to top layer because of the constraints of the layer definition (i.e., each layer can communicate only with the adjacent upwards or downwards layer). Thus, the performance of overall layer system can be reduced abruptly (i.e., the delay time of overall system = (the number of layers) * $\sum$ (the delay time in a layer)

- Cost, Schedule: (-, more to specify, develop, and verify; +, reduce rework)

--> I am not sure that the effort of making layers can be captured by SLOC. It is easy to separate a function into two functions by adding just one line, which is a function-call specification. Layering is a matter of control according to the constraint of the layer definition.

Example 2.Error-reducing user input/output, Input Checking, Input assertion/type checking



Definition:

- An architectural composition that precedes a function by an acceptability check of its inputs

Preconditions:

- Candidate inputs, acceptability criteria

Postconditions:

- If valid, pass input into the function, otherwise, indicate "Invalid Input" and exit.

Domain Independent Effects on quality attributes:

++, Dependability (-> Reliability -> Anomaly_Management -> Improper input data)[1]: unacceptable inputs filtered out

++, Survivability (-> Reliability -> Anomaly_Management -> Improper input data): unacceptable inputs filtered out

+, Dependability (-> Reliability -> Anomaly_Management -> computation failures): unacceptable inputs filtered out

-, Adaptability (-> Expandability -> Augmentability -> Computation extensibility): more efforts to extend the functions.

--, Performance (-> Effectiveness Processing -> Processing effectiveness measure): needs more execution time

Domain Dependent Effects on quality attributes:

if (Candidate inputs = "integers or characters string") and
(acceptable criteria = "the input is valid type and in right range")
then, (++, Dependability -> Accuracy -> Accuracy_checklist)
(++, Dependability -> Reliability -> Anomaly_Management -> Improper input data)
(-, if validation checking algorithm is dependent on machine platform,
Interoperability -> Hardware_compatibility -> word_length; instruction_set)

if (Candidate inputs = "ID") and
(acceptable criteria = "the input is valid type and the input is in current DB)
then, (++, Dependability -> Reliability -> Anomaly_Management -> Improper input data)
(-, if the size of DB is large or DB is distributed across network,
Performance -> Effectiveness_Processing -> Processing_effectiveness_measure)

if (Candidate inputs = "natural language") and
(acceptable criteria = "valid grammar and semantics")
then, (++, Dependability -> Reliability -> Anomaly_Management -> Improper input data)
(--, Performance -> Effectiveness_Processing -> Processing_effectiveness_measure)
- (--, Cost_Schedule)

1. It means that this strategy affects on "Improper input data" under "Anomaly Management" under "12.1.1 Reliability/Accuracy" under "12.1 Dependability" in chapter 12.