Analysis and Evaluation of Methods for Activities in the Expanded Requirements Generation Model (x-RGM)

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(ABSTRACT)

In recent years, the requirements engineering community has proposed a number of models for the generation of a well-formulated, complete set of requirements. However, these models are often highly abstract or narrowly focused, providing only pieces of structure and parts of guidance to the requirements generation process. Furthermore, many of the models fail to identify methods that can be employed to achieve the activity objectives. As a consequence of these problems, the requirements engineer lacks the necessary guidance to effectively apply the requirements generation process, and thus, resulting in the production of an inadequate set of requirements.

To address these concerns, we propose the expanded Requirements Generation Model (x-RGM), which consists of activities at a more appropriate level of abstraction. This decomposition of the model ensures that the requirements engineer has a clear understanding of the activities involved in the requirements generation process. In addition, the objectives of all the activities defined by the x-RGM are identified and explicitly stated so that no assumptions are made about the goals of the activities involved in the generation of requirements. We also identify sets of methods that can be used during each activity to effectively achieve its objectives. The mapping of methods to activities guides the requirements engineer in selecting the appropriate techniques for a particular activity in the requirements engineering process. Furthermore, we prescribe small subsets of methods for each activity based on commonly used selection criteria such that the chosen criterion is optimized. This list of methods is created with the intention of simplifying the task of choosing methods for the activities defined by the x-RGM that best meet the selection criterion goal.

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Introduction

1. Introduction

This thesis presents the synchronization of methods/techniques with requirement engineering activities, which are conducted by the requirements engineer to obtain a well-defined requirement specification. This chapter motivates the need for this research, and introduces the research issues involved and the solution approach taken to address them.

1.1 State of Affairs in the Software Industry

Beginning in the early seventies, the software industry has seen an increase in the complexity of the applications developed. However, the software methodologies in the seventies were inadequate for complex and large scale projects; this resulted in frequent budget overruns and schedule delays. To overcome these problems, it was necessary to modify software development approaches in order to cope with project complexities.

The software industry of the present day has a better understanding of the activities involved in the development of software. The different phases of development have been identified and organized in the form of life cycle models, which have provided a much needed structure to the development process [Sud 2003]. In addition, several techniques have been proposed to support the various activities in the software development life

cycle [Leffingwell 2000]. However, these advances have not ended the problems encountered during software development; projects continue to exceed budget and schedule constraints. An additional problem is that the software delivered often does not meet the customer's intent.

In the sections that follow, we provide a brief description of the software development life cycle and its evolution.

1.1.1 Software Development Life Cycle Approach

In order to address the initial of lack of structure in the software development process, several models were proposed. These models typically contained the following phases: Requirements Analysis, Design, Implementation, Integration and Testing, and Maintenance [Pressman 2001].

The first software development life cycle model (SDLC) that was proposed was the Waterfall Model [Royce 70], which placed these phases in a sequential order as shown in Figure 1.

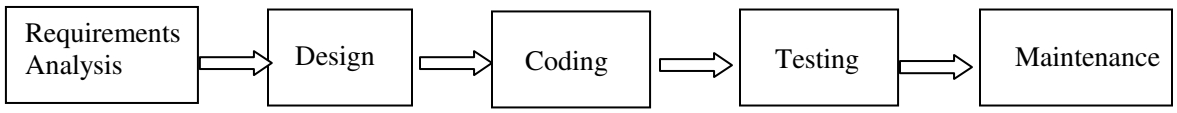


Figure 1.1 Waterfall model

The objectives of each of these phases are given below:

- **Requirements Analysis**: This phase involves understanding the function, behavior, performance and interface of the proposed system. In addition, the software requirements are documented and reviewed by the customer.
- **Design**: It involves translating requirements into a system representation that can be assessed for quality before coding begins. The focus is on data structures, software architecture, interface representation and algorithmic details.
- **Coding**: This phase translates design into a machine readable form.
- **Testing**: This involves conducting tests to uncover errors in code and to ensure that the results produced are correct for a given input.

- **Maintenance**: This phase is necessary to incorporate changes to the software.

The drawback to the waterfall model is its rigidity and its oversight of requirements creep [Carter 2001]. However, the model did identify the major software development phases which formed the core of the models proposed thereafter.

To overcome inadequacies of the waterfall model, several other models such as the iterative enhancement model [Basili 75], prototyping model [Gomma 81], spiral model [Boehm 88], and Extreme Programming [Beck 99] have been proposed.

1.1.2 Shifting Focus in the SDLC

With the advent of the SDLC models, the phases in the development process became more apparent. However, the techniques and activities for these phases were still not clearly defined; this resulted in the software engineer having difficulties in conducting the different phases. Hence, it was crucial to begin refining the SDLC phases in order to provide the necessary guidance on performing these phases during the development process.

Although logic dictates that attention should be directed towards the first SDLC phase, requirements analysis, most of the examination emphasis was initially placed on the end product. As a result, we have seen the re-examination and phase refinement being addressed in reverse order [Groener 2002]. Studies show that 60-70% of the product life cycle is spent in the maintenance phase [Bravo 93]. The high cost and difficulty of maintaining code prompted the software engineers to focus on the testing phase. Techniques for black box and white box testing were identified and used extensively for the detection on errors in code [IPL 96]. Testing was further facilitated by tools which automated testing methods.

On analyzing the code during testing, it was realized that the code was being written in an ad-hoc fashion, which made the code difficult to comprehend. Hence, coding guidelines were developed; this improved the readability and understandability of the code.

Integrated Development Environments (IDE)[1] were developed to help the programmers in writing and debugging the code.

After the coding phase, the refinement focus shifted to the design phase. The design phase was broken down to high level and low level phases on realizing that "step-wise" refinement, (solving complex problems by breaking them down to smaller units) could be successfully applied to design. The high level phase provides an abstract view of the design whereas low level design is more detailed and refined [Robertson 99]. Besides this development, new design paradigms, such as the object-oriented paradigm, were proposed as it helped in adding better structure and maintainability to the code. Design notations, such as those proposed by the Unified Modeling Language (UML), and supporting tools were developed for better design representations [Jacobson 99].

The requirements analysis phase was the last phase to receive attention from the software engineering community, and it is only in recent years that a meaningful refinement of this phase is taking place. Prior to this, the somewhat inappropriate name "Requirements Analysis" contributed to the perception that activities like problem analysis and elicitation were minor ones [Davis 93].

1.2 Importance of Requirements

The focus on the requirements phase is crucial as a system is only as good as its requirements. Moreover, all of the other phases in the SDLC depend on the requirements phase in one way or another. The importance of requirements is continuously reinforced as we recognize the manifold relationships between the quality of the product and the quality of the requirements from which the product is developed [Sidky 2003]. In addition, empirical studies have shown that incomplete, inconsistent or ambiguous requirements have a critical impact on the quality of the developed product [Thayer 76]. The significance of requirements is succinctly captured by the following statement [Brooks 87]:

[1] IDEs provide an integrated set of tools and artifacts supporting a process; e.g. Microsoft's Visual Studio

> *"The hardest single part of building a software system is deciding precisely what to build. No other part of the conceptual work is as difficult as establishing the detailed technical requirements, including all the interfaces to people, to machines, and to other software systems. No part of the work so cripples the resulting system if done wrong. No other part is more difficult to rectify later"*
>
> - F.P. Brooks

Supporting the above statement, Boehm claims that corrections of faulty requirements later in the life cycle could cost up to 200 times more than correction during the requirements phase [Boehm 81]. The importance of requirements is further emphasized by Figure 1.2, which depicts the distribution of defects in the SDLC and the effort needed to fix those defects [Leffingwell 2000]. It can be clearly seen that the bulk of the effort (82%) is attributed to fixing requirement errors.

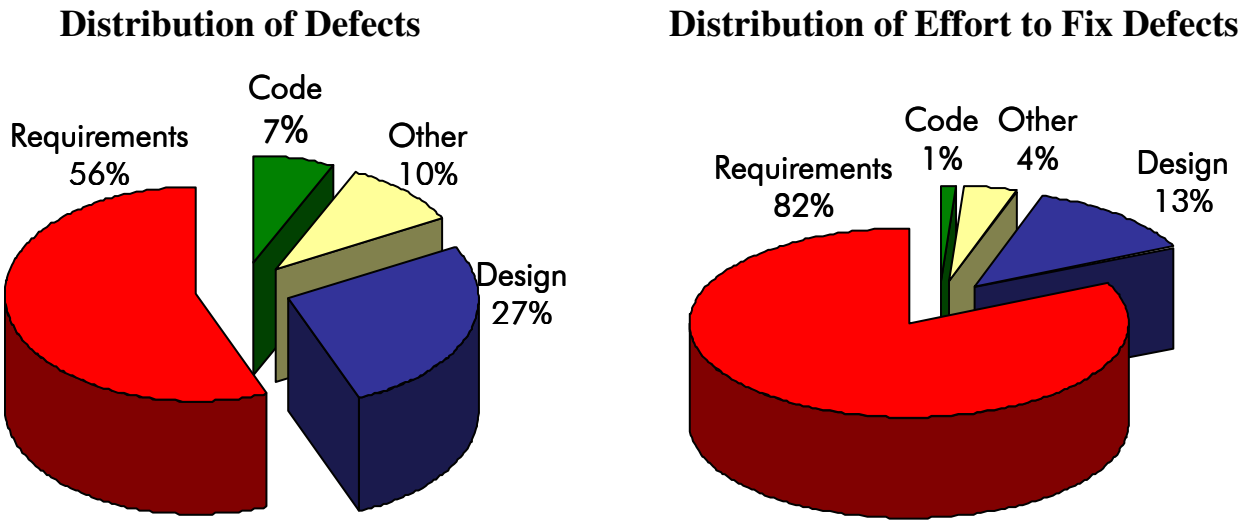


Figure 1.2 Distribution of defects and effort distributions to fix defects

Several studies have been conducted which illustrate that requirements hold the key for the success of a project. The CHAOS report states that five of the top eight causes for project failure relate to requirements [Standish 95]. Also, the study conducted by Williams cites poor requirements as the main risk factor for project success [Williams 98].

These studies indicate that a clear and complete set of requirements lays the foundation for a successful project.

With greater awareness of requirements by the software engineering community, the 'requirements analysis' phase is now termed as 'requirements engineering' and comprises the following activities [Thayer 97]:

- **Requirements Elicitation:** The process through which the customers and the requirements engineer discover, articulate, record and understand the user needs and constraints.
- **Requirements Analysis:** This involves examining the customers' and users' needs in order to obtain a set of requirements. This activity involves assessing the risk, feasibility, cost, schedule and other factors which affect the requirements.
- **Requirements Specification:** This activity records the elicited and analyzed requirements in a precise and unambiguous manner. The deliverable of this activity is the software requirements specification (SRS), which is the binding document between the customer and the developer.
- **Requirements Verification:** The process of ensuring that the SRS is compliant with system standards, conformant to document standards, and is adequate enough to support the design phase.
- **Requirements Management:** This activity involves the planning and controlling of all the other requirement engineering activities. In addition, this activity facilitates communication, in case any changes are made.

Software engineering researchers are now re-examining the activities in the requirements engineering phase in order to make the task of conducting these activities easier.

1.3 Problem Motivation

Over the past few years, the software engineering community has acknowledged the significance of research on requirements and, as a consequence, the present day software industry has a better understanding of the requirements engineering phase. However, in

spite of the increased awareness, requirements engineering is still plagued with problems which have hampered the effective application of this discipline in the software industry. In this section, we highlight the hurdles in requirements engineering that motivate the need for our research.

The main problem in applying requirements engineering in the industry is the lack of a comprehensive requirements engineering model that can be followed to produce a good requirements document [Bubenko 95]. Most of the literature describes requirements models as being composed of activities such as elicitation, analysis, specification, verification and management. These descriptions, however, are at a high level of abstraction which makes it difficult to conduct them in real project scenarios. For example, the analysis activity consists of several sub-activities to evaluate risk, cost, feasibility, schedule, etc. Knowledge of the interaction among these sub-activities and the sequence in which they are executed is necessary in order to achieve the goals of the higher-level activities. In effect, the lack of specific details in the definition of the requirements engineering model also results in unclear procedures for conducting the required activities. Consequently, the requirements engineer faces several problems when such an abstract model drives the requirements phase.

Another problem is that a majority of the requirements engineering models address only portions of the complete requirements process. For example, the RE process model proposed by Debbie Richards provides a set of guidelines for the elicitation and analysis phases, but fails to address the verification and specification phases [Richards 2000]. The integration of models focusing on different segments of the requirements process is a difficult task because the models tend to overlap and have their own specific characteristics. Moreover, such an amalgamation of different models can result in a loose coupling of activities causing a loss of information as requirements evolve through the engineering process. Finally, models that do address the entire requirements process often lack the descriptive detail needed for the defined activities.

One last concern with existing requirement engineering models is that activity objectives are often implied rather than explicitly stated. As a consequence, the requirements engineer lacks a clear understanding of the appropriate objective(s) which, in turn, has a

negative impact on the outcome of the requirements engineering phase. Thus, the problems with the current requirements engineering models strongly indicate the need for a clear enunciation of activities and associated objectives.

An additional obstacle in requirements engineering is concerned with the selection of methods to achieve the objectives of the activities defined by the requirements generation process. Currently there exist a number of methods for the requirements engineering process, but these methods are mapped to the high level activities (elicitation, analysis, specification, verification and management); there is a lack of coordination of methods with lower level activities. [Davis 2003]. For example, the literature specifies techniques such as scenarios, interviews, and inspections, for the high level analysis activity. Methods are not listed for evaluating the cost, rationale, feasibility as defined by lower level activities. The consequence of methods being mapped to activities of higher-level abstraction is that the requirements engineer has difficulty in selecting the appropriate methods for a sub-activity. Hence, the requirements engineer often selects methods in an ad-hoc fashion, resulting in an output which inadequately addresses the activity objective. To compensate, an additional set of methods are applied, causing additional burden on the budget and the schedule. Thus, it is crucial to map methods to activities of the requirements process model, which also must be specified at the right level of granularity, to aid the requirements engineer in his/her selection of methods.

This research is motivated by the need to solve the problems discussed above in order to make the requirements engineering discipline easier to implement within the software development life cycle.

1.4 Problem statement

The problems examined in the previous section have shown that the lack of a structured, well-defined requirements engineering model can hamper the goal of obtaining a complete and precise set of requirements. In addition, we note that the absence of coupling methods and activities at the right level of decomposition affects the requirements engineer in his decisions regarding the choice of methods. In effect, the problems stem from the lack of an appropriately decomposed/refined requirement

engineering model, and from the lack of a well-defined mapping between methods and activities of that model.

This research attempts to address these problems by defining a prescriptive model for the selection of methods for various activities in the requirements engineering process, so that the objectives of the activities are achieved. This model is prescriptive because it prescribes an appropriate set of methods to be used for each activity defined at lower levels of decomposition. In addition, the model further refines the selected set of methods for each activity based on common selection criteria such as cost, time, etc. *(detailed explanation in Chapter 4)*

The next two sections discuss the issues involved in solving the recognized problem and the approach taken to obtain the solution.

1.4.1 Key Issues

To obtain the solution to the problems discussed, the following key issues need to be addressed.

- Incomplete RE model
- Inadequate level of activity abstraction
- Implicit activity objectives
- Methods mapped to high level activities only
- Lack of guidance in selecting among methods for a specific RE activity

We explain each of these issues in detail in the next few paragraphs.

- **Incomplete RE model:** One of the research problems concerns the lack of a comprehensive requirements engineering model. To overcome this obstacle, a model is required which covers the entire requirements engineering process and can accommodate change (decomposition / refinement). However, most of the existing requirements engineering models are incomplete and / or ill-defined. Many of the models consider only a subset of the major phases in the requirements process. For example: Requirements Triage by Alan Davis covers

only the analysis activity and overlooks the other activities in the requirements process [Davis 99]. Although there are models which address the complete requirements engineering process, unfortunately they often are either overly complicated, or difficult to change. For example, the Knowledge level process model [Herlea 99] addresses the complete requirements process but the interactions in the model are complex, which makes the task of decomposing the model difficult. Thus, the first issue is the identification of a model which encompasses all the major phases in the requirements process and accommodates change.

- **Inadequate level of activity abstraction:** The high level abstraction of the activities in the requirements engineering models is another factor which complicates the application of these activities in a real project scenario. The high level of abstraction at which these activities are defined results in the hiding of sub-activities, their interrelationships and their sequence of execution. As a consequence, the requirements engineer may skip crucial sub-activities, and can adversely affect the outcome of the requirements phase. Hence, the second issue is the decomposition of the high level activities to the right level of abstraction so that the model covers all the important sub-activities. The decomposition should be performed such that the activities are neither too high level (e.g. analysis activity) nor too low level (e.g. steps within verification activity).

- **Activity objectives implicit:** Another aspect of the current requirements engineering models that complicates the requirements engineering process is that the activity objectives are often implied rather than stated. As the models are highly abstract, the defined activities specify only the top level objective, while the objectives of the lower level activities are either ignored or simply implied. For example, the requirements engineering model proposed by Kotonya states that the objective of the analysis phase is to establish a set of unambiguous requirements that can be used as the basis for system development [Kotonya 98]. In this model, the lower level activity objectives are implied in the description of the analysis phase. Thus, when such models are followed it is possible that some

of the objectives are overlooked, and this may prove to be critical. Hence, to make the requirements engineering model easy to follow, it is necessary to present activities at the right level of abstraction and to state their objectives explicitly.

- **Methods mapped to high level activities:** In the current requirements engineering scenario, a major problem faced by the requirements engineers is the selection of methods for achieving the objectives of the activities. This is mainly because the methods are defined only for the high level activities in the requirements engineering model. The mapping of methods to higher level activities is a result of models being specified at a high level of abstraction. Thus, the requirements engineer lacks the necessary guidance in selecting the appropriate methods for particular lower level activities. Put in this situation, the requirements engineer chooses the methods in an ad-hoc fashion; this may compromise the quality of the requirements. Hence, in order to assist the requirements engineer in choosing the appropriate methods to perform a particular activity, the appropriate set of methods must be identified and synchronized with the activity objectives.

- **Lack of guidance in selecting among methods for a specific RE activity:** Each activity in the requirements engineering process can be performed using any number of methods; each method has its own pros and cons, satisfying the activity objectives to varying extents. The choice of method to use should be based on some common selection criteria like time, cost, personnel needed, etc. For example, for the elicitation activity, brainstorming is less time consuming when compared to interviews. The task of selecting methods for a particular activity is simplified if the requirements engineer is provided with a list of activity specific methods that is organized according to the achievement of the selection criteria. Thus, the final issue is to find such common selection criteria and determine the path of methods for a requirements engineering process based on a chosen criteria.

1.5 Solution Approach

The solution approach consists of two major phases:

- Phase 1: Enhancement to the requirements engineering model – Involves identifying requirements engineering model, identifying activities at the appropriate level of abstraction and determining activity objectives
- Phase 2: Synchronization of the methods with activities – involves mapping methods to activities and choosing methods based on selection criteria.

Phase 1: Enhancement to the requirements engineering model: The starting point of this phase is the selection of a requirements engineering model which is well-defined and complete. The Requirements Generation Model (RGM) [Arthur 99] is a partial answer to this need as it includes all the major requirements engineering phases and is easy to modify. In addition, the RGM has decomposed the requirements capturing activity into its constituent sub-activities. However, the activities are still at a high level of abstraction and hence, must be further decomposed and refined to reflect the appropriate level of granularity. The objectives for the activities in the expanded RGM (x-RGM) must then be identified and explicitly stated.

Phase 2: Synchronization of the methods with activities: After the requirements engineering model is identified, the activities refined and the objectives determined, phase 2 of the research commences. In this phase, methods used in the industry are analyzed and their pros and cons are recorded. The methods are then mapped to the activities of the x-RGM based on the activity objectives. Finally, commonly used criteria, like time and effort, are identified and linked to methods that support them.

Chapter 2

Background

2. Introduction

The focus of this chapter is to present the background for the research described in this thesis. Specifically, the contents of this chapter are structured to address four main objectives:

- To provide a comprehensive description of the software development life cycle models (SDLC) used in the industry, with the emphasis on the requirements phase. The focus is on obtaining insights into the requirements process and how this phase relates to these models.
- To present a literature review on different requirements engineering processes and highlight the advantages of these processes. The positive features of the reviewed requirement engineering models are useful in developing the expanded RGM.
- To describe the research conducted on identifying methods for the various phases in the requirements generation process.
- To summarize the problems faced in the field of requirements engineering and the issues that need to be addressed to obtain solutions.

The first objective is addressed in Section 2.1, where the role of requirements engineering in the SDLC is explored. This section provides a description of the various SDLC models and examines the integration of the requirements phase with the rest of the model. In addition, the models are studied to gather insights about how the requirements engineering phase is conducted.

Section 2.2 addresses the second objective and introduces the various requirements engineering approaches presented in the literature. The main purpose of this section is to provide an understanding of these approaches and also to emphasize on the pros and cons of these approaches. The strengths and weaknesses of these approaches guide the enhancement and refinement of the requirements model described in Chapter 3.

The third objective is covered in Section 2.3, where the research on identifying methods for the requirements engineering phase is discussed. This section highlights the methods proposed for the different requirement engineering activities, but does not provide detailed description of these methods - this is the focus of Chapter 4.

Section 2.4 addresses the final objective and places it in context of the problems and issues addressed in this research. This main purpose of this section is to serve as a prelude for Chapter 3 and Chapter 4.

2.1 Requirements Engineering and the Development Life Cycle

In this section, we examine several life cycle models used in the industry and the role of the requirements engineering phase in these models. Many models exist for the software life cycle, the series of steps that a system goes through from the first realization of need, through construction, operation and retirement [IEEE 90]. Due to the large number of SDLC models, we briefly describe only a few of the better- known life cycle models.

2.1.1 Waterfall Model

The waterfall model suggests a linear, systematic and sequential approach to the development of software as depicted in Figure 2.1. The model begins with the

requirements analysis phase and progresses through design, implementation, integration and testing.

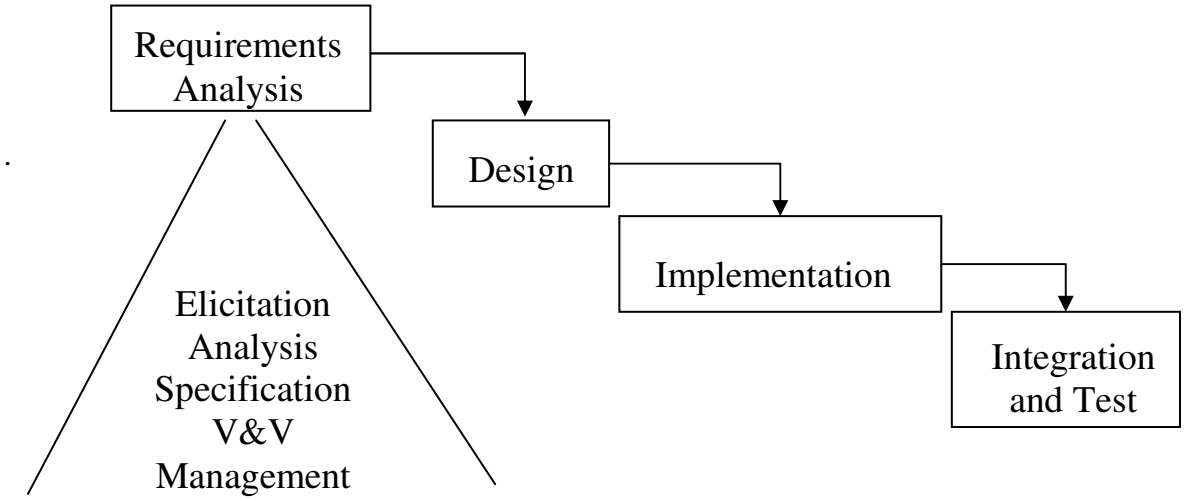


Figure 2.1 Waterfall model

The requirements phase appears at the start of the model and it culminates with the production of the SRS. This phase is at a high level of abstraction and is not explained in detail. The high level requirement objectives pertaining to the activities of elicitation, analysis, specification, verification and validation (V&V), and management are identified. However, neither the process of achieving these objectives nor the methods for this phase are well-defined.

The waterfall model has been criticized for representing an unrealistic approach to software development [Charette 86]. Software projects in industry seldom follow the sequential pattern that the waterfall model proposes. To overcome this drawback, the model can be modified to incorporate iteration. Because iteration is often indirectly implemented, changes in specification and design can cause confusion as the project proceeds [Pressman 2001]. Furthermore, the waterfall model stipulates that requirements be completely specified before rest of the development can proceed. Freezing requirements before design may be possible for some projects, but it is difficult for the majority of the software projects because the user is often unsure about his/her requirements. The waterfall model has problems in accommodating this uncertainty during requirements analysis and the effective management of changing requirements. In

effect, the requirements engineering phase in this model is rigid and provides process details at a high level of abstraction.

Despite these limitations, the waterfall model is the most widely used process model. It is well suited for projects where the requirements are well understood. To provide flexibility to the waterfall model, the literature includes a number of variations of this model [Holt 97].

2.1.2 Prototyping Model

The goal of the prototyping model is to address several limitations of the waterfall model. Instead of freezing the requirements before design, a throwaway prototype is developed to help better understand the requirements. As a result, the model produces more stable requirements that change less frequently.

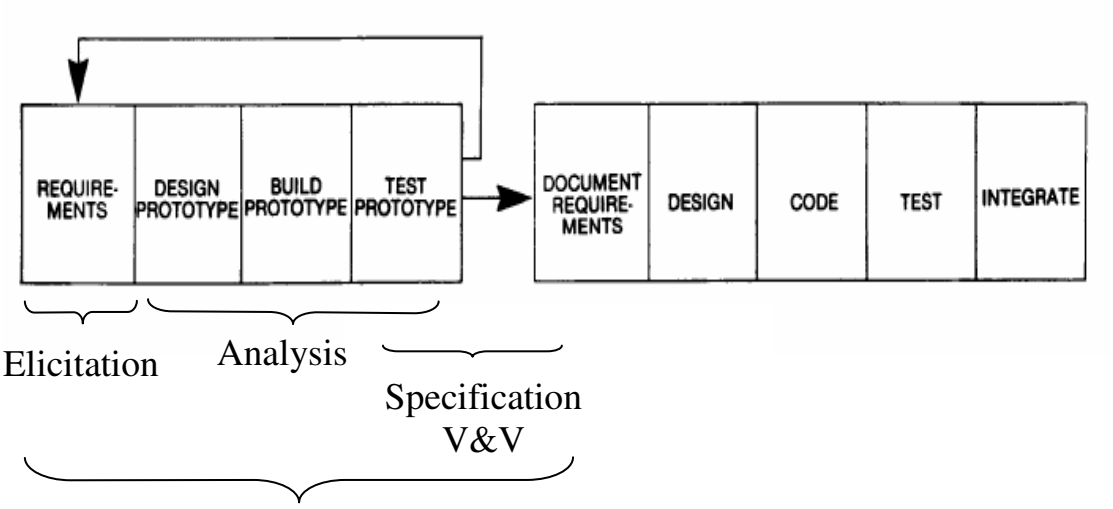


Figure 2.2 Prototyping model

The prototyping model consists of an iterative requirements analysis phase as shown in Figure 2.2. [Gomaa 81] Requirements analysis commences with the preliminary requirements gathering activity. This is followed by a rapid design phase which focuses on the parts of requirements that are visible to the users. The design results in the construction of a prototype that is functionally a subset of the final product. The users then allowed to “play” with the prototype and the feedback obtained is used to drive the next iteration of the requirements phase. Prototypes are generally throwaways and it is

the responsibility of the software engineer to make the customer understand that the product has to be rebuilt in order to maintain a high level of quality [Brooks 95]. The prototyping cycle is repeated until, in the judgment of the software engineers, the benefit from further changing the system and obtaining feedback is outweighed by the cost and time involved in conducting the iteration [Jalote 99].

The requirements analysis phase in the prototyping model is highly iterative and culminates with the generation of the SRS. Prototyping is an iterative cycle comprising design, coding and testing. Thus, the requirements phase is like an iterative waterfall model generating the SRS. An important characteristic of the prototyping model is that it emphasizes user feedback to obtain a clear and stable set of requirements. The literature does provide a description of the requirements generation process in the prototyping model, but this description lacks the identification of activities, objectives and methods.

Prototyping is an attractive approach for complicated and large systems for which there are no existing systems to help determine the requirements. In addition, prototypes are an effective method to demonstrate project feasibility and identify risks associated with the project.

2.1.3 Incremental Model

The incremental model combines the iterative process of prototyping and the linear waterfall model [Basili 75]. The basic idea is that the software should be developed in increments with each increment adding some functional capability to the product until the complete system is developed. Thus, the incremental model applies the waterfall approach in a staged fashion as time progresses, as shown in Figure 2.3. Each application of the waterfall model results in a deliverable increment [McDermid 93]. In addition, the incremental model is iterative with each increment providing user feedback for the next iteration.

The first increment produced is the core product, which addresses the basic requirements; supplementary features are delivered in the subsequent increments. Each of the developed increments is used / evaluated by the user and the feedback obtained is used to drive the

plan for the next increment. This model is very similar to the prototyping model except that the increment is the part of the final product and is not a throwaway.

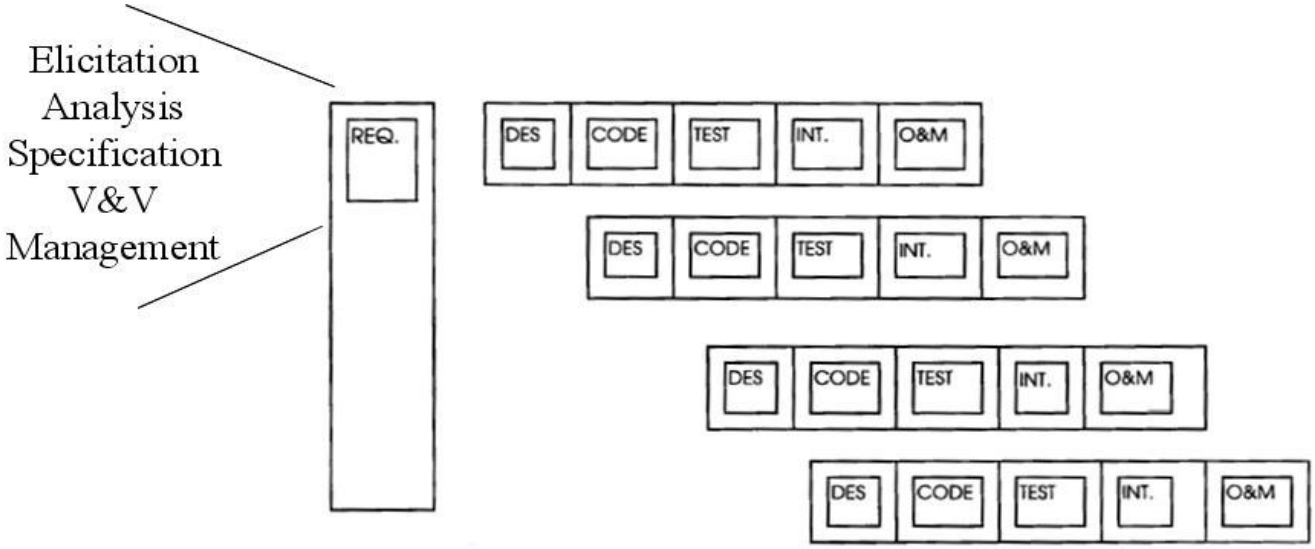


Figure 2.3 Incremental model

Unlike the waterfall model, the incremental approach does not produce the complete requirements upfront. In the first increment, the requirements phase lists the basic requirements, which is implemented as part of that iteration. The SRS for the first increment briefly mentions the features which are to be implemented in subsequent iterations. Thus in each incremental iteration, the SRS is expanded and modified to include new requirements and changes. The complete SRS is generated only in the final iteration of the incremental model. A key characteristic of the requirements phase is that it encourages user feedback, which drives the completion of the SRS. Conducting the requirements phase of the incremental model is problematic, as the literature provides only a brief explanation of the objectives of this phase and also fails to provide the necessary guidance about the activities involved and the techniques that can be utilized. One such problem that is inadequately addressed is how the incremental model can be applied in a situation where the client has to essentially approve every specification.

The incremental model is effective for the development of a product, whose specifications are provided by the developers themselves. This approach can be applied to other projects too, provided the customer has a clear understanding of the requirements, so that problems / misunderstandings do not arise while agreeing to the specification for

each incremental cycle. The benefits of this model are better product testing and the continuous incorporation of user feedback into the development cycle.

2.1.4 Spiral Model

The objective of the Spiral model is to combine the best features of the waterfall and prototyping approaches, and add to it the element of risk analysis [Boehm 88]. This model was proposed by Boehm and the idea is to minimize the risk through prototyping [Pressman 2001]. Activities in the spiral model are organized in the form of a spiral that has cycles. The radial dimension of the model represents the cumulative cost incurred in conducting the steps performed thus far, and the angular dimension represents the progress made in each spiral.

A simple explanation of this model is to look at it as the waterfall model with each phase preceded by a risk analysis activity. Before the commencement of each phase, an attempt is made to control or resolve the risks identified. If it is impossible to resolve the main risks then the software engineer can decide to terminate the project [Schach 96]. At the completion of each phase, the product developed is validated to obtain feedback, which is useful in making the plans for the next spiral. (Figure 2.4)

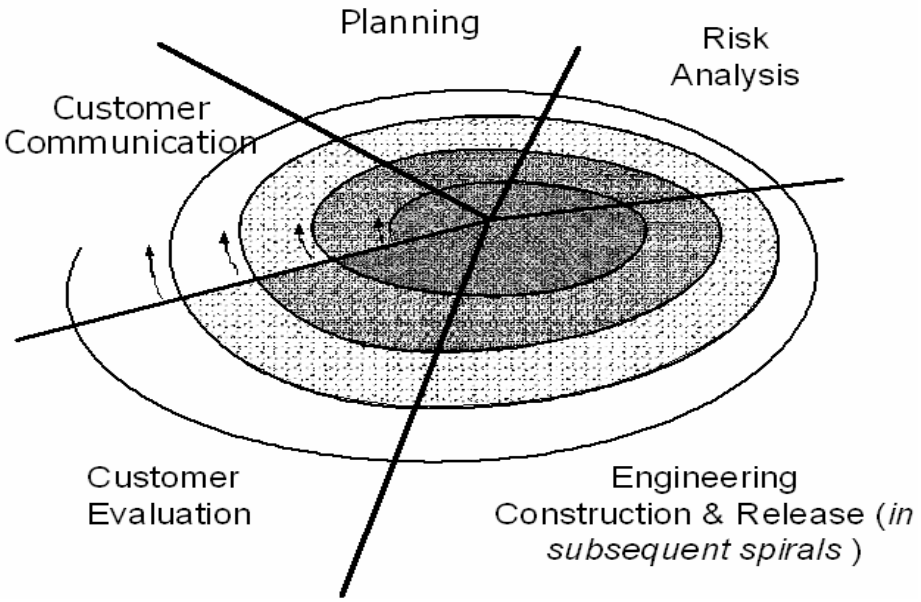


Figure 2.4 Spiral model

The requirements phase in the spiral model is different from those in other SDLC models in that this phase explicitly identifies the high level activities. The phase includes customer communication, planning, analysis, and customer evaluation (validation). These activities correspond closely to the activities in the general requirements engineering process, which is explained in Section 2.2. Another positive feature of the requirements phase is that it is iterative in nature and encourages user feedback. Even though this model identifies the activities in the requirements phase, it fails to give an in-depth explanation of these activities and the techniques that can be used to achieve the activity objectives.

A drawback of the spiral model is that the customer communication activity does not completely reflect the negotiations between the customer and the software engineer. This shortcoming has been overcome by the Win-Win spiral model, which provides a better representation of the customer communication activity by including the following sub activities:

- Identifying stakeholders.
- Identifying stakeholder win conditions[2].
- Reconciliation of win conditions.

Negotiation in the win-win spiral model is supported by the win-win negotiation model, which specifies the steps for resolving conflicts. The negotiation model is well-defined and can easily be incorporated into the requirements process to handle conflicts among requirements.

The spiral model is a robust and realistic approach to software development and is suitable for large scale software systems. Compared to the other SDLC models, the spiral model has a better requirements phase. However, like the other models, the requirements phase is not clearly described and there is inadequate information about the methods to be used in this phase.

[2] Win conditions capture the customer's goals and concerns.

2.1.5 Extreme Programming (XP)

Extreme programming is one of the new SDLC models and is a light weight, low-risk and flexible approach [Beck 99]. Extreme programming proposes a set of principles such as on-site customer, no prototyping, simple design, small increments, no documentation, etc, which form the essence of this approach.

The requirements phase in extreme programming includes elicitation, analysis, and validation (Figure 2.5). Elicitation is performed with the on-site customer using brainstorming techniques to obtain the customer needs in the form of stories/scenarios. The customer, along with the requirements engineer, analyzes the stories and determines the priority the elicited stories. Once prioritization is complete, the test cases for the stories are determined and the stories are broken down into small tasks, which can be taken up by the developers for design and coding [Clifton 2001]. Testing of the stories provides customer feedback, which is useful for making necessary changes to the system in the next iteration. Requirements documentation is skipped as it is considered to be a factor for project delay and increase in cost [Horrian 2003]. Thus, the requirements phase is iterative with an emphasis on continuous user involvement throughout the process.

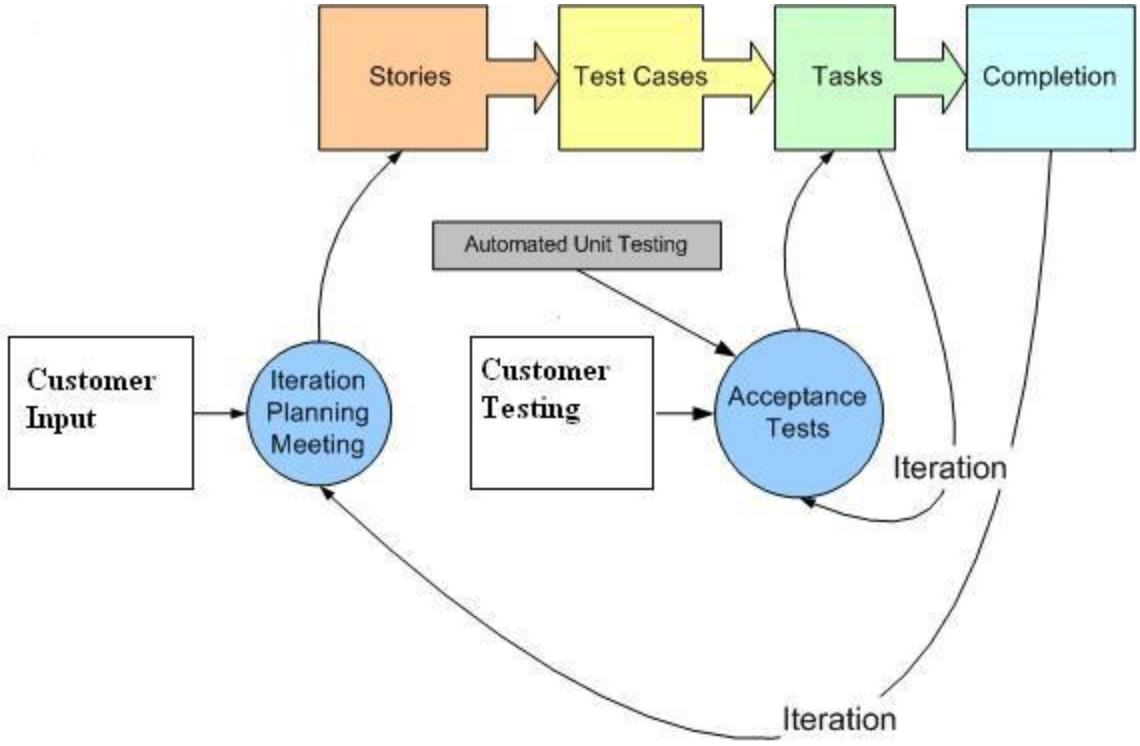


Figure 2.5 Requirements engineering phase in Extreme Programming

Since XP is a new development model, an attempt is made to provide some structure to the requirements phase. Thus, we see a decomposition of the phase into different sub-activities. However, this decomposition is again at a high level of granularity with the objectives still being abstract. This model (XP) proposes brainstorming as a technique for elicitation but it fails to list the other possible methods. In addition, techniques for the other activities in the requirements phase have not been adequately identified.

Extreme programming is a light-weight approach which is suitable for small to medium projects. Handling large projects is problematic as one of the core concepts is "no documentation" and without a clear requirements specification, confusion and misunderstandings can arise.

In the previous sections, some of the better known development models are discussed. The focus of this section is on understanding the requirements process in these models and identifying the features that are useful for this research.

All of the models have a requirements phase under the name requirements analysis, requirements definition, etc. While the waterfall, prototyping and incremental model have a single activity for the requirements phase, the spiral and extreme programming model have several activities for the generation of requirements. A common characteristic of all the models reviewed is that the requirements phase is described briefly with the objectives implied. Furthermore, the models have paid inadequate attention to methods that can be used for the requirements phase. While some models do specify techniques, the coverage of the methods is minimal. Moreover, the methods fail to address all the requirements engineering objectives.

The SDLC models discussed provide some useful insights to the requirements process. A majority of the models recognize the fact that requirements generation is not sequential but an iterative process. Customer feedback is another aspect that is featured in all of the models and the feedback often directs the next iteration. Extreme programming emphasizes the importance of customer participation by including continuous customer involvement as one of its core concepts. The negotiation model in the Win-Win spiral approach is well-defined and can be a good inclusion to the requirements model.

The examination of different SDLC models shows that the requirements phase is inadequate in two ways:

- Decomposition of the requirements process into activities, and
- Identification of methods for activities

The next section presents the research addressing the refinement of the requirements process; Section 2.3 reviews the literature that identifies methods for the requirements phase.

2.2 Requirements Engineering Process and Models

Models such as the spiral model and extreme programming have attempted to decompose the requirements phase but this decomposition fails to consider all aspects of the requirements process. To provide a better understanding of how requirements are generated, we present the major phases of the requirements process in the next section. We also describe research focusing on refining each of the phases within the requirements generation process (Section 2.2.2).

2.2.1 Requirements Generation

Traditionally requirements engineering was considered as a fuzzy and rather "dirty" stage of software development where a formal specification (SRS) is generated from some possibly vague and informally expressed ideas. However, over the years the realization of the importance of requirements and related research has resulted in a better understanding of the requirements phase. This awareness in the software engineering community has resulted in redefining the term "requirements engineering" as [IEEE 90]:

(1) The process of studying user needs to arrive at a definition of system, hardware, or software requirements;

(2) The process of studying and refining system, hardware or software requirements.

Thus, the requirements phase focuses on generating a clear and well-defined set of requirements, which specify what the system should implement, how the system should behave and what constraints bound the system [Sommerville 97]. In the requirements engineering literature, the phases or activities of the requirements process have been

given different names. Krasner identifies five phases of requirements engineering: need identification and problem analysis, requirements determination, requirements specification, requirements fulfillment, and requirements change management [Krasner 85]. Leite and Freeman proposes that requirements engineering activities be comprised of elicitation and modeling activities, the former being concerned with fact finding, communication and fact validation, and the latter with representation and organization of requirements [Liete 91]. Davis developed a requirements model which included five phases: problem recognition, evaluation and synthesis, modeling, specification, and review [Davis 1993]. Apart from the above decompositions of the requirements phase, there are several others, which are described in the literature [Sommerville 97a][Potts 94][Jirotka 94].

Even though the literature specifies diverse names for the requirements engineering phases, the essence of these phases can be effectively captured by the following five components of the requirements process:

- Requirements elicitation
- Requirements analysis
- Requirements specification
- Requirements verification and validation
- Requirements management.

Each of these phases is discussed in the sections that follow.

2.2.1.1 Requirements Elicitation

Requirements elicitation is the iterative process of seeking, uncovering, acquiring and elaborating user needs and constraints. It is the means by which the requirements engineer determines the problems and needs of the customers, so that system development personnel can construct a system that actually resolves the problems and addresses the customer's needs [Davis 2003].

The requirements elicitation process comprises the following steps [Rzepka 89]:

- Identify the sources of requirements for the system. Sources include problem owners, organizational documentation, end users, interfacing system and environmental factors.
- Obtain the "wish-list" for each relevant party. This list is likely to be ambiguous, incomplete, inconsistent, and untestable.
- Analyze, refine and document the "wish list" obtained. The refined "wish-list", henceforth called requirements, is precise and unambiguous.
- Finally the non-functional requirements such as reliability and performance, are determined and documented

The steps described are common to most of the definitions of the requirements elicitation process found in the literature. Methodologies such a as Joint Application Design (JAD), Participatory Design (PD) [Carmel 93] and Facilitated Application Specification Techniques (FAST) [Zahniser 90] are commonly used for the elicitation phase. These methodologies employ various techniques to achieve the objectives of the elicitation process and the choice of the method is based on criteria such as cost, ease of conducting, time required, etc. Research related to the identification of methods for the elicitation process is discussed in Section 2.3.

Several problems are faced by the requirements engineer in the process of eliciting system requirements. These problems can be classified into three broad categories:

- Problems of scope – Requirements address too little or too much information.
- Problems of understanding – Occurrence of misunderstanding within groups and between groups (e.g. customers and developers).
- Problems of volatility – Problems related to continuous change in requirements.

The problems that generally appear under these categories are listed below: [Christel 92].

Problems of scope

- The boundary of the system is ill-defined
- Unnecessary design information may be given

Problems of understanding

- Users have incomplete understanding of their needs
- Users have poor understanding of computer capabilities and limitations
- Analysts have poor knowledge of problem domain

- User and analyst speak different languages
- Ease of omitting "obvious" information
- Conflicting views of different users
- Requirements are often vague and untestable

Problems of volatility

- Requirements evolve over time

The problems listed above appear in some form or the other during the elicitation phase of the requirements generation process. In spite of the large number of elicitation techniques, the difficulties faced during elicitation cannot be completely overcome. However, the problems can be minimized by involving the stakeholders throughout the requirements elicitation process. This ensures that all the stakeholders have a better understanding of the requirements process, and as a consequence, the task of obtaining a stable and complete set of requirements becomes easier.

2.2.1.2 Requirements Analysis

Requirements analysis is the process of analyzing the users' and customers' needs to obtain a definition of the software requirements. This phase includes representing the requirements in different forms in order to facilitate the analysis of requirements from different perspectives. Hence some authors refer to this phase as requirements modeling [Greenspan 94] or conceptual modeling [Loucopoulos 92]. Requirements analysis entails elaborating the alternative models for the target system and negotiating the conflicting aspects of the models so that the final model is agreeable to the systems stakeholders. Models that are explicit and sufficiently formal can be shared by a group of people and can be used for reasoning about the requirements [Yeh et. al. 84].

Requirements modeling improves the communication between the customers and the requirements engineer since graphic representations of the requirements are easier to comprehend by the customer. Thus, any misunderstandings in the requirements are identified early on in the requirements engineering life cycle. Modeling also helps the requirements engineer to better comprehend the requirements and to identify the impact of requirements changes more rapidly.

Another objective of requirements analysis is to analyze the requirements from different perspectives. To accomplish this, it is necessary to identify requirement attributes such as risk factors, importance of the requirement, value of the requirement to the product and so on. These attributes are helpful while evaluating the requirements against factors like risk, cost, schedule, etc [Nord 2003]. In addition, during the requirements analysis phase, the requirements engineer has to decide whether or not to continue with the project. Furthermore, the requirements analysis phase also identifies conflicts among requirements and attempts to resolve them through negotiation techniques. Thus, requirements analysis is concerned with the evaluation and modeling of the requirements.

Customer participation is critical for requirements analysis as the goal of this phase is to ensure that all stakeholders arrive at a common understanding of what they will have when the software is deployed [Weigers 2001]. Several authors have proposed techniques to achieve the goals of the requirements analysis phase and this research is discussed in Section 2.3. A detailed description of the methods for the different activities in the requirements analysis phase is provided in Chapter 4.

2.2.1.3 Requirements Specification

In conjunction with requirements elicitation and analysis, it is necessary that the captured requirements are also documented. During requirements specification, the requirements are precisely and clearly recorded to act as a basis for a contract between the customer and the problem solver/developer. The need for a well-defined requirements specification has led to the emergence of several different specification languages such as Requirements Specification Language (RSL) [Bixler 76], Gist [Balzer 82], Problem Statement language (PSL) [Teichroew 1982], etc.

A well-defined software requirements specification (SRS) has the following benefits:

- Acts as a binding contract between the customers and the suppliers
- Reduces the effort needed for maintenance and changes
- Provides a basis for estimating costs and schedules
- Provides a baseline for verification and validation

The exact contents of the requirements specification varies from situation to situation. However, the SRS should include the functionality of the system, description of the environment and the system objectives, function and design constraints, and data and communication protocols. In addition, the contents of the SRS should adhere to the quality characteristics listed below [IEEE 93]:

- **Correctness**: Every stated requirement is one that the system shall meet.
- **Unambiguity**: Every stated requirement has only one interpretation.
- **Completeness**: Requirements capture all aspects of the system
- **Consistency**: Requirements stated have no conflicts
- **Ordered:** Requirements stated are ranked for importance and/or stability
- **Verifiable:** Each requirement should be testable of performing its function in a given amount of time
- **Modifiable:** Structure and style of the SRS should be such that changes are incorporated easily
- **Traceable:** Origin of each requirement should be traceable.

The content of the SRS can be presented in different formats and styles with the textual format being the most commonly used in the industry. A textual format of the requirements can be cumbersome to validate if the SRS is large and unstructured. In such situations, other alternatives like prototypes or context diagrams may be advantageous. Prototypes are best used for applications that include visual displays and interact heavily with the user [Pressman 2001]. Context diagrams depict the product as a black box surrounded by users and external system with which it interacts [Lauesen 2002]. The focus is on the interfaces of the system, and thus it enables the users to easily identify missing functionalities or interfaces. Use cases and scenarios provide a “story-like” description of the system and this facilitates easier comprehension and validation. However, translating these informal descriptions into design is difficult because of the lack the formal structure and the potential for multiple interpretations.

Each of the above mentioned formats are suitable for the specification of requirements. However, an ideal SRS should include a blend of these formats so that the specification facilitates user validation and translation of requirements to design.

2.2.1.4 Requirements Verification and Validation

Verification is the process that ensures the high quality of the Software Requirements Specification (SRS) and the adequacy of requirements to continue with design, construction and testing. In addition, verification determines whether the requirements are correctly derived from the system requirements. The compliance of the SRS with the documentation standards is also checked during verification.

Verification examines the requirements as soon as they are generated and determines if the requirements possess the desired quality attributes [Weigers 2001]. When requirements elicitation is still under progress, quality attributes [3] like correctness, verifiability, modifiability, etc. are considered for the verification of each individual requirement. Other attributes like completeness and traceability are assessed only after obtaining the complete set of requirements. Several techniques are used during verification and the most widely used methods are internal and external reviews, audits, walkthroughs and inspections.

Validation is the process which ensures that the requirements accurately capture the customer's intent/needs. Its main objective is to find if there are disagreements between what the user desires and what the requirements state. Conflicts are identified for corrections to the requirements in order to minimize the probability of changes made to the SRS in the future.

Validation is conducted after verification at different stages in the requirements engineering phase. Initially, when the subset of requirements is captured during the elicitation phase, the requirements are first verified and then validated by the user. Similarly, on obtaining the complete set of requirements, validation is once again performed. Finally, at the end of the requirements engineering life cycle, validation is carried out on the SRS, which is created as per the documentation standards and formats [IEEE 98].

Commonly used techniques for validation are scenarios, walkthroughs, guided discussions, prototyping, storyboarding, etc. Techniques should be chosen based on the

[3] Quality attributes are explained in Section 2.2.1.3

stage in the requirements engineering life cycle and the product being validated. For example, prototyping is better suited to validate the complete set of requirements than the individual requirements. In addition, interactive applications are more easily validated using prototypes than by other methods.

The terms verification and validation are sometimes used interchangeably in the literature but as pointed out in this section, they are indeed different activities. The task of verification is to ascertain that the SRS complies with standards, and is consistent, complete and unambiguous. On the other hand, validation determines whether the requirements satisfy the users' intentions. Requirements verification and validation (V&V) can uncover and rectify many deficiencies that may otherwise go undetected until late in the development cycle, where the correction would be much more expensive. Thus, requirements V&V has a critical impact on the outcome of the software development life cycle and should be conducted carefully.

2.2.1.5 Requirements Management

Requirements managements refers to the set of procedures that assist in the management of the requirements process and product as well as maintaining the evolution of the requirements throughout the development life cycle. Effective requirements management is essential for producing a good SRS and eventually a good quality product. The activities in requirements management include planning, prioritization, traceability, impact assessment of changing requirements, configuration control, and so on. Requirements management encompasses the entire development life cycle, starting from the requirements phase till the testing phase.

The main issues in the requirements management phase are

- Requirements traceability, and
- Change management

A requirement is traceable if one can discover who the owner of the requirement is, the rationale behind the requirement, the relationships to other requirements, and how the requirement relates to other artifacts such as design and documentation [Sawyer 97]. Requirements traceability is useful in determining the impact of requirements changes on

design and implementation. In addition, traceability facilitates the identification of inconsistencies among requirements by linking all the requirements to the user needs. Furthermore, traceability provides insights to non-functional components such as quality, completeness, impact analysis and process improvement [Palmer 96].

Requirements are volatile in nature and it calls for effective change management in order to maintain the consistency of the requirements. Once the requirements engineering phase is completed, requirements management is mainly concerned with change management, which includes the following activities:

- Identification of the required changes
- Impact analysis of the requirement changes
- Alternative ways of incorporating the requested changes
- Updating the SRS without causing any inconsistencies
- Recording the changes and its rationale

Documentation of the rationale and the traceability matrix are valuable artifacts in handling changes to requirements. Recordings of tentative requirements[4] [Robertson 99] as well as discarded requirements[5] [Sommerville 97] are also useful strategies for effective change management. To maintain the consistency of the SRS, several approaches such as Software cost reduction (SCR) [Heitmeyer 96], Requirements state machine language (RSML) [Heimdahl 95], etc, have been proposed.

Requirements management is a complex phase, which is supported by a number of tools that are readily available in the software market. Tools such as Rational Suite, DOORS, Caliber-RM, Omni Vista, etc. provide document templates, configuration control, visual representations and other features, which make requirements management more effective and easier to conduct.

2.2.2 Requirement Models

In this section, we present a survey of different requirements engineering models, which attempt to refine the requirements process by decomposing the major phases – elicitation,

[4] Requirements that are currently under consideration/negotiation
[5] Requirements that have been proposed and subsequently rejected after analysis and negotiations

analysis, specification, verification and validation, and management. The models discussed provide additional insights into the requirements generation phases and help in the development of the requirements model for this research. At the end of this section, we provide a comparison of the different models, listing their pros, cons and the coverage of the requirements process.

2.2.2.1 *Requirements Engineering Process Model*

The requirements engineering process model is proposed by Debbie Richards and considers the requirements phase to be composed of the following phases – gathering (elicitation), modeling (analysis), validation, specification and management [Richards 2000]. However, the model addresses the refinement of only the first three phases.

The model is comprised of five stages as shown in Figure 2.6:

- Requirements acquisition
- Concept generation
- Concept comparison and conflict resolution
- Negotiation
- Evaluation

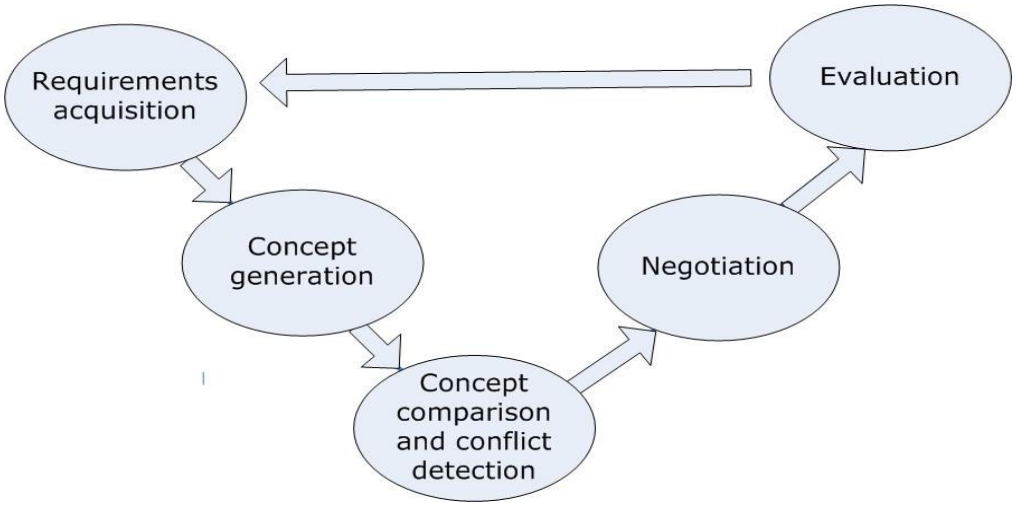


Figure 2.6 Requirements engineering process model

Requirements acquisition involves capturing the stakeholders' requirements and corresponds to the elicitation phase of the requirements generation process. The model proposes the use of interviews as a technique for the elicitation of the requirements. This

activity results in the gathering of requirements in formats such as use case descriptions and interview transcripts.

Concept generation is the second stage in this model and involves representing the requirements of different stakeholders in the form of a table, which has requirement objects as rows and object attributes as columns. The visual representation of the viewpoints of different stakeholders helps in easier understanding and comparison of the viewpoints.

Once the table representations of the requirements are generated, the tables are compared for conflicts. Requirements which appear in the tables are classified as being in one of the four states [Gaines 88]:

1. *Consensus* is the situation where the same requirement is described using the same terminology.
2. *Correspondence* occurs when the same requirement is described using different terminology.
3. *Conflict* is where different requirements are being described but the same terms are used.
4. *Contrast* is where there is no similarity between requirements or the terminology used.

States 2,3 and 4 correspond to misunderstandings among the viewpoints of different stakeholders.

On detecting the conflicts, the next stage is to resolve them through different negotiation techniques. This model adopts the five strategies of conflict resolution proposed by Easterbook and Nuseibeh [Easterbook 96]:

- Resolving - remove inconsistency
- Ignoring - take no action
- Circumventing - don’t include
- Delaying - put on hold
- Ameliorating - reduce the degree of inconsistency

Evaluation is the last stage of the model and determines if another iteration of the model is necessary. The requirements engineering process model uses the number of conflicts to decide whether to go through another cycle of the model.

This model identifies activities in the requirements phase such as negotiation and conflict detection. However, the model is inadequately decomposed and fails to identify all the activities in the requirements phases, which the model attempts to refine. In addition, the model covers only the elicitation, analysis (partly) and validation phases and overlooks the management, verification and specification aspects. Methods are specified for each stage or activity but the methods are limited to only one or two and this restricts the application of the model. Furthermore, this model provides only an overview of the activities and does not explicitly state the activity objectives.

2.2.2.2 *Requirements Triage*

Requirements triage is a requirements engineering model proposed by Alan Davis and it is the process of deciding precisely what features the product will include in its implementation. From a naïve development manager's perspective, requirements triage is simple. The time and effort needed to develop the features of a system are compared with the project budget and schedule. If there is incompatibility of these project parameters (time, effort, schedule, cost), then the features are removed so that the project parameters synergize. However, this strategy completely overlooks the impact of market, price, revenue and profit. To incorporate these features, the requirements triage considers marketing, financial and development factors.

The requirements triage is a collection of activities, which fit into the requirements analysis phase and the goal of this model is: a set of features, which can be developed using available resources within acceptable levels of risk and which can be sold at an acceptable price to a known market in sufficient quantities to achieve satisfactory levels of profit and thus achieve a reasonable return on investment [Yourdon 99].

This model includes five activities (Figure 2.7), which are briefly described below:

- **Risk analysis**: Determines acceptable levels of risk for the requirements

- **Cost and Schedule Estimation**: Determines the effort and time required to implement potential features of the system.
- **Price Analysis**: Determines the optimal price to charge customers.
- **Market Analysis**: Determines the types of customers, their numbers, their buying power/capability, urgency for a particular feature, and so on.
- **Feature Triage**. The process which determines the features that are the right ones to be developed.

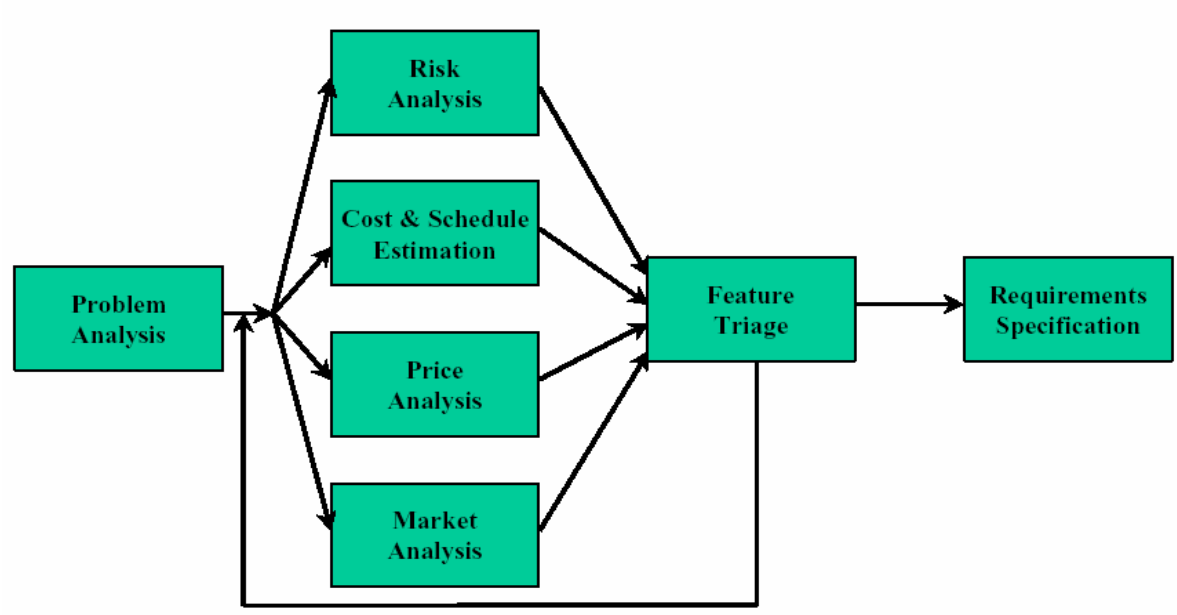


Figure 2.7 Requirements triage

In order to achieve a balance of the market, financial and development factors, the following variables need to be adjusted until a reasonable result is produced [Davis 99]:

- Add, delete or change a feature
- Make the delivery date earlier or later
- Increase or decrease the resources applied to development
- Increase or decrease the price
- Increase or decrease costs of good sold
- Increase or decrease the resources devoted to marketing and sales.

Several tools such as Omni-Vista SP[6], Primavera Monte Carlo[7], QSS TechPlan 2[8], etc. have been developed to support the requirements triage model. These tools allow the requirements engineer to visualize the effects of various factors like cost, schedule, price, etc. on the development of the project.

The requirements triage model attempts to refine the analysis phase of the requirements generation process. Specifically, the model focuses on the analysis portion where the requirements are complete. The decomposition into activities is adequate and at the right level of abstraction. However, the model fails to describe in detail what transpires within each of these activities. In addition, since the model addresses only a portion of the analysis phase, the applicability of the model is restricted and it has to be plugged into other models for effective usage.

2.2.2.3 *Knowledge Level Process Model*

The knowledge level process model attempts to address the entire requirements generation process and provides different levels of process abstraction as illustrated in Figure 2.8.

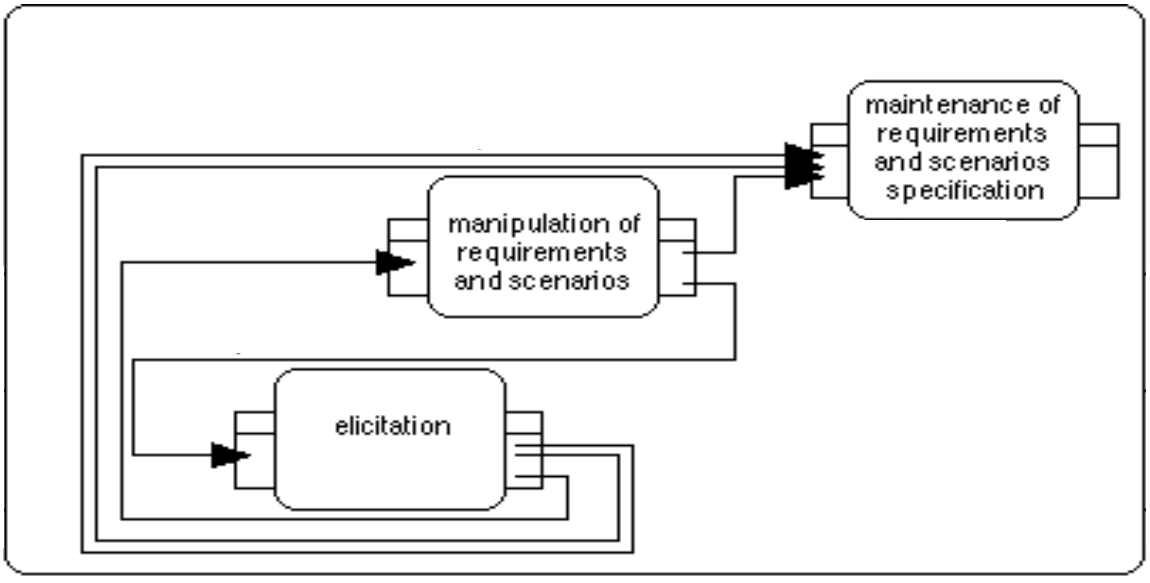


Figure2.8 Knowledge level process model

[6] See www.omni-vista.com/products
[7] See www.primavera.com/products/monte.html
[8] See www.qssinc.com/products/visiontools/techplan.html

As shown in the figure, the knowledge level process model is comprised of three processes:

- **Elicitation** – It involves the identification of problems, elicitation of requirements and scenarios from the stakeholders, and documentation of the domain knowledge.
- **Manipulation of requirements and scenarios** – It entails resolving the ambiguity and inconsistency among the requirements and scenarios. In addition, this process reformulates the informal requirements to semi-formal and formal requirements and establishes the relationships between the requirements and the scenarios.
- **Maintenance of requirements and scenario specification** – This process involves the configuration control of traceability information and documents containing the requirements and scenarios.

Each of these processes is further broken down into activities and the inputs and outputs for each of these activities are identified. The interfaces (input and output information) of the high level process abstraction are shown in Table 2.1 [Herlea 99].

Process	Input information type	Output information type
Elicitation	Requirements and scenarios information	Elicitation results Elicitation basic material (*problem description and domain knowledge*)
Manipulation of requirements and scenarios	Elicitation results	Requirements and scenarios information
Maintenance of requirements and scenarios specification	Elicitation results Requirements and scenarios information Elicitation basic material	Elicitation results Requirements and scenarios information Elicitation basic material

Table 2.1 Input and output flows in the Knowledge Level Process Model

The knowledge level process model is a complex model, which addresses the complete requirements generation process. It includes all the major requirements phases and refines

the elicitation, analysis and V&V (verification and validation) phases. The decomposition of the requirement phases into activities is inconsistent as some of the activities are at a low level of granularity (describing steps within activities) while others are highly abstract (grouping of activities). Also, since the model is scenario based with the requirements and scenario activities closely intertwined, it is difficult to incorporate changes into the model. Another drawback is that even though the model identifies activities in the requirements process, the literature fails to provide adequate information about the activities and their objectives. Furthermore, this model skips the issue of providing techniques for conducting the activities identified. Compared to the triage and the requirements engineering process model, this model has better coverage of the requirements process.

2.2.2.4 *Win-Win Spiral Model*

The spiral model discussed in Section 2.1.4 lacked the activities for customer negotiation and, as a result, the Win-Win Negotiation model was developed to fill this gap. On combining the two models, we have the Win-Win spiral model, which has a better representation of the customer communication activity. The Win-Win spiral model has been proposed as a requirements model because it incorporates the major components of the requirements process (Figure:2.9):

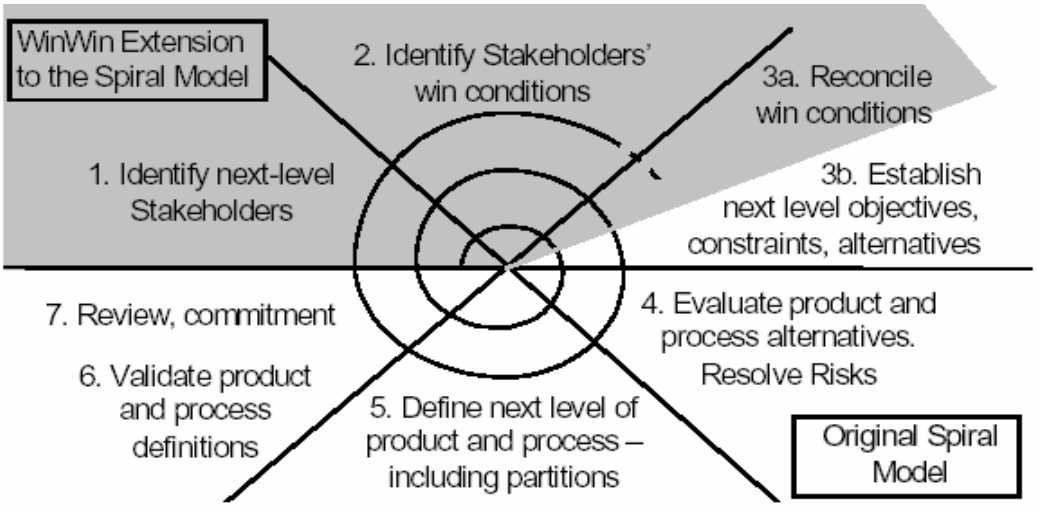


Figure 2.9 Win-Win spiral model

The requirements generation process in the Win-Win spiral model comprises the following steps:

- The first step is the identification of the stakeholders and their win conditions (needs, requirements and concerns). This activity corresponds to the elicitation of requirements form the stakeholders.
- The next step in the spiral is to resolve the conflicts in the requirements and identify system constraints. In addition, the requirements are also evaluated for risk and the system alternatives. These set of activities map to the analysis phase in the requirements process.
- Finally the requirements are validated and reviewed; this step matches the objectives of the requirements verification and validation phase.

The above mentioned steps are repeated until a complete and well-defined software requirements specification (SRS) is obtained.

The negotiation model is based on four artifact types: Win conditions, issue, options and agreements (see Figure 2.10) [Boehm et al., 1994].

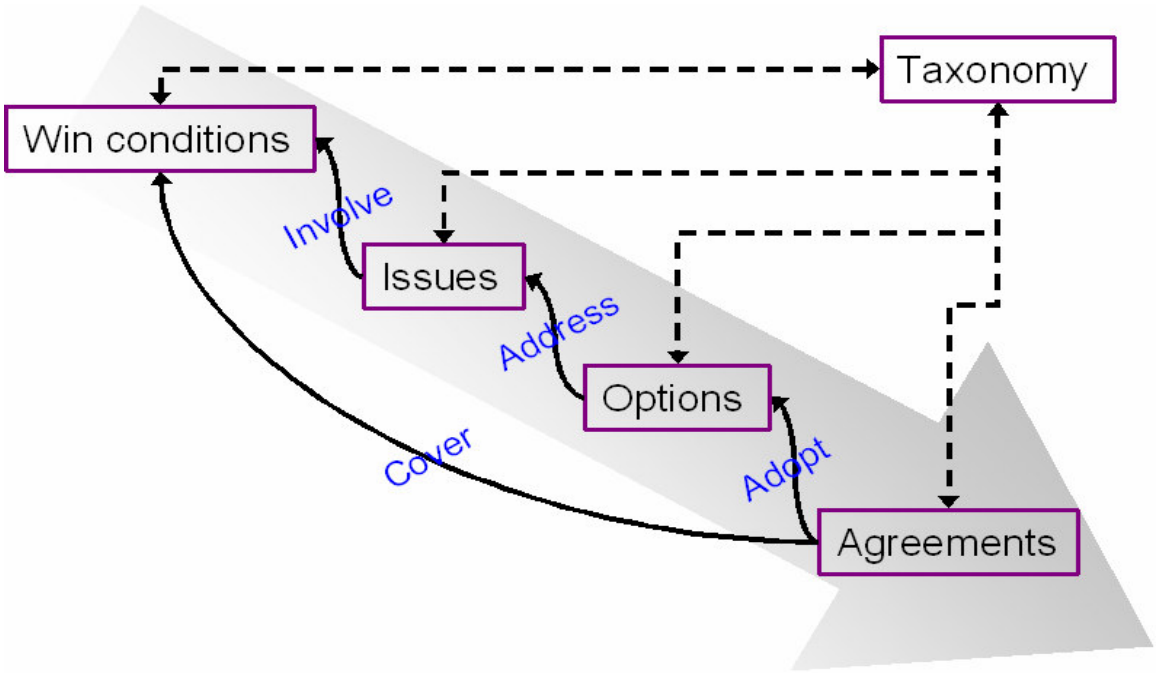


Figure 2.10 Win-Win negotiation model

Win conditions capture the stakeholder goals and concerns with respect to a new system. If a win condition (requirement) is non-conflicting, it is accepted and included in the agreement/specification. Otherwise, an issue artifact is created that records the conflict among the win conditions. To resolve the issues, the stakeholders are allowed to suggest alternative solutions, which form the content of the options document. The solutions are then evaluated and the option agreeable to the stakeholders is adopted in the agreement artifact. The negotiation model includes a tailorable domain taxonomy, which links to the artifacts and this ensures that the stakeholders have a unified understanding of the artifacts generated during the negotiation process.

The Win-Win spiral model presents a general framework for the requirements process but lacks the adequate decomposition of activities. Moreover, all the activities except negotiation are briefly explained with their objectives being implied. Also, the issue of identifying techniques for the activities is left unaddressed. The positive feature of this model is the clearly defined negotiation activity, which can be adapted to the conflict resolution activity in the requirements process.

2.2.2.5 *Process Framework*

The process framework attempts to address the issue of providing a framework for the requirements generation process. This model consists of four main activities, which are conducted iteratively until a precise and complete SRS is obtained (Figure 2.11) [Alcazar 2000]:

- Capture user requirements
- Analyze requirements
- Build solution specification
- Verify specification

Capture user requirements: This activity involves the elicitation of requirements and other pertinent information such as business process, organization description, stakeholders profile, etc. The model recommends the use of requirements lists, graphs, and free texts for the representation of requirements.

Analyze requirements: This activity focuses on building a common understanding of the requirements, problem domain, vocabulary and other relevant information among the stakeholders. To capture this information, UML and ER diagrams have been prescribed to the requirements engineer. A second objective of this activity is to classify the requirements in a hierarchical order and to identify the relationship among the requirements.

Build solution specification: The objective of this activity is to express what the system has to accomplish in such a way that the requirements engineer and the customer get a clear picture, and the latter accepts it. This model advocates the use of use cases [Jacobson 92] for the presentation of requirements to the customer.

Verify specification: This activity allows the requirements engineer to confirm that all the requirements have been captured and recorded. In addition, the requirements are checked for adherence to the quality characteristics such as correctness, preciseness, verifiability, etc.

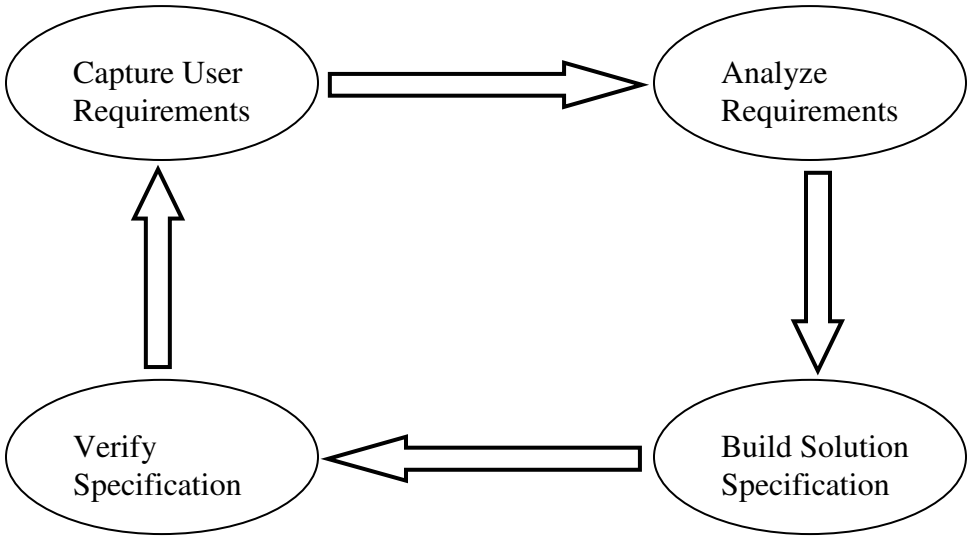


Figure 2.11 Requirements engineering process framework

The process framework identifies the main phases of the requirements generation process but fails to provide the decomposition of these phases. In addition, the activities are explained briefly with the objectives being specified at a high level of abstraction. The focus of this model seems to be on determining how the information generated from each phase is to be represented rather than on the decomposition of the process itself.

2.2.2.6 *Requirements Generation Model (RGM)*

The requirements generation model provides a structured framework for the requirements phase and identifies the major components of the requirements process (Figure 2.12). [Arthur 99]. This model splits the requirements generation process into two parts:

- Requirements Definition, where the requirements are elicited and evaluated iteratively until the exit criteria is satisfied.
- Requirements Analysis, where the complete set of requirements is analyzed, documented, verified and validated.

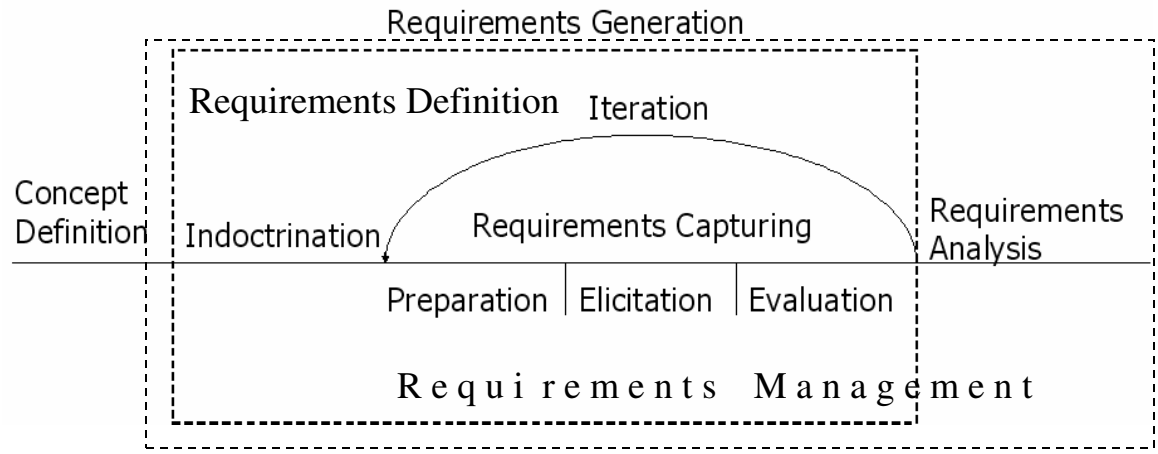


Figure 2.12 Requirements generation model

The requirements definition phase is decomposed into indoctrination and an iterative requirements capturing sub-phase. Indoctrination is concerned with familiarizing the customer about the RGM, educating the requirements engineer about the problem domain, and specifying the customer's responsibilities. The requirements capturing phase is further refined into sub-activities, which focus on obtaining requirements from the customer and refining them in an iterative manner until the complete set of requirements is collected. The RGM also provides protocols and guidelines to structure the activities identified. Protocols define boundaries for the RGM within which the customer and the requirements engineer must operate whereas guidelines are recommendations or suggestions that are optional for the requirements engineer or the customer [Groner 2002].

The RGM identifies all the major requirements engineering phases – elicitation, analysis, specification, verification and validation, and management. In addition, the model

decomposes the capturing phase into activities, which are clearly defined. Furthermore, the RGM specifies constraining and guiding components in the form of protocols and guidelines, which help in effectively conducting the activities. The drawback of the RGM is that the decomposition of the model into activities is inadequate and as a result the objectives are stated at a high level of granularity. However, the RGM does facilitate future decomposition by providing detailed explanations of the activities identified. Another shortcoming of the RGM is that the techniques that can be applied to achieve the objectives of the activities are not identified.

2.2.2.7 *Comparison of the Requirement Engineering Models*

Pros / Cons of Requirement Engineering models		**RE process coverage**
Requirements engineering process model		
+	Methods specified for each activity	Elicitation
-	Inadequate decomposition	Analysis
	Overview of activities	Validation
	Single method specified for each activity	
	Overlooks phases of the requirements process	
Requirements triage model		
+	Adequate decomposition of activities identified	Portion of
-	Overview of activities	analysis
	Methods not specified for the activities	
	Overlooks phases of the requirements process	
Knowledge level process model		
+	Identifies all phases of the requirements process	All phases
-	Inadequate decomposition	(Elicitation
	Overview of activities	Analysis
	Methods not specified for the activities	Specification
	Complex, difficult to change	V&V
	Not general in nature (scenario based)	Management)

Pros / Cons of Requirement Engineering models		RE process coverage
Win-Win spiral model		
+	Clear and well defined negotiation activity	Elicitation,
-	Inadequate decomposition	Analysis
	Overview of activities	V&V
	Methods not specified for the activities	
	Overlooks phases of the requirements process	
Process framework		
+	Identifies all phases of the requirements process	All phases
	Focus on documents produced	(Elicitation
-	Inadequate decomposition	Analysis
	Overview of activities	Specification
	Methods not specified for the activities	V&V
		Management)
Requirements generation model		
+	Identifies all phases of the requirements process	All phases
	Detailed explanation of identified activities	(Elicitation
	Facilitates future decomposition	Analysis
-	Inadequate decomposition	Specification
	Methods not specified for the activities	V&V
		Management)

Table 2.2 Pros/cons and process coverage of requirement engineering models

From Table 2.2, it is clear that only three models include all the phases of the requirements generation process – Knowledge level process model, Process Framework and Requirements Generation Model. All the three models inadequately decompose the model and fail to specify methods for the activities identified. Among these models, the process framework has the least amount of decomposition and the activities have a one to one mapping to the phases of the requirements generation process. The knowledge level process model is complex and is scenario based making it difficult to decompose and

incorporate changes. The RGM facilitates decomposition and provides a detailed explanation of activities. Comparing the models, which cover all the phases in the requirements process, the RGM looks most promising for decomposition.

Among the other models, which cover one or more phases of the requirement process, the requirements triage and win-win spiral model provide useful insights. Requirements triage examines and decomposes the portion of the analysis phase that evaluates the complete set of requirements. This model considers the effects of financial, marketing and development factors on the requirements and proposes activities at the right level of abstraction. The win-win spiral model includes a well-defined negotiation activity that synergizes comfortably with the conflict resolution activity of the requirements generation process.

2.3 Requirement Engineering Methods

One of the drawbacks of the requirement engineering models is that they fail to specify the techniques for the activities in the models. This section focuses on the research conducted in identifying methods for the activities in the requirements phase. We do not provide an explanation of the methods, as this is the objective of Chapter 4.

This section is structured according to the research conducted in the different phases of the requirements engineering process. Prior to requirements elicitation, the needs of the customer are determined and this is accomplished through the problem synthesis phase. Section 2.3.1 will discuss the research on identifying methods for this phase. Subsequent sections will present the literature review on method identification for the different requirement phases.

2.3.1 Methods for Problem Synthesis

Problem synthesis is the phase that entails learning about the problem to be solved, understanding the customer needs and identifying the constraints on the solution. The problem synthesis phase includes two main activities:

- **Problem analysis**: Involves understanding and decomposing the problem in addition to identifying the problem context and constraints.

- **Needs generation**: Involves elicitation, analysis and evaluation of the user needs.

Alan Davis identifies brainstorming and interviewing as the main techniques for understanding the problem and the domain [Davis 90]. Brainstorming provides a number of ideas in a short amount of time and it can bring out details which cannot be obtained through a prolonged interview process. Brainstorming works well in understanding the real problem if the customer is unsure about his/her problem. In order to determine the needs of the customer, it is necessary to identify the cause of a particular problem and for this purpose Leffingwell recommends the use of the Fish bone diagram [Leffingwell 2000]. Figure 2.13 illustrates how the Cause-Effect (or Fishbone Diagram) is used to decompose the perceived problem into potential causes of that problem.

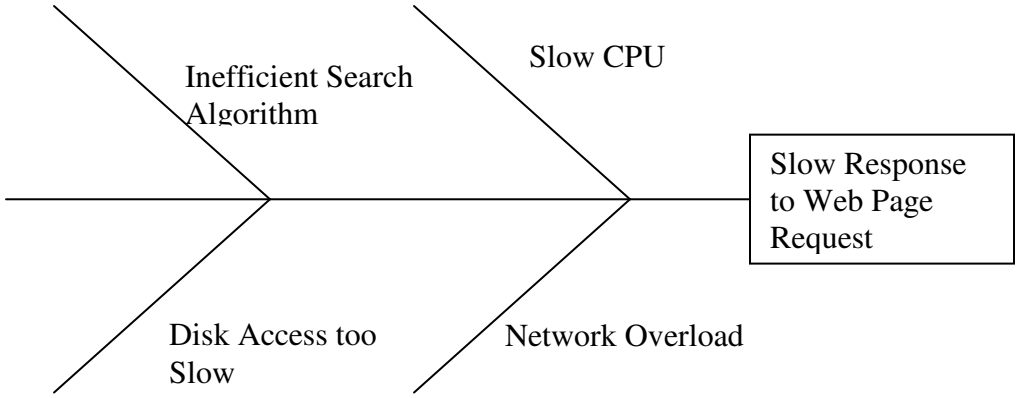


Figure 2.13 Fishbone diagram

Leffingwell also prescribes demographic studies and brainstorming for identifying the stakeholder profiles and the constraints on the solution. Context free questions is another method that poses high-level questions to understand the problem and its domain [Gause 89]. Furthermore, the walkthrough technique (WALT), which poses questions to the user as s/he is guided through a description of the problem, is an effective method to obtain information about the problem as a whole and the potential causes of the problem [Lenart 98].

Research on identifying methods for needs generation is less compared to problem analysis. Techniques such as interviews, storyboarding, brainstorming, questionnaires, etc, which apply to requirements elicitation can be used for capturing user needs [Davis 90]. Prioritization and conflict resolution techniques are useful during the analysis of the user needs [Leffingwell 2000]. Inspection techniques are usually applied for the needs

evaluation activity, which separates the needs to be incorporated in the system from the ones which are to be left out or delayed for the next release [Gilb 93].

2.3.2 Methods for Requirements Elicitation

Requirements elicitation is the process through which the customers and requirements engineers of a software system discover, review, articulate, and understand the user needs and constraints of the software and development activity [Thayer 97]. A number of methods have been proposed to elicit requirements from the users and these techniques are best used in combination with each other.

Requirements are usually elicited through discussion and interviews with the stakeholders [Gause 89]. Workshops, brainstorming, storyboards, role playing and prototyping[9] are some of the other techniques for capturing requirements.[Leffingwell 2000]. Each of these methods have their own advantages and disadvantages and the choice of the techniques should be based on several factors such as type of application, technology used, skill and sophistication of the customer, etc. Lauesen proposes methods such as focus groups, questionnaires, observation, document studies and pilot experiments for this phase [Lauesen 2002]. Scenarios [Weidenhaupt 98] and use cases [Cockburn 2002] are some of the more recent techniques that have been found to be effective.

In addition to these methods, there are some other useful techniques that have emerged in recent years from sociology and sociolinguistics that seem promising. Goguen examines the elicitation phase from a social science perspective and discusses the use of techniques like introspection, discussion, open ended interviews and protocol analysis [Goguen 93]. The Human Computer Interaction (HCI) community has also contributed to the research on identifying methods for the elicitation phases. Techniques such as ethnography studies, contextual inquiry [Holtzblatt 93], artifact analysis [Rosson 2002] and scenarios, which are an integral part of usability engineering[10], are now being used effectively for requirements elicitation.

[9] Techniques listed are explained in Chapter 4

[10] Process that ensures that a system is easy to learn, pleasant to use, error-free and error-forgiving, easy to remember and efficient.

Apart form the methods listed in this section, there are several other elicitation techniques and a detailed list of these is provided by [Young 2001] and [Sommerville 97].

2.3.3 Methods for Requirements Analysis

Requirements analysis is the process of analyzing the users' and customers' needs to obtain a definition of the software requirements. The analysis phase encompasses a large number of activities, which the current requirements engineering models fail to include. As a consequence, most of the requirements engineering literature identify methods for the high level objectives of the analysis phase. Hence, in this section, we review the literature from various disciplines (including requirements engineering) and focus on the research that identifies methods for objectives which map to the ones of the requirements analysis phase.

One of the objectives in the analysis phase is to obtain the rationale for the requirements and prioritize them. Techniques such as brainstorming, I-time, discussions and slip method [NYS 2003] have been found effective in determining the rationale behind an idea in the management industry. Prioritization techniques such as analytic hierarchy process (AHP), priority groups, minimal spanning tree, etc. can be used to organize the requirements as this helps in easier evaluation of the requirements [Wohlin 97]. Requirements can also be effectively organized based on prioritization scales such as high, low, medium or essential, conditional, optional [Weigers 99].

Analysis also involves evaluation of the effects of factors like risk, cost, price, etc on the elicited requirements. The software engineering community has classified the software estimation techniques as: model based, expertise based, learning oriented, dynamics based and regression based [Boehm 99]. Under each of these categories various methods like COCOMO, SLIM, Delphi, etc have been proposed and successfully used in the industry [Chulani 98]. Evaluation of the risk and feasibility of requirements can be accomplished through techniques like decision tree analysis [Pfeiffer 97], net present value, criticality analysis [MIL 80] and fault tree analysis [Elliot 98].

Conflict resolution is an integral part of requirements analysis as it is critical to resolve misunderstandings in order to generate a good requirements specification. There are a

number of resolution methods, which include negotiation [Thomas 76], arbitration, coercion and education [Strauss 78]. Furthermore, the software engineering literature provides clear guidelines for each resolution technique [Easterbook 91].

2.3.4 Methods for Requirements Specification

Requirements specification is the development of a document that clearly and precisely records each requirement of the software system [Dorfman 97]. This aspect of requirements engineering is one of the most researched areas that has resulted in the emergence of several specification techniques. However, the use of each method depends on the type of requirements being specified.

Finite state machines have been used effectively for representing requirements which are described in terms of input and output states [Whitis 81]. When it is necessary to describe the behavior of a system and relate a set of conditions to prescribed actions, decision table and decision tress are the most suitable [Matsumoto 77]. Decision trees capture the same information as decision table but are more visual than the other. Even though both of these techniques have been known for many decades, it was only in the past two decades that its uses have been thoroughly explored [Chvalovsky 83].

Natural language, though inherently ambiguous, is the most commonly used technique for requirements specification. This method facilitates easier comprehension but it makes the task of translating requirements into design difficult. Another similar technique is the program design language (PDL), which uses structured English and pseudo code for representing requirements [McMenamin 84]. This results in a specification which is neither too informal nor formal.

Finite state machines (FSM) were incapable of representing complex behavioral requirements. Hence, they were extended by Harel, who proposes the statecharts for specifying complex requirements [Harel 88]. The requirements engineering validation system (REVS) [Davis 77] and requirements language processor [Davis 79] were developed with the motivation of handling complex specifications.

Several specification languages such as specification and description language (SDL) [Rockstrom 82], requirements specification language (RSL), etc., have been developed

with the intention of generating unambiguous and precise requirements. Other specification techniques included in the literature are PAISLey[11] [Zave 81], Petri nets [PET 62] and Gist [Balzer 82].

2.3.5 Methods for Requirements Verification and Validation

Verification ensures that the requirements specification conforms to document standards, and is an adequate basis for design. During the verification phase, the requirements are checked for various quality characteristics like completeness, ambiguity, verifiability, correctness, etc. Several techniques have been presented in the literature that enable achieving the verification objectives effectively.

Sutcliffe discusses inspection as the main technique for ensuring the adherence of requirements to the quality attributes [Sutcliffe 2003]. Inspection is a rigorous process and identifies a high percentage of errors. Hence, inspection is the most widely used method for the verification of requirements. The other techniques included in the literature are reviews and walkthroughs [Melo 2001]. The walkthrough technique is an informal process and involves the stakeholders in the verification process, unlike the inspection method [Collofello 88]. Hence, walkthroughs are usually conducted to supplement the inspections technique.

Validation is the process by which the stakeholders indicate the extent to which the requirements reflect their intent and that the SRS describes the right system. Prototyping is one of the most commonly used techniques to illustrate the capabilities of the system to the customer [Luqi 93]. The customer get a "hands on" experience of the requirements formulated and can recommend further changes to the requirements. Young describes the use of scenarios and walkthroughs to effectively validate the requirements with the users of the system [Young 2002]. The HCI community uses techniques such as storyboarding, role playing, discussions, high/low fidelity prototyping and interviews, to obtain user feedback on the requirements specification [Rosson 2002]. Some of the occasionally used validation methods described in the literature are simulation [Lerch 95], animation [Siddiqi 97] and formal reviews.

[11] Process oriented, Applicative, and Interpretable Specification Language

2.3.6 Methods for Requirements Management

Requirements management is the process involving the planning and controlling of the requirements elicitation, specification, analysis, and verification activities. The two main concerns of requirements management are traceability and change management, and this section focuses on methods for these issues.

Requirements traceability is defined as the ability to describe and follow the life of a requirement, in both a forward and backward direction. Cross referencing is the simplest technique to achieve traceability. This method involves embedding phrases like "see section x" throughout the project documentation (e.g., tagging, numbering, or indexing of requirements) [Kean 97]. Gotel recommends the restructuring method, which organized the requirements in terms of an underlying graph to keep track of the requirements changes [Gotel 95]. Another technique is the traceability framework that attempts to capture links between the requirements by answering questions pertaining to rationale of the requirements [Pohl 96]

Change management is concerned with ensuring the consistency of the SRS, in spite of changes to the requirements. To achieve this objective, the impact of requirements changes needs to be determined and this is accomplished through traceable requirements. Automation of consistency checking stipulates that the SRS is expressed in formal notation. Techniques such as Software Cost Reduction [Heitmeyer 96], requirements state machine language (RSML) [Heimdahl 95], etc, represent the requirements in a form, which can be automatically checked for inconsistency. Another technique for handling changes to requirements is the logic based framework, which ensures that the specification is complete and consistent.[Zowghi 99]. If the requirements specification is checked manually for inconsistency, methods such as inspections, reviews, internal and external audits and discussions can be used [Pressman 2001]. External audits and reviews are usually performed to get a third party view of the consistency of the document and this strengthens the confidence of the customer in the requirements specification (SRS). In addition to these techniques, applications such as DOORS and Requisite Pro provide graphical tools which ensure faster and efficient change management.

2.4 Research Issues Revisited

The previous sections in this chapter provided the necessary background for this thesis. Research on the SDLC models, requirements engineering models, and methods for requirements process activities was discussed. This section is a prelude to Chapter 3 and 4 and aims to provide a brief recapitulation of the issues[12] addressed in this research.

2.4.1 Problem Statement and Issues

The literature review highlighted some of the problems faced in the requirements engineering field. The first problem is concerned with the abstraction level of the requirements phase and this hampers the effective implementation of the requirements process. Most of the requirement engineering models consist of activities presented at a high level of abstraction and fail to consider the entire requirement generation process. The second problem in requirements engineering is that there is a lack of synchronization between the methods and activities at the right level of decomposition. As a consequence, the requirements engineer lacks the necessary guidance in the selection of methods for achieving the objectives of a particular activity in the requirements generation process.

This research attempts to overcome these problems by decomposing the requirements process to the right level of abstraction and mapping methods to the activities identified. In order to achieve the proposed solution, the following steps must be taken:

1. **Identify an amenable requirements engineering model**: The foundation for this research is a well defined requirements engineering model. After analyzing a number of requirement engineering models (see Section 2.2), we chose RGM for this research because it includes all the major requirement phases and facilitates further decomposition
2. **Decompose activities to proper level abstraction:** The current requirement engineering models provide activities at a high level of abstraction making it necessary to decompose the requirements process to the right level of abstraction.

[12] A detailed explanation of the issues is provided in Chapter 1

The decomposition should be such that the activities identified should neither be too low level nor too high level and is discussed is Chapter 3.

3. **Identify activity objectives:** Another problem with the requirement engineering models that was identified in the literature review was that the models express the objectives of the activities implicitly. As a result, the requirements engineer may overlook some objectives, which are crucial to the requirements phase. Hence, along with the decomposition of the model, it is necessary to identify the objectives of each activity and explicitly state them. This issue is also addressed in Chapter 3.

4. **Map methods to activity objectives:** Since the requirement engineering models lack the necessary level of decomposition, methods are synchronized with the high level activities. Hence, the requirements engineer chooses methods in an as-hoc manner, which may have a negative impact on the quality of the product. Thus, it is necessary to map methods to the activities at the right level of decomposition in order to assist the requirements engineer in his/her task of selecting methods for activities and this issue is resolved in Chapter 4.

5. **Method selection driven by priority criteria:** The task of choosing methods for activities is based on certain criteria like cost, time, etc. In order to simplify this job of the requirements engineer, it is essential to identify the selection criteria and determine the path of methods satisfying these criteria for the entire requirements generation process. This issue is also addressed in Chapter 4.

Chapter 3

The Expanded Requirements Generation Model (x-RGM)

3. Introduction

The previous chapter highlights the issues that need to be addressed in order to solve the problem of mapping methods to activities in the requirements process. This chapter focuses on the first two of those issues: providing a well defined requirements engineering model, and defining the objectives of activities. Chapter 4 will explain the mapping of methods to the activities based on the activity objectives.

In order to avoid reinventing the wheel, a suitable requirements engineering model had to be chosen as a starting point for the research. The RGM was selected over other requirements engineering models for expansion as it covers all the major requirements generation phases. An added advantage of the RGM is that it goes one step further and decomposes the requirements capturing activity.

The objective of x-RGM is to provide a framework for the requirements engineering process so that methods can be mapped to the activities in the model. In addition, the x-RGM is intended to capture the positive features of the various models discussed in Chapter 2 and to provide a much needed structure to the requirements engineering process. Thus, with RGM as the basis, the x-RGM decomposes the requirements

generation process to the right level of abstraction by identifying the necessary activities and their objectives.

Note: The x-RGM has been developed for a contract based development project of a medium to large size. The primary stakeholders in such a project are the user, customer and developer. Furthermore, the customer is clearly identified and is an active participant in the requirements generation process.

Components of the expanded Requirements Generation Model (x-RGM)

At the highest level, the x-RGM consists of four major phases: Requirements capturing, global analysis, organization and compilation, and confirmational analysis shown below.

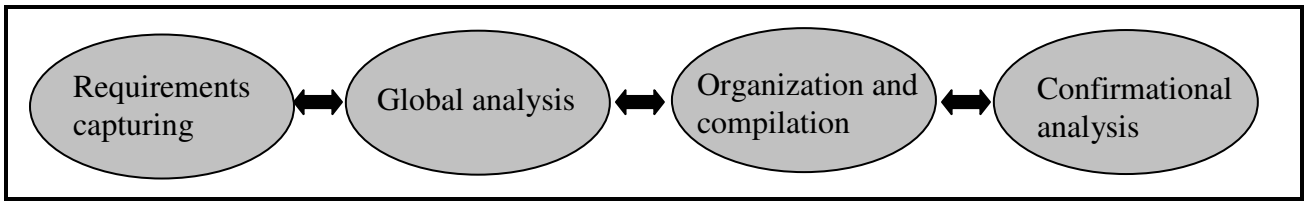


Figure 3.1 Expanded requirements generation model

The concept of "Separation of concerns" [ICSE 2001, OOPSLA 99, Hursh 95], which focuses on identifying and satisfying a small set of concerns for organizing and decomposing processes, is used for modeling the requirements engineering process. The phases in the x-RGM are decomposed in such a way that activities have clear, well-defined objectives, which drive the selection of methods. The activities in the x-RGM are characterized by the following attributes [Kingston 96]:

Activity Name	**Name of the activity**
Objective	Goal/aim of the activity
Action Points	Milestones to be achieved by the activity
Pre-condition	Conditions to be satisfied before activity commencement
Doer	Person conducting the activity
Participants	Participants in the activity
Input documents	Documents needed for the activity to begin
Output documents	Documents produced at the completion of the activity

Table 3.1 Activity characteristics

The decomposition of the phases into activities and the objectives identified for these activities are discussed in detail in the sections that follow.

3.1 Requirements Capturing

Requirements capturing comes after the problem analysis phase, which encompasses learning and understanding the problem, needs of the stakeholders, and constraints on the solution [Davis 93]. The problem analysis phase produces the needs document, which documents the customer problem and needs. In the requirements capturing phase, the needs document drives the elicitation of requirements from the stakeholders. As illustrated in Figure 3.2, prior to elicitation, there is a customer indoctrination activity, which educates the customers about the requirements engineering model and their responsibilities during the process. In addition, the indoctrination activity familiarizes the requirements engineer with the customer problem and domain. Once the elicitation is complete, the requirements are analyzed; and this entails identifying the rationale for each requirement and justifying them with the stakeholders. In addition, the set of requirements are evaluated for quality standards, which are decided in consultation with the customer. Finally, the requirements are validated by the stakeholders.

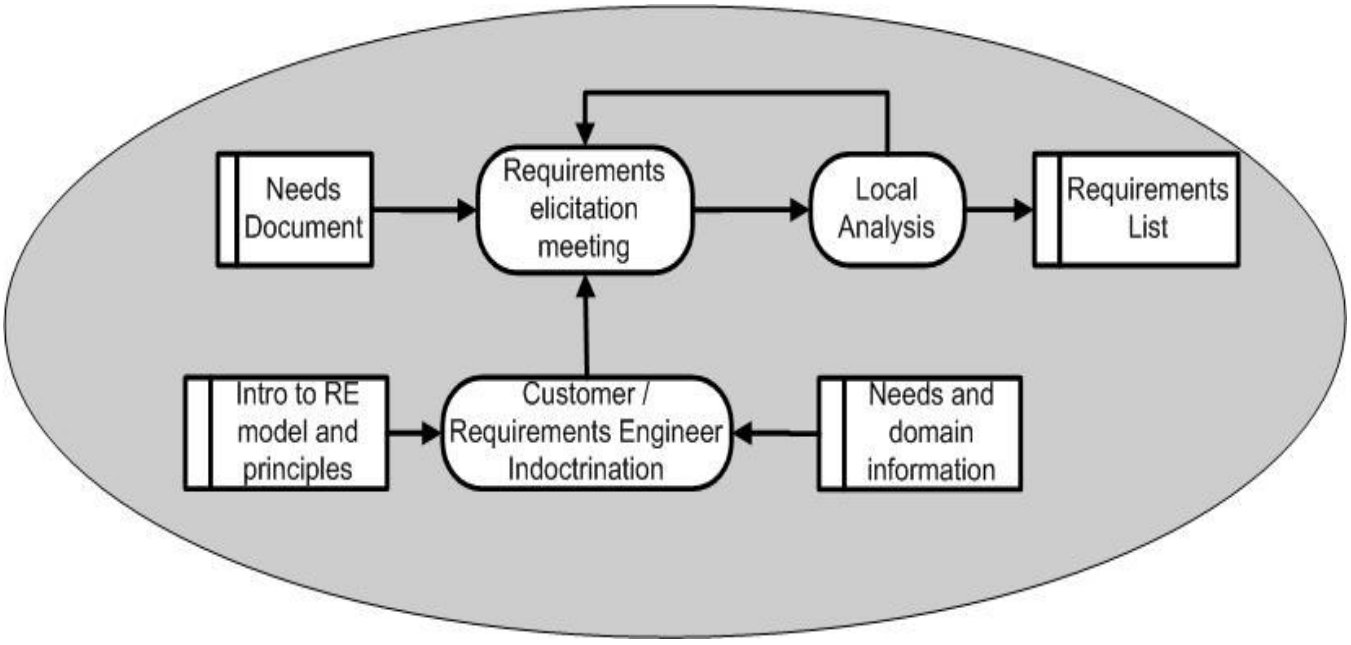


Figure 3.2 Requirements capturing

The subsequent sections elucidate the activities in the requirements capturing phase.

3.1.1 Customer/Requirements Engineer Indoctrination

This activity is performed after the needs generation phase [Song 2002] and can be bypassed by directly performing the requirements elicitation activity. However, educating the customer about the requirements engineering process helps in the goal of achieving a good set of requirements. Familiarization with the process helps the customer appreciate the importance of a particular activity, and his/her role in the activity. It is recommended that the indoctrination be carried out not only for the customers but also for all the stakeholders. (*The customer is the organization paying for the software while the stakeholders are the parties affected by the development. The stakeholders include customer, user, developer, etc.*) Indoctrination results in greater awareness about the requirements process among all the stakeholders. As a consequence, the stakeholders have a better understanding of the process being followed.

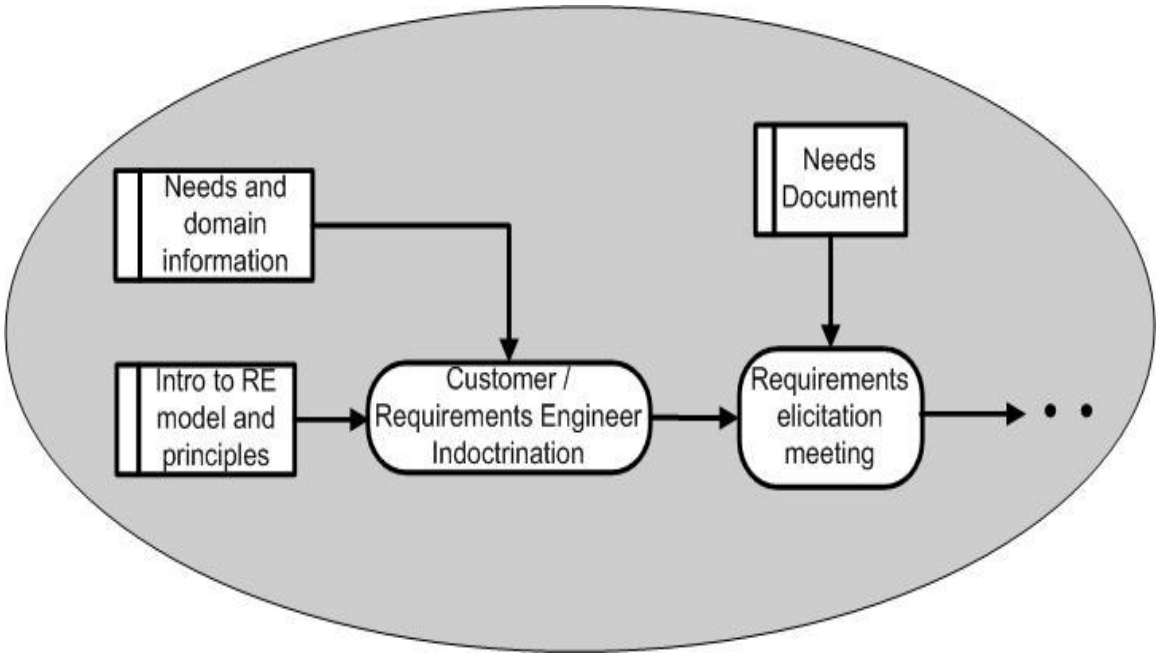


Figure 3.3 Customer/requirements engineer indoctrination

The requirements engineer should focus on the following points during indoctrination:

- A description of the software development life cycle and the importance of requirements engineering

- Explanation of what constitutes a good requirement and what does not
- Overview of the requirements generation model and the description of responsibilities of each participant in the requirements process
- Preparation on the part of the participants for the upcoming elicitation activity

Preparation and readiness for requirements elicitation is critical in obtaining requirements which reflect the needs of the customer. It is the responsibility of the requirements engineer to accentuate the importance of ownership and preparation, and to maintain an open communication channel with all participants.

Software projects are constrained by time and cost, and the stakeholders themselves may be uninterested in spending time on this activity. Hence, the indoctrination of the customer is not mandatory but is a guideline which helps in attaining a clear set of requirements.

The indoctrination activity also involves the education of the requirements engineer that is accomplished by the customer. The requirements engineer is presented with information about the current system and how it provides for the customer needs. In addition, the customer discusses the motivation for changes to the current system, outlining the purpose and overall scope for the new system. The objective of educating the requirements engineer is to provide them with as much preliminary information about the current and proposed system, so that they ask relevant questions to the stakeholders as the requirements are elicited and defined. Unlike the indoctrination of the customer, the education of the requirements engineer is mandatory as it significantly affects the outcome of the requirements phase.

3.1.2 Requirements Elicitation Meeting

The problem and the needs of the customer are identified in the needs generation phase, which precedes the requirements capturing phase. Once the needs are finalized, the requirements capturing phase commences with the elicitation meeting, which focuses on the solution to the problem. The participants, i.e. customers, users and developers, need to be prepared for the elicitation meeting. Hence, in order to facilitate the preparation of the participants, we included the customer/requirements engineer indoctrination activity

in this phase. The indoctrination of the participants prepares them for the elicitation meeting, yet even the best prepared participants can make mistakes during the requirements communication sessions [Arthur 99].

The objective of the requirements elicitation meeting is to correctly identify and capture requirements of the stakeholders. The participants of the meeting may be unclear in the description of the requirements. In addition, they may make certain assumptions about the requirements. For example, a participant may assume that a requirement is trivial, and hence may not convey it to the requirements engineer. Therefore, the task of identifying the requirements is a difficult one for which the requirements engineer should be well prepared. Several approaches such as Joint Application Design (JAD)[CMS 87] , Participatory Design (PD) [Floyd 89] and Facilitated Application Specification Techniques (FAST) [Zahniser 90] have been proposed for requirements elicitation; the choice of the approach taken is left to the requirements engineer.

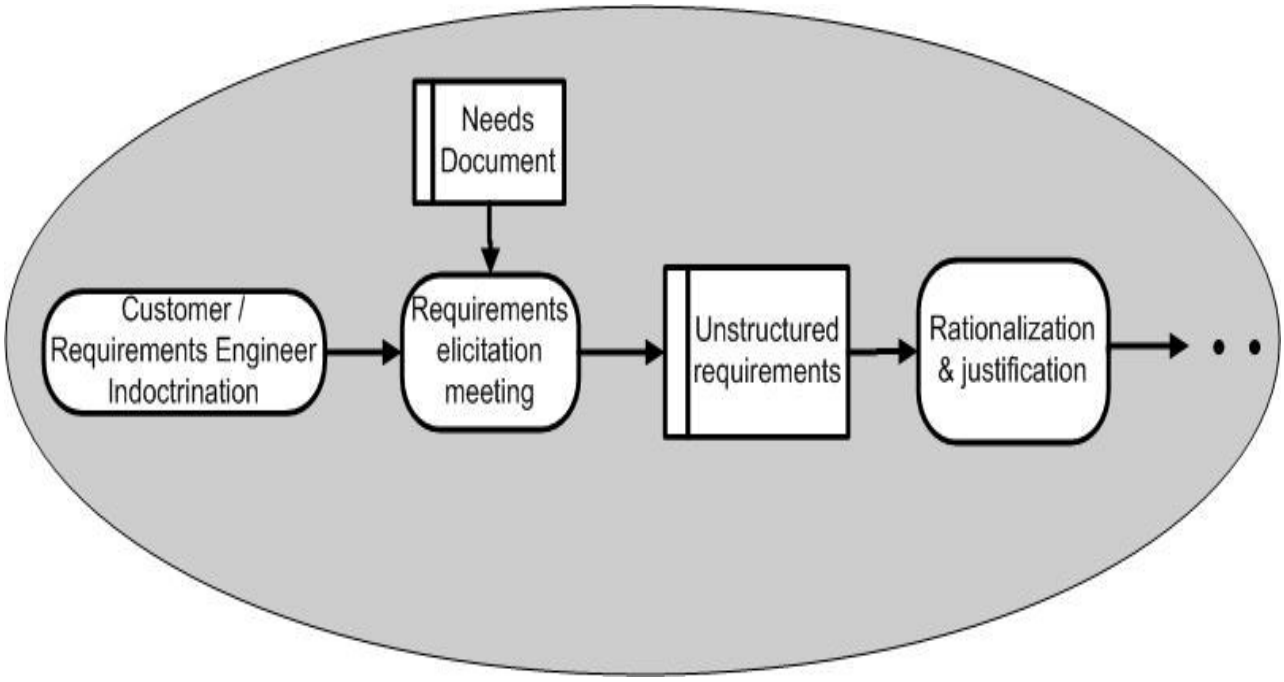


Figure 3.4 Requirements elicitation meeting

The input to the elicitation meeting is the needs document which is produced after the completion of the needs generation phase. There are some subtle differences between the needs and requirements. This is described in the table below

Needs	Requirements
Needs represent the problem domain	Requirements represent the solution domain
Needs are derived from problem elements, which is a breakdown of the main problem	Requirements are derived from needs obtained in the needs generation phase
Needs lack formal representation	Requirements follow standards prescribed by the software requirements specification (SRS)

Table 3.2 Comparison of needs and requirements

Before the elicitation starts, the requirements engineer must identify the participants of the meeting. The Joint Application Design (JAD) or Participatory Design (PD) approach can be used to assist the identification process. The JAD approach advocates the selection of participants by taking a vertical slice of the organizational hierarchy. However, the PD differs from JAD by selecting participants from the same hierarchy level in the organization [Carmel 93]. Again, the choice of approach taken is left up to the requirements engineer.

Once the participants have been selected, the requirements engineer then selects conducts elicitation techniques such as interviews, brainstorming, focus groups, etc., to produce a set of requirements. The success of these techniques depends largely on the active involvement of the participants, and hence selecting the right participants is critical.

In addition, the selection of the techniques is also important as some methods are better suited to a specific situation than the other methods. For example, brainstorming is superior to interviews in eliciting new ideas. The proceedings of the elicitation activity should be recorded as they form an important source of requirements. The recorded proceedings can be analyzed later to provide information about implicit requirements and assumptions made by the participants.

The roles of the requirements engineer and the participants in the meeting differ. It is the participant's responsibility to convey all necessary information to the requirements engineer about the system. The participants should make no assumptions about the

requirements and should be precise in their description. The requirements engineer's responsibility is to capture the requirements and the context for each requirement conveyed by the participants. Moreover, s/he should probe for more information if the requirements are unclear. Thus the roles of the participants and the requirements engineer for the elicitation meeting differ – one provides information, the other captures that information.

3.1.3 Local Analysis

As depicted in Figure 3.2, the local analysis activity is conducted after the elicitation activity. The elicitation activity produces small sets of requirements, and hence the iteration of the elicitation meeting becomes inevitable in order to get the complete set of requirements for the system. The term "Local" refers to the analysis being performed on requirements as and when they are generated. The requirements are not for the whole system, but may be for a single or several small components. The information collected during this activity helps the "global analysis" phase, which analyzes the requirements in its entirety. Local Analysis is further decomposed into subordinate activities as shown in Figure 3.5.

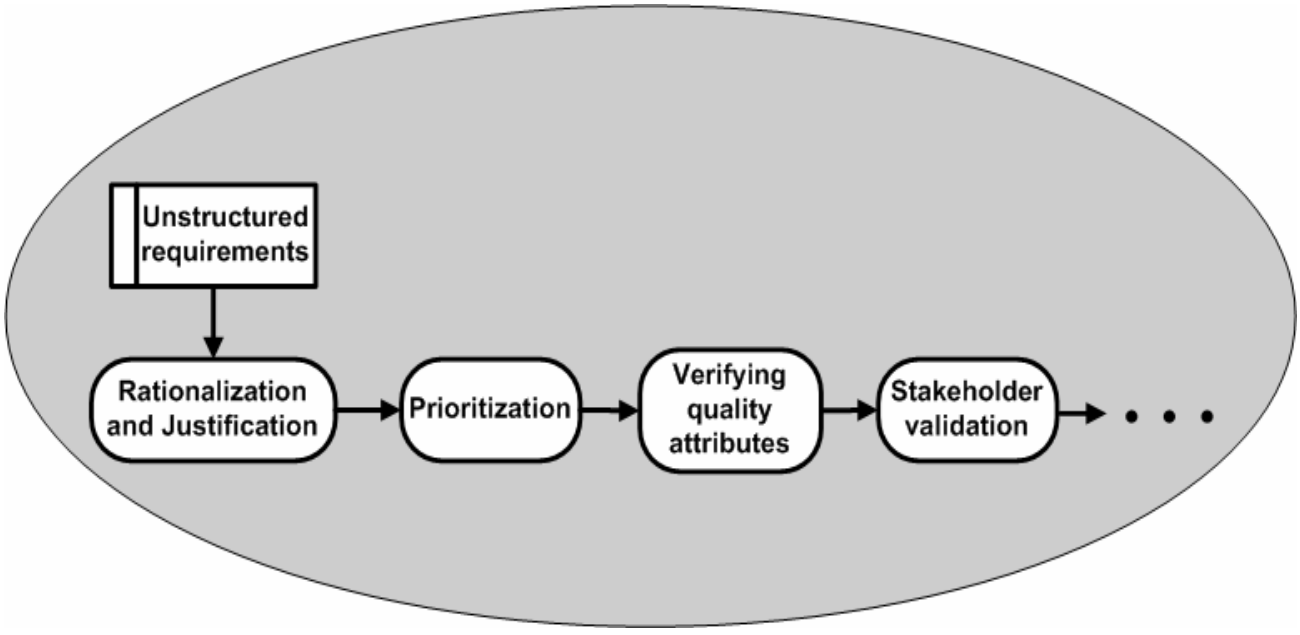


Figure 3.5 Local analysis

Local analysis begins with identifying the rationale of the requirements and confirming the requirements with the stakeholders. The set of requirements is then prioritized, verified and validated. Each of these activities is described in detail in the next few sections.

3.1.3.1 Rationalization and Justification

On completion of a requirements elicitation meeting, a list of requirements is obtained that should be examined with the stakeholders. The rationale of the requirements gathered in the elicitation activity should be analyzed to determine whether the true requirements are hidden in this rationale [Christel 92]. Moreover, identifying the rationale helps in justifying whether a particular requirement is valid, i.e. the requirement maps to a stakeholder need.

Besides attempting to find the rationale of the requirements from the stakeholders, this activity also justifies the requirements identified during elicitation. If the requirements are found to be of a high level, they are decomposed or refined after discussions with the stakeholders. The requirements engineer is in control of this activity, and it is his/her responsibility to identify the rationale behind the requirements from the stakeholders.

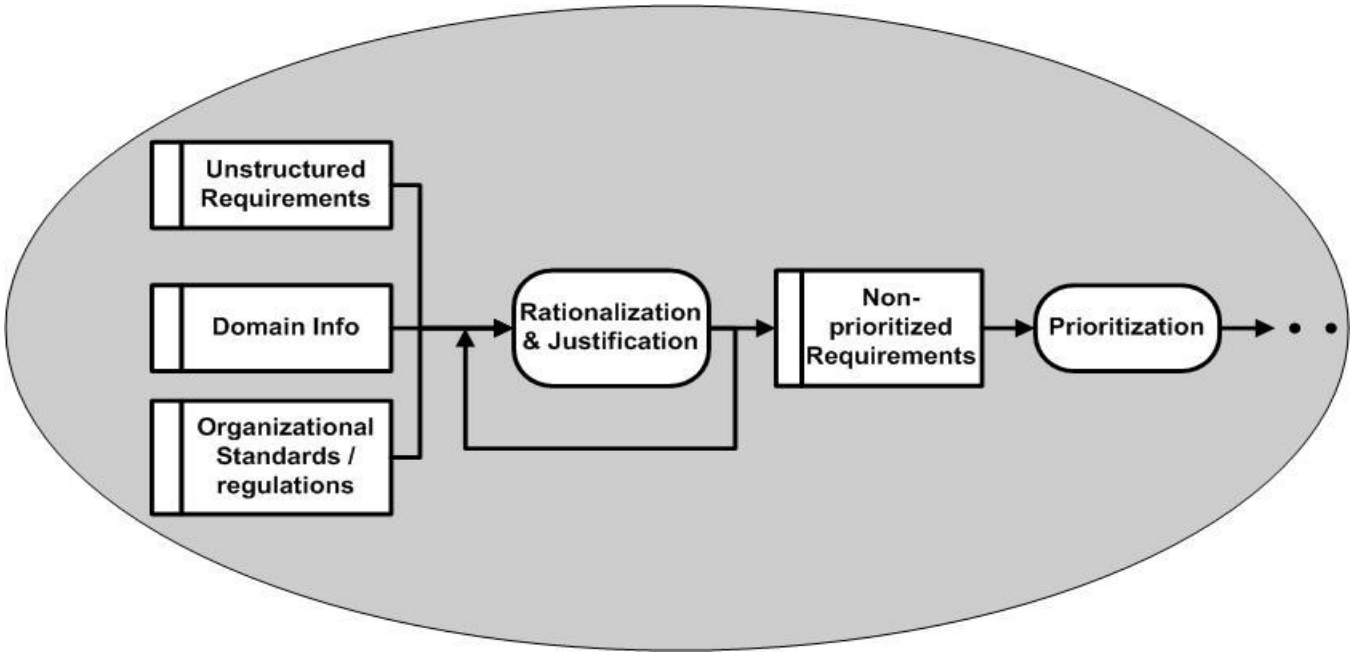


Figure 3.6 Rationalization and justification

The inputs to this activity are the unstructured requirements list, domain information, and the organization standards/regulations document as shown in Figure 3.6.

- **Unstructured requirements list**: This document consists of the list of requirements obtained during the elicitation activity
- **Domain information**: It specifies the working environment of the system and the constraints on the proposed system.
- **Organization standards/regulations**: This documents also specifies constraints but from the management perspective.

These documents help in justifying the requirements obtained from the requirements elicitation meeting.

The rationalization and justification activity begins with the requirements engineer identifying the functional and non-functional requirements for the system components. Once the identification is complete, the stakeholders are asked to answer the question "why" underlying the requirements. This is usually accomplished during a meeting that is headed by the requirements engineer. Several techniques like brainstorming, issue based information system (IBIS) [Kunz 70], etc. are used for this activity. Stakeholder participation is key to the success of this activity.

After the rationale has been collected and examined, the requirements engineer identifies any hidden requirements, and also determines if the requirements conform to the system and organizational constraints. If requirements are found within the rationale, then the current requirement is at too high of a level and needs to be further decomposed or refined. The stakeholders are involved when the requirement is changed in order to develop the feeling of collective ownership of the requirement. An added benefit of identifying the rationale is that the requirements engineer knows about the dependencies between requirements and how they trace back to the needs. This helps in the later phase of traceability analysis when the actual traceability document is created.

After rationalization, the requirements are examined by the stakeholders to determine if the requirements satisfy the constraints specified for the system and organization. There may be requirements that lack traceability to the needs; this lack of traceability indicates

that either the requirements are unnecessary, or that the needs are incomplete. This inconsistency must be conveyed to the stakeholders, and either the needs document or the requirements list is updated depending on the stakeholders' decision.

This is an iterative activity and it continues until the local set of requirements is justified and their rationales identified. Before continuing further into the local analysis activity, the requirements engineer should make sure that the requirements are at an acceptable level of decomposition. Requirements should address "what" a system should do NOT "how" to achieve it [Davis 90]. Also, the requirements should not be at too high of a level which might allow latitude for misinterpretation. A fine balance between the two should be achieved and, it is the responsibility of the requirements engineer to accomplish this equilibrium.

3.1.3.2 Prioritization

The prioritization activity is conducted after the justification and rationalization of the requirements identified during the elicitation activity. The objective of the prioritization activity is to identify the pertinent attributes of the requirements and determine their values. Requirements are also ranked based on the priority ratings given by the stakeholders. The requirements engineer conducts this activity with active participation from the stakeholders. Prioritization is an iterative activity as seen in Figure 3.7. Meetings are held with the stakeholders to determine the objective of the activity and the proceedings are documented for later reference. On completion of this activity, a prioritized list of requirements is obtained and is then submitted to the next activity.

Several requirement attributes are identified and their values determined during the local analysis activity. The major attributes are listed below:

- Risk factors – The stakeholders determine the main risk factors for a requirement, e.g. cost, time, lack of expertise, etc
- User urgency – The user determines how important the requirement is to him/her. A numerical rating scale is often used for this purpose.

- Value to product – A customer representative determines the relative benefit that each requirement provides to the customer or the business on a scale from 1 to 9, with 1 indicating very little benefit and 9 being the maximum possible benefit.[Weigers 99] These benefits indicate alignment with the product's business requirements.
- Effort – The developer determines the rough estimate for the work needed to implement the requirement.

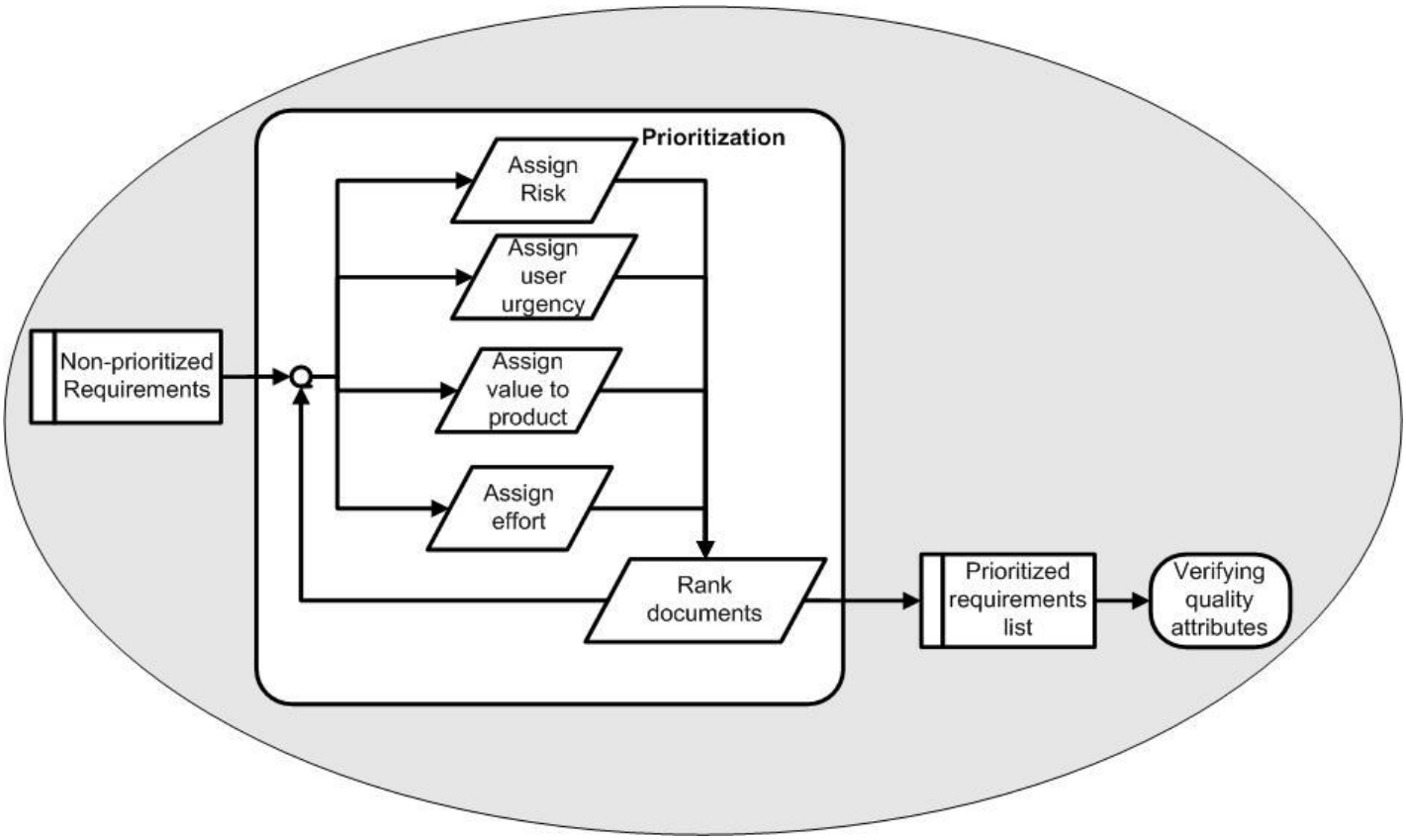


Figure 3.7 Prioritization

After obtaining requirement attributes, the requirements engineer asks the customer to rank the requirements into high, medium and low priority categories. To prevent the customer from ranking all requirements as high priority, the requirements engineer provides an example of a requirement within each priority class. This gives the customer an idea of the priority classes and assists him/her in ranking the requirements relative to these requirements.

The next activity, verifying quality attributes, begins after all of the requirements have been ranked and their respective attributes determined. The output of the prioritization activity is a list of ranked requirements with their associated attribute values.

3.1.3.3 Verifying Quality Attributes

After the prioritization of the requirements is completed, the next step is to verify the local set of requirements for adherence to quality attributes. Verification enables the identification of inconsistencies and redundancies in the requirements. The requirements engineer can verify the requirements provided he has the necessary experience and expertise. But usually, verification is performed by quality experts. As illustrated in Figure 3.8, on completion of this activity, we have a local set of requirements verified for quality attributes.

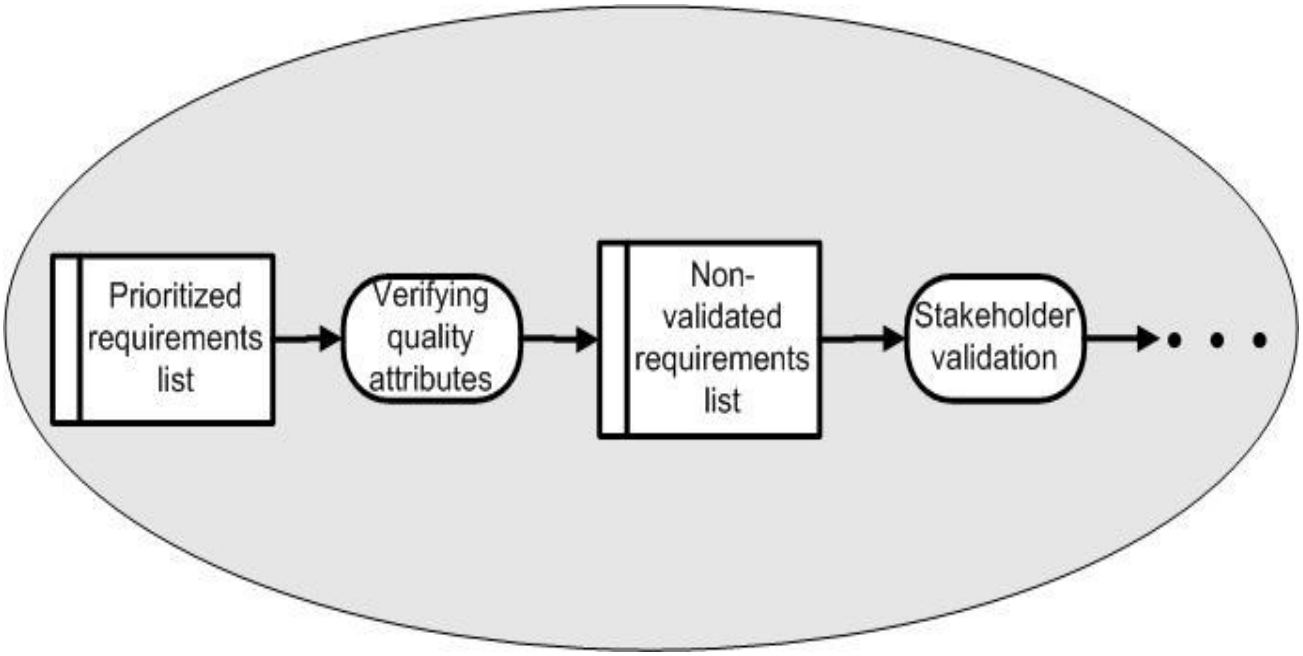


Figure 3.8 Verifying quality attributes

Before the verification of requirements begins, the quality attributes that need to be verified must be identified. There are several sources which provide a number of requirements quality attributes [IEEE 99]. Several of those attributes are shown in Figure 3.9. In order to conduct this activity, it is necessary to identify quality experts, who are either internal or external to the organization.

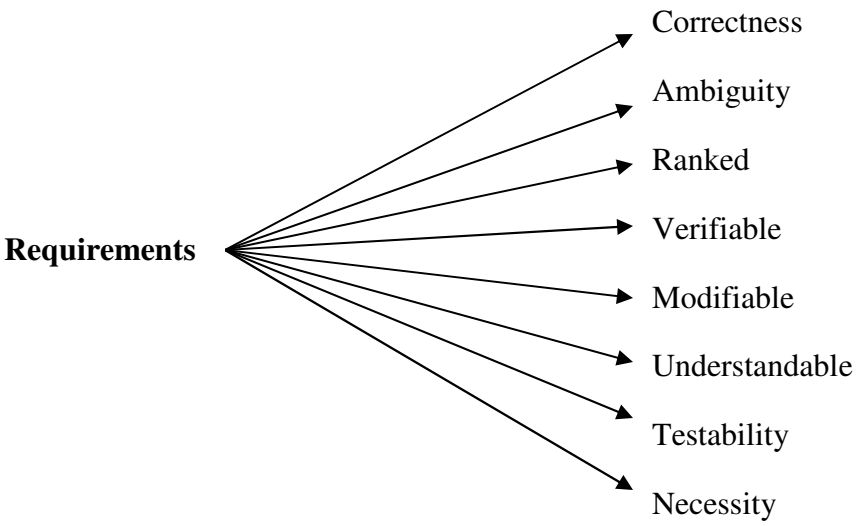


Figure 3.9 Requirements quality attributes

During local analysis not all quality attributes can be verified for the set of requirements captured. Attributes such as completeness and consistency cannot be checked at this stage as only small portions f the whole set of requirements are being examined. At this stage it is recommended that the following attributes be examined

- Ambiguity – each requirement has one and only one possible interpretation
- Correctness – each requirement represents something required of the system to be built
- Testability/verifiability – each requirement should be testable through inspection or demonstration to perform its desired functionality within a reasonable amount of time [Gröner 2002]
- Understandability – each requirement should be comprehendible by all classes of readers (users, customers, developers, etc.)
- Precise – When appropriate each requirement should be stated in numerical terms, and are at the right level of precision

Several techniques are used to perform the verification of requirements for the quality attributes – the most common technique being inspections [Fagan 76]. After the requirements are verified for quality adherence, the quality experts prepare reports stating the extent to which the requirements satisfy the quality attributes. Requirements which fail to meet the quality standards are also included in the reports. These documents are

helpful when the decision regarding whether or not an additional iteration of the requirements capturing phase is to be taken. After verification, the list of requirements is analyzed with the stakeholders in the validation activity.

3.1.3.4 Stakeholder Validation

Validation is necessary to determine if the requirements captured meet the stakeholders' intent. The main objective is to uncover disagreements between what the stakeholder desires and what the requirements state. If the incorrect requirements have been elicited, then validation identifies these discrepancies so that they can be rectified. The requirements engineer conducts the stakeholder validation activity, which takes place after verification of the requirements. At the end of validation, a decision is made by the requirements engineer whether to continue to the next phase or to have another iteration of the requirements capturing phase as shown in Figure 3.10.

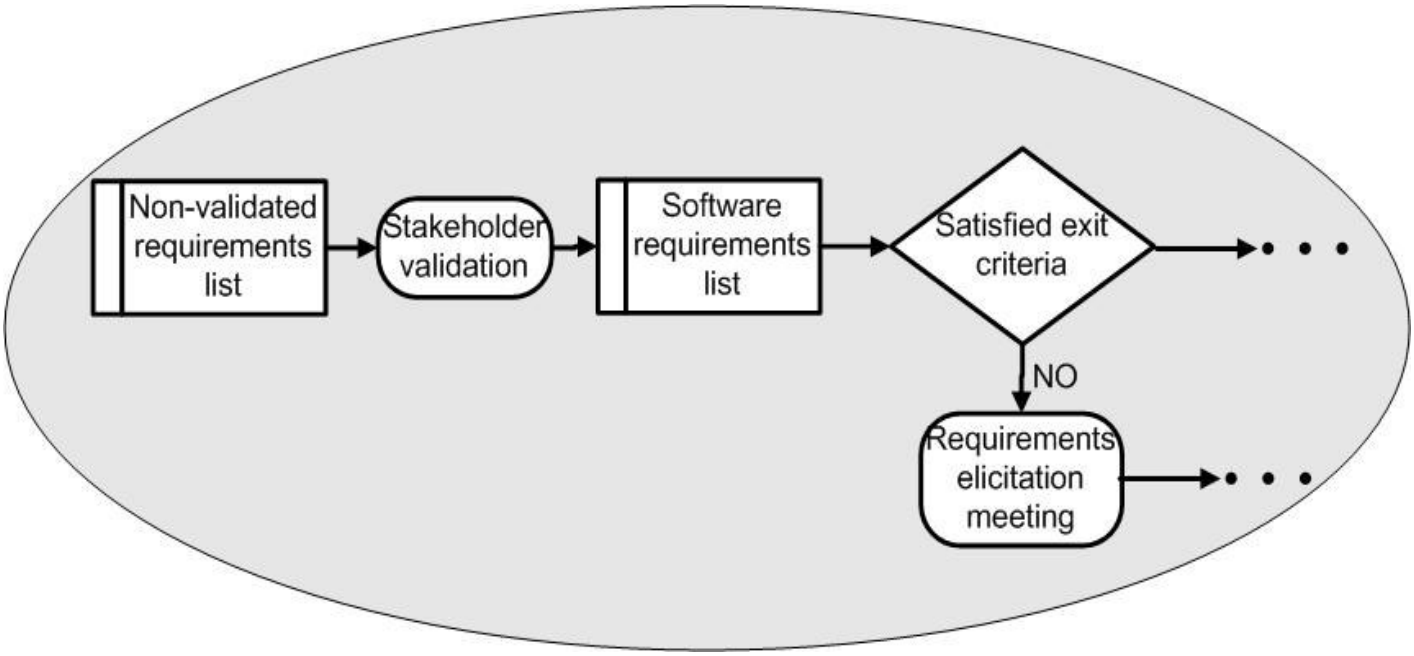


Figure 3.10 Stakeholder validation

Validation at this stage in requirements generation is performed on individual sets of requirements and not on the set as a whole. We propose early validation, as compared to the conventional validation activity at the end of the process, because it reduces the schedule and cost as inconsistencies are identified earlier in the life cycle. An added

advantage is that the stakeholders now feel involved in the process and their confidence in the requirements is also increased.

The proceedings of the validation activity and disagreements (on requirements) with the stakeholders are recorded. If there is a misinterpretation of the stakeholders' intent, it indicates that elicitation was incomplete and that an additional iteration of the elicitation meeting is necessary. This decision is made after the validation activity is completed.

Validation is a process which increases the confidence of the stakeholder in the requirements. Hence, it is difficult to predict the right time to stop. However, in the real world, time and cost act as principal controlling factors for validation. There are several techniques for determining whether the stakeholders' needs are met. Prototyping and walkthroughs are the most commonly used methods for validation during the requirements generation process.

Once the stakeholder validation activity is concluded, the requirements engineer must decide whether to have an additional iteration through the requirements capturing process. The requirements engineer, in consultation with the stakeholder, determines whether the requirements capturing phase is complete. To answer this question, the following exit criteria are examined. As described by Groener [Groener 2002], each criterion consists of a checklist of items pertaining to:

- Inspecting quality attributes of requirements
- Ensuring no open or unresolved issues remain
- Finding agreement among all stakeholders that all requirements have been collected

The first exit criterion is addressed in the verification activity; the requirements engineer uses the report prepared by the quality expert(s) to answer the questions in the checklist. The validation activity identifies unresolved issues or problems with requirements; the outcome of this activity answers the second criterion. Finally, the stakeholders need to answer questions whether their requirements and intent have been captured. If the answer to any of the above criteria is in the negative, then it indicates that another iteration of the capturing process is needed.

The exit criteria listed above are necessary items to determine if the transition to the global analysis phase can be made. This list is not a comprehensive list and we encourage the users of x-RGM to include any additional items, which are necessary for their development effort.

3.2 Global Analysis

Once the complete set of requirements have been captured and evaluated from a "local" perspective, the next step is to evaluate the requirements as one whole set. The set of activities which accomplish this task collectively form the global analysis phase. In effect, it is in the global analysis phase where we analyze factors that globally affect the system under development [Nord 2003]. In this phase, the requirements are examined from the development, market, sales and management perspectives as seen in Figure 3.11. Conflicts among stakeholders emerge during global analysis, and hence negotiation is an integral part of this phase.

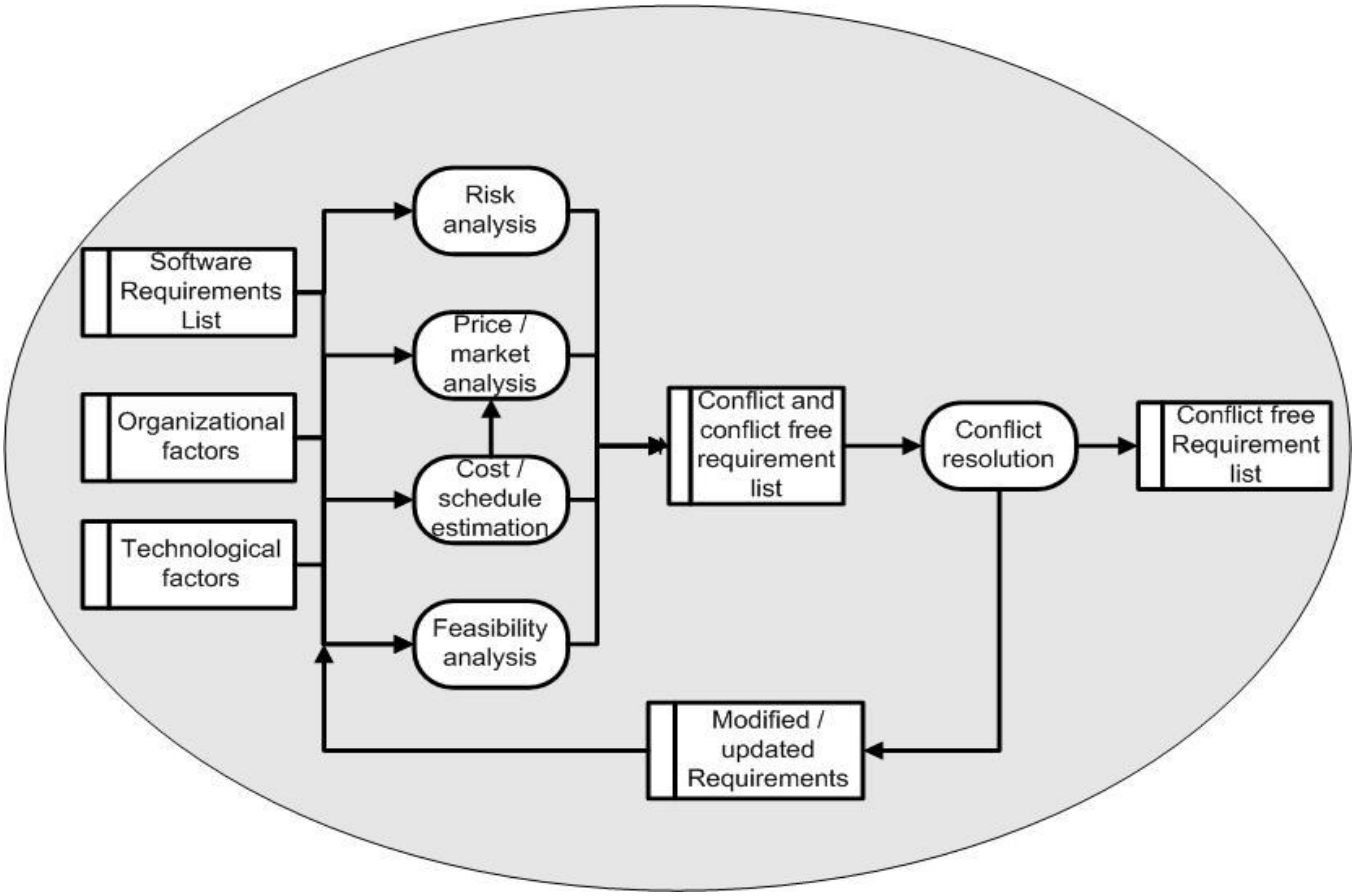


Figure 3.11 Global analysis phase

Global analysis can be divided into two parts – the first part (adapter from [Davis 2003a]) analyzes the requirements and the second part resolves the conflicts. The input to the activities at the start of global analysis comprises three documents – requirements list, organizational factors document and technological factors document.

- **Requirements list**: It is the complete set of requirements obtained from the requirements capturing phase.
- **Organizational factors document**: It arises from the business establishment and has an external influence on the development of the system. These factors include cost, profit margins, personnel available, etc., which constrain options in defining the system.
- **Technological factors document**: This lays down the technological constraints such as the availability of operating systems, hardware, etc. Just like the organizational factors, technological factors affect the system externally, the difference being that the technological factors affect the system throughout its lifetime.

During the process of evaluating the complete set of requirements from the global perspective, conflicts within the requirements are identified and documented. It is the responsibility of the requirements engineer to resolve these conflicts with the stakeholders in an amicable manner.

The sections which follow will explicate the activities in the global analysis phase in detail.

3.2.1 Risk Analysis

One of the first activities in the global analysis phase is risk analysis. The objective of this activity is to analyze the complete set of requirements for the risk factors identified during local analysis. Risk factors are broadly classified into 3 categories - Product engineering, development environment and program constraints [SEI 96].

- **Product engineering**: The risk factors considered in this category pertain to technical aspects of the work to be accomplished. Questions such as the following are considered under this category:
    - *Are there requirements that are technically difficult to implement?*
    - *Is the system size or complexity a concern?*
    - *Does the hardware limit the ability to meet any requirements?*
    - *Are the safety requirements infeasible and not demonstrable?*
- **Development environment**: In this category, risk factors related to the development process, management practices and work environment are examined. A sample set of questions are listed below:
    - *Are there mechanisms for controlling changes in the product?*
    - *Are the managers experienced in software development, software management, the application domain, and the development process?*
    - *Is there a non-productive, non-creative atmosphere?*
- **Program constraints**: Risk factors associated with resources, contract and stakeholders are examined in this category. Questions such as the following are considered:
    - *Are the facilities inadequate for building and delivering the product?*
    - *Is the funding insufficient or unstable?*
    - *Does the contract include any inappropriate restrictions?*
    - *Are there any customer problems such as a lengthy document-approval cycle, poor communication, or inadequate domain expertise?*

The person who analyzes the requirements for risk is usually an expert in risk analysis. However, the requirements engineer can perform this activity provided s/he has the necessary competence. The number of risk analysts needed depends on the size of the project.

During risk analysis, the risk analyst must review each risk factor, estimate the probability of its occurrence, and the loss if the risk occurs. The loss could be represented financially (in dollars) or on a scale of 1 to 10. The risk analyst then estimates the risk exposure for the requirements. Risk exposure is defined as the product of the likelihood that the risk will occur and the magnitude of the consequences of its occurrence. Once this estimation is complete, requirements are ranked based on their risk exposure values. The ranked list indicates the high risk requirements, which are at the top of the ordering. This document is then reviewed by the analyst(s) for errors and is submitted as an input for the feasibility analysis activity, where the requirements engineer in consultation with the management decides whether or not to proceed with the project. In some cases, the overall project risk exposure can be so high that the project intent cannot be attained at a reasonably probable expense.

3.2.2 Cost/Schedule Estimation

Cost and schedule estimation can be performed in serial or in parallel with the risk analysis activity. This activity is conducted by the requirements engineer in consultation with the developers. The objective of this activity is to determine the cost of developing the software components and the time needed for the implementation. The cost and schedule estimates are critical to the success of the project as they affect the budgeting decisions, project planning and control, and tradeoff analysis. In addition, these estimates are one of the drivers for the feasibility analysis activity.

Cost estimation is the evaluation of separate elements (e.g. personnel experience, platform difficulty, etc.) that affect the development of the system to determine if the total cost estimate satisfies the customers' budget. Put in simpler terms – cost estimation is the process of predicting the amount of work or effort required in developing the system.

There exist several techniques for estimating the cost of the requirements. Whichever method is selected, the requirements engineer must pay attention to the following points to get the best results [Leung 2002]:

- Coverage of the estimate (some methods consider the effort for the whole life cycle, while others leave out the requirements phase)
- Assumptions made by the technique
- Sensitivity of the estimate to the different cost parameters
- Deviation of the estimate from the actual cost

The size of the software is a major factor in determining the cost of the project. There are several metrics for determining project size. The organization can choose any of these as long as the metrics are used consistently throughout the project life cycle. The following metrics are the most commonly used in industry:

Lines of code: This is referred to as LOC and it is the number of lines of delivered source code, excluding the comments and blank lines [Fenton 97]. This is the most widely used metric even though it is language dependent and can fail in providing consistently accurate estimates.

Function Points: This metric measures the functionality of the system to determine the cost. The functions of the system are classified under different categories such as user output, user input, etc. Each of these functions are then weighed on a scale of 1 to 3 (1=simple, 2=medium, 3=complex). These weights are then used in a mathematical formula to calculate the cost [Albrecht 83].

In addition to these metrics, there are several others which have been proposed as extensions to the existing metrics. Function points have been extended to include algorithms [Jones 97] and control aspects [St-Pierre 97] of the systems. Software science is another metric, which estimates the cost based on code length and storage space used by the implemented software [Halstead 77].

The requirements engineer should choose a metric which can provide an estimate closest to the actual cost. A good cost estimate should be [Royce 98]:

- Conceived and supported by the development team and management
- Based on a well-defined cost technique, which has credibility in the industry
- Based on the knowledge of relevant projects

- Defined in sufficient detail so that the key cost parameters are understood.

Schedule estimation involves determining the development time of the components and identifying the critical components of the software system. The schedule estimate document helps management in the planning phases as it shows the dependencies of the various software components. In addition, schedule estimation enhances control over complex development work and enables management to use resources in an appropriate manner.

There are five inputs to schedule estimation – requirements list, constraints, resource requirements, resource capabilities/availability and historical information [Burns 2003]. An organization may use one or more of the following approaches to get a good estimate of the schedule.

- **Expert judgment**: Calculation of the schedule is performed based on the knowledge of an expert in the field.
- **Analogous estimating**: Similar projects are considered and the time for development of a similar component is used as the current estimate.
- **Simulation**: It calculates multiple durations for different assumptions.

A good schedule estimate should provide a range of the duration times. For example: a GUI component may take one week plus or minus three days for development. Moreover, schedule estimation must be performed aggressively i.e. the requirements engineer should strive to get an estimate that deviates as little as possible from the actual time needed. If it is estimated that a component will need two weeks instead of three weeks for development, then there is a high probability that the task will take two weeks. People tend to use the time allotted even if the task can be accomplished earlier. Hence, it is important that the requirements engineer involves the right developers to get a good estimate. On completion of the activity, a project schedule document is prepared, reviewed and submitted as input for feasibility analysis.

3.2.3 Price Analysis

Price analysis is the process of deciding a product price which is fair and reasonable, without evaluating the separate cost components and proposed profit [FAST 2004]. In addition, it also determines which functionalities are optional and can be dropped without affecting the value of the product.

The concept of fairness is a relative term, and depends on the perspective of the different party's involved. The users' perspective of a fair price is one that covers the maximum number of functionalities desired. However, the customer's perspective of fairness is a price which provides maximum profit. This indicates that the customer desires a decrease in implementation cost, perhaps at the expense of user functionality. It is the responsibility of the requirements engineer to establish an equitable price which synchronizes the concerns of the user with those of the customer. Reasonability of price depends on the market environment – that is, what is reasonable today may not be so tomorrow. The requirements engineer should examine factors such as supply, demand, economic conditions and competitor's price, before making a decision about the product price.

While both cost estimation/analysis and price analysis deal with the total cost of the product, they differ in their approach. Cost analysis looks at the total cost from the developers' perspective while price analysis is more from the management perspective. Both activities complement each other as can be seen in the example provided in the shaded box (Figure 3.12) [FAST 2004]. Even though cost analysis may provide the total cost in terms of the individual components, the cost may still be unreasonable.

The requirements engineer conducts the price analysis activity and s/he relies on the market survey data for the analysis. The market survey document should provide information about the following factors of reasonability:

- Number of buyers and sellers in the market
- Prices of similar/competitor products
- Intensity of demand
- Quality of products in the market

In addition to this information, the requirements engineer should also be knowledgeable about the production costs and the functionalities of the system. Several techniques such as historical data, cost estimation relationships, etc. can be used in determining a fair and reasonable price.

Background:

Suppose the Government wants to purchase a new vehicle for Government use only. The Government decides to have a mechanic build the car from "scratch" instead of buying a pre-assembled vehicle. Competitive quotes are received on all the individual parts and necessary tooling. All workers receive minimum wage, and the mechanic asks for a very small profit.

Evaluation:

- Even though cost analysis determined that the proposed costs for parts and labor are reasonable, the final price of this car will be much more expensive than a car bought off the assembly line.
- Parts purchased independently may be many times more expensive than when bought in bulk quantities to support an assembly line.
- The entire cost of tooling will be charged to one car, instead of thousands.
- Labor might be cheaper, but it will not be as efficient as assembly line labor.

Conclusion:

Even though all parts were purchased from competitive quotes and the labor rates are reasonable, this does not ensure the final price will be reasonable

Figure 3.12 Cost and price analysis

The output of price analysis is a price estimate document, which is one of the inputs for analyzing the feasibility of the project. This document should clearly state the proposed

price, the functionalities for the proposed price, and the functionalities recommended for implementation in later releases. Also, if the proposed price estimate conflicts with the customer's estimate, then it should be documented for discussion with the customer.

3.2.4 Feasibility Analysis

Feasibility analysis is performed during the global analysis phase, but after the completion of the risk, cost and price analysis activities. It is the process by which the requirements engineer examines how beneficial or practical the development of a system will be to the customer organization. After evaluating the feasibility of the requirements from the business, technological and cost perspective, a 'go - no go' decision is made at the end of the activity. Since this activity involves managerial decisions, the requirements engineer works with managers on this activity.

The previous activities in the global analysis phase provide estimates for the risk, cost, schedule and the price. These estimates are used for the five types of feasibility tests – Operational, Technical, Schedule, Economic, and Legal and Contractual feasibility.

Operational Feasibility: It deals with determining how well the solution will meet its business objective and whether the users feel comfortable using it. Operational feasibility is based on issues such as managerial support, training required, workforce reduction and effects on customers and users. The solution should solve the business problems and at the same time should help the users in their work rather than causing a hindrance. Prototypes are often used to determine if the proposed solution satisfies its objective. If the solution is for the entire organization, then the prototype is deployed only in a small portion of the organization to examine how well it works. If the solution is for individual users, then the prototype is tested for effectiveness by a sample of users. Usability is an important factor during these tests and should be considered while evaluating the prototypes.

Technical feasibility: The objective of technical feasibility is to determine the development team's ability to build the proposed system. The development team's understanding of the target hardware, software and operating environment is assessed. In

addition, the group's experience with systems of similar size and complexity is also examined. Questions such as the following are analyzed:

- Is the proposed technology or solution practical?
- Do we currently possess the necessary technology?
- Do we possess the necessary technical expertise?

Expertise in the target software is essential, otherwise the learning curve will be longer and can have an adverse affect on the schedule of the project.

Schedule feasibility: The schedule estimate that is determined during the cost and schedule estimation activity is checked for reasonability. Factors such as the sensitivity to variations, assumptions of methods, number of schedule parameters, expertise of the participants involved, etc. are analyzed to determine a level of confidence in the estimate.

Economic feasibility: The purpose of economic feasibility is to evaluate whether or not the projected benefits of the system outweigh the estimated cost of the system. It is commonly referred to as cost-benefit analysis. To determine the economic feasibility, costs for acquisition, development and maintenance is evaluated against the tangible and intangible benefits. Tangible benefits are those which can be measured financially, e.g. cost reduction and avoidance, error reduction, increased flexibility, improvement of management planning and control. Intangible benefits are those which cannot be assessed monetarily. They include competitive necessity, increased organizational flexibility, promotion of organizational learning and understanding.

Legal and contractual feasibility: This is the process of assessing potential legal and contractual ramifications due to the construction of a system. Considerations might include copyright or nondisclosure infringements, labor laws, antitrust legislation, foreign trade regulation, and financial reporting standards.

During feasibility analysis, the documents produced by the preceding activities (risk, cost and schedule, price analysis) are analyzed. The requirements engineer has to determine if all the risk items have been considered. The profit margin is the main concern of the customer, and hence it is necessary to examine if the projected profits meet the customers expectations. There is a possibility that the project may end up in losses if the technology

is unavailable or if the product is ahead of the times. Schedule is another important aspect to examine as customers want their products as early as possible - their time-lines, however, may be unreasonable. As feasibility analysis progresses, the requirements engineer observes conflicts with the customers requirements, and these are documented for discussion with the customer. In addition, conflicts between requirements are also detected as the activities – risk analysis, cost and schedule estimation, price analysis and feasibility analysis – are used to evaluate the whole set of requirements. On completion of feasibility analysis, the requirements engineer collects all the conflicting requirements and documents them. The document also includes the decision whether to proceed with the project and the reasons responsible for reaching this decision.

If the project is infeasible, then discussions can be held with the customer so that the project expectations are made more realistic and practical. Even if the project is given the "green light", negotiations must be held with the stakeholders to smoothen out the conflicts in the requirements.

3.2.5 Conflict Resolution

This is the final activity of the global analysis phase and is conducted by the requirements engineer. The initial activities of global analysis identify requirements which are inconsistent and are counter to the customer's project constraints. Conflict resolution is a process by which differences are negotiated to reach a satisfactory solution. The parties involved usually communicate through face-to-face discussions and trade demands and counter proposals.

The success of conflict resolution depends on the requirements engineer. S/he should have good communication skills in addition to possessing the qualities of being honest and respectful. A key concept of negotiation is group ownership of the decisions taken, since solutions are agreed to and not imposed. There is a perceived commitment on the part of all parties to reach an agreement through compromise. If an agreement cannot be owned, the requirements engineer should examine alternative solutions.

Conflict resolution consists of three mains steps: Identify issues, Identify options and Finalize agreements (Figure 3.13) [Boehm et al. 94].

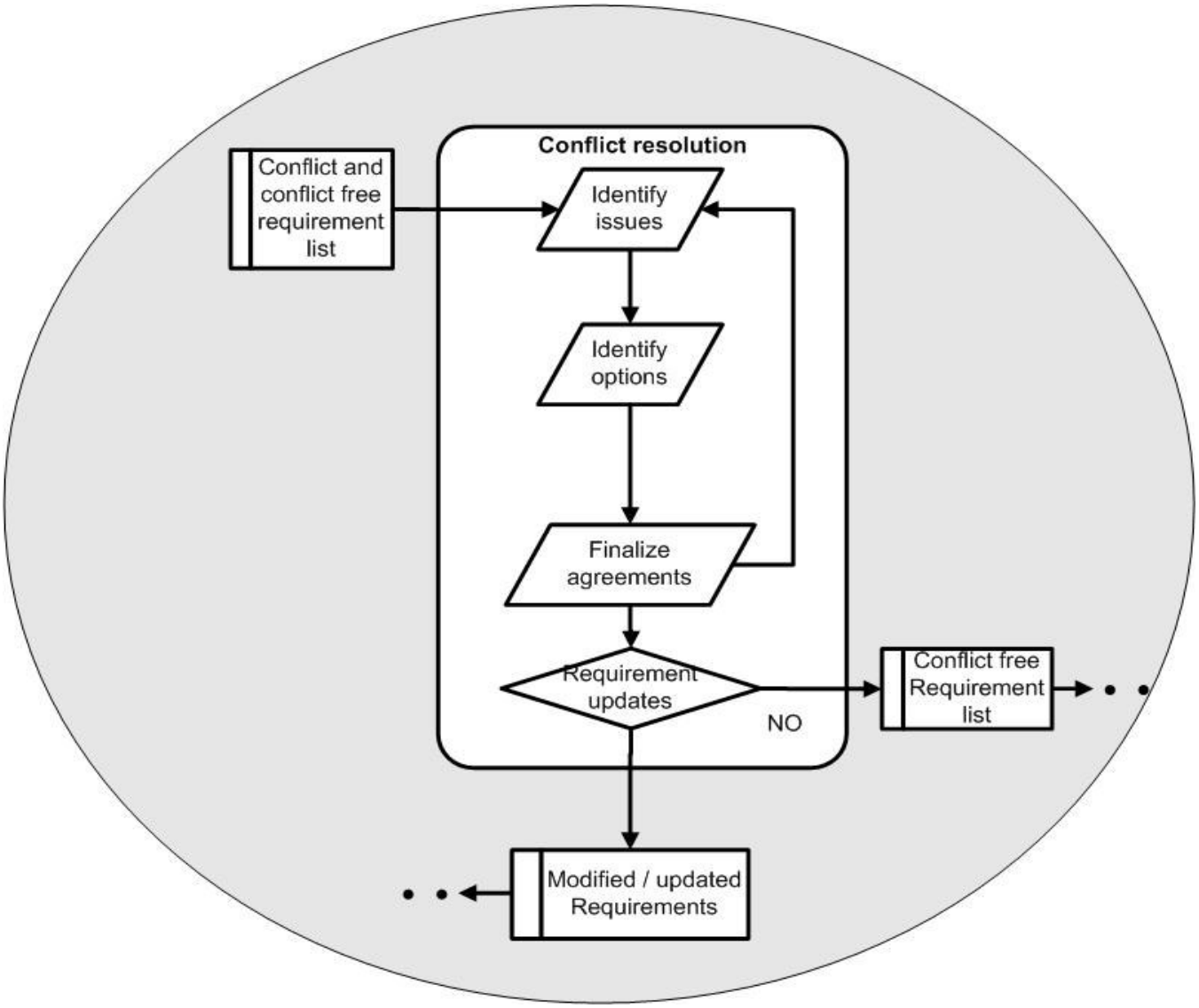


Figure 3.13 Conflict resolution

Issues specify the conflicts in requirements along with the arguments from the stakeholders who own the requirements. The options specify various alternatives to resolve the conflict. Agreements are the final solutions which are agreed upon by all the stakeholders. Conflict resolution is a difficult activity to perform, and there is no single clear-cut strategy which ensures that an agreement will be reached. If the discussion with the stakeholders is in a deadlock situation, the requirements engineer has to approach a higher authority who can make a decision on behalf of the stakeholders. (For example, when the negotiation with the customer representatives is in a stalemate situation, then the customer management can be contacted to intervene.) If the negotiation still fails,

then the requirements engineer conveys the status of the negotiation to management so that they can decide upon the appropriate action.

Before the meeting with the stakeholders, the requirements engineer has to plan for the discussion. The conflicting requirements need to be prioritized so that the most critical are addressed first. In addition, facts which highlight the pros and cons of the different opinions should be collected and documented. Requirements which can(not) be compromised are also listed. The requirements engineer also has to establish judgment criteria. For example, a prioritized list of merits (cost, time, effort, etc.) for the evaluation of the alternate options. These judgment criteria help participants in making consistent judgments about different options [Sutcliffe 2002]. During the meeting with the stakeholders, the requirements engineer has to exhibit his/her communication and negotiation skills. A good strategy is to open the discussion with a position which the stakeholder agrees to. Threats can play an important role if used minimally and carefully. Negotiations should be under control so that it does not digress to an unrelated issue. Once negotiations are complete, the agreements are documented and signed by all participants. The global analysis phase is repeated if the conflict resolution activity results in requirement updates or additions, whose impact has not been evaluated.

At the end of the global analysis phase, the conflict free requirements list is produced which is then used by the next phase for structuring the requirements.

3.3 Organization and Compilation

After the conflict free requirements list is obtained, it needs to be organized and compiled into a single unit such that it fits into the software requirements specification (SRS). This phase consists of a single activity, which excludes any analysis of the requirements. Hence this activity is neither grouped under global analysis nor confirmational analysis phase so that there is a clear understanding of what each phase and its activities accomplish. The specification of requirements, which is a section of the SRS, is the output of the activity; the SRS is NOT the output. During the structuring of the requirements list, the format for the requirements as specified by the SRS is followed. The organization and compilation phase is shown in Figure 3.14

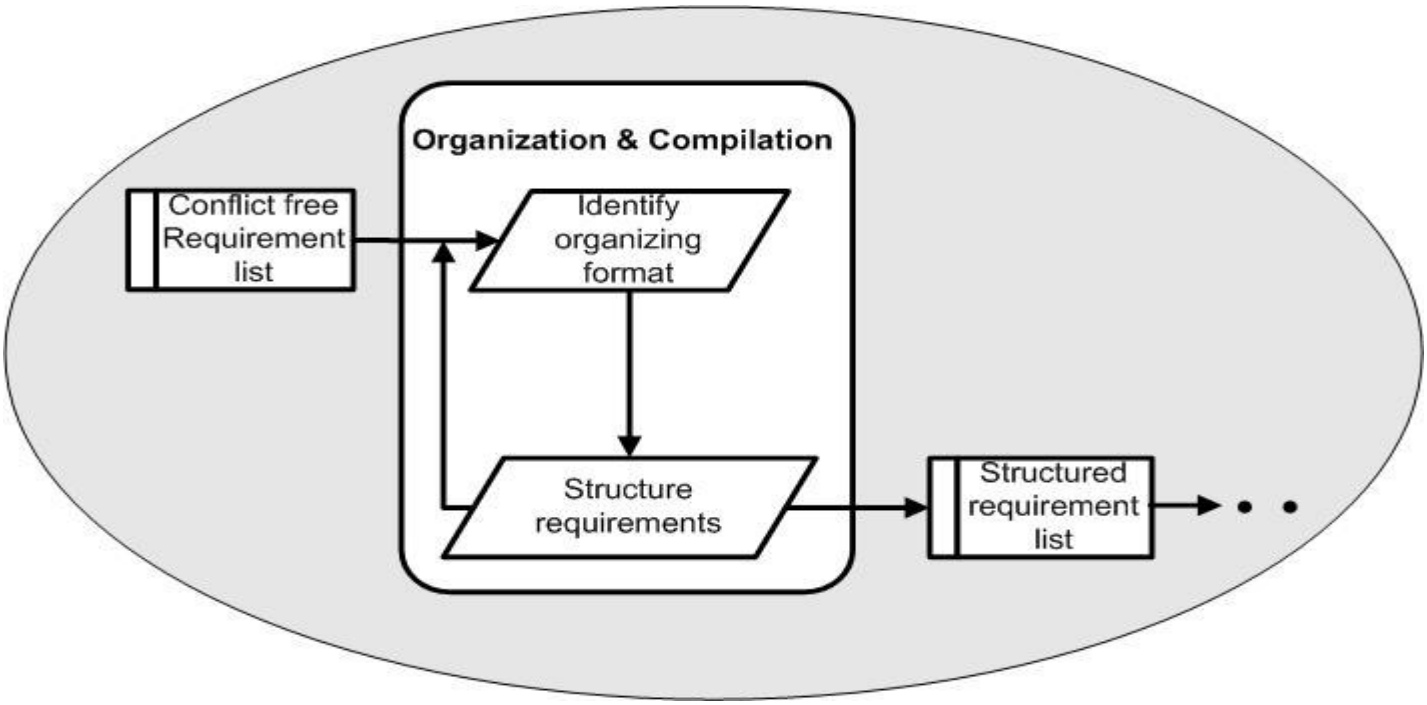


Figure 3.14 Organization and compilation

Coming into this activity the requirements have been classified into functional and non-functional requirements for the different system components during the rationalization and justification activity. However, the requirements need to be organized in a manner which is optimal for understanding. Modification of requirements should also be a concern so that changes to requirements can be made easily, completely and consistently while retaining the structure and style [IEEE 98a]. There are several ways in which the requirements can be organized. Some of these are described below:

System mode: A system may have different behavior depending on the mode of operation. For example, a critical control component may provide different sets of functionalities depending on whether it is operating in normal or emergency mode of operation. Thus, the requirements are structured according to the modes of operation. The template for this organization is provided in A.1 of Appendix A.

User Class: A system may provide different functionality for different set of users. For example, a web application provides different capabilities to users, database administrators, maintenance personnel, etc. Section A.2 of Appendix A provides an outline for the requirements organization based on user class.

Stimulus: For some systems, stimulus is critical for the different operations. For example, a control system can be perceived by the different trigger signals that it receives. Requirements of such systems are best presented based on trigger classification, which is outlined in section A.3 of Appendix A.

Response: Just like the organization based on stimulus, the requirements can also be organized based on response. Requirements which are responsible for obtaining a particular response are grouped under the same category. For example, in a web application, all of the functional requirements responsible for generating the credit card payment report can be clustered together. The template for this organization can be seen in section A.4 of Appendix A.

Functional hierarchy: The overall functionality of a system can be structured into a hierarchy of functions that reflect the information flowing in the system. For example, a high level functionality could be database manipulation while a sub-function of this functionality can be an authorization check. Section A.5 of Appendix A shows the outline for this organization.

Any of these organizations can be selected for representing requirements - the choice is left to the requirements engineer. The organization and compilation phase produces a structured requirements list which forms a subset of the SRS. The organized requirements list is now passed to the confirmational analysis, which forms the last phase of the expanded requirements generation model (x-RGM).

3.4 Confirmational Analysis

This phase performs the final verification and validation of the complete set of requirements. Traceability diagrams are created and the requirements are checked if they trace back to the needs. In addition, minor changes to the requirements are made in response to customer validation. Figure 3.15 shows the activities that comprise the confirmational analysis phase.

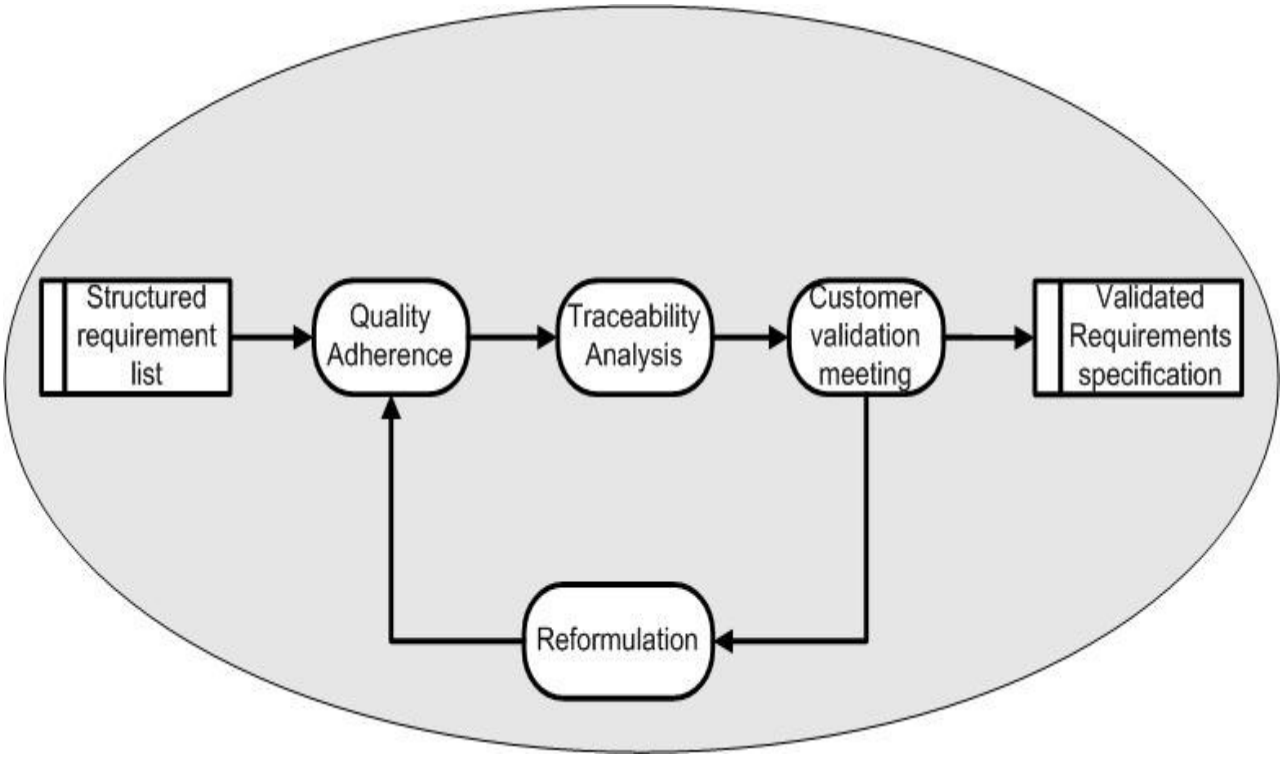


Figure 3.15 Confirmational analysis

On completion of this phase, the validated and structured list of requirements is ready to be included into the SRS. The activities in the global analysis phase are explained in more detail in the sections that follow.

3.4.1 Quality Adherence

This activity checks the requirements from the global perspective, and differs from the quality adherence activity in the requirements capturing phase. The verification of quality attributes in local analysis examines a small set of requirements, and hence attributes like completeness and consistency cannot be evaluated. However, during confirmational analysis the whole set of requirements can be analyzed for quality attributes since this phase is entered only after all the requirements have been captured.

The adherence of requirements to quality attributes is verified by a quality expert. However, a requirements engineer can perform the task provided he has the necessary expertise. The quality analyst verifies additional quality attributes, some of which are shown in Figure 3.16.

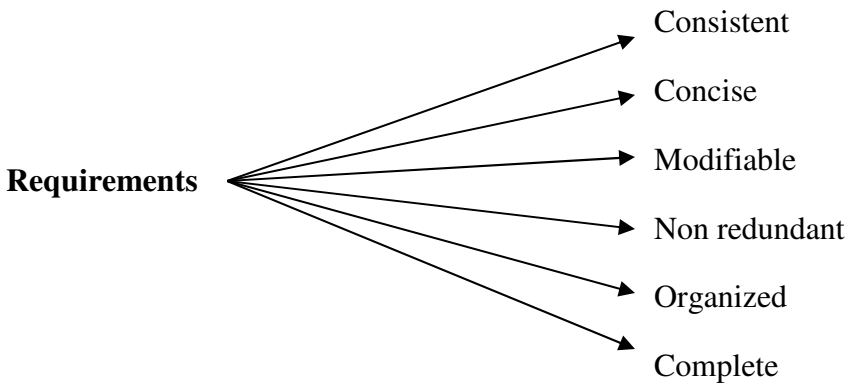


Figure 3.16 Quality attributes

Consistent: The requirements are consistent if and only if no subset of individual requirements conflict with each other [IEEE 84].

Concise: The requirements list is concise if it is as short as possible without adversely affecting other quality attributes of requirements.

Modifiable: The collection of requirements is modifiable if its codified structure is such that changes can be made easily, completely and consistently. This property is important because requirements change frequently during the software life cycle and these changes need to be incorporated with minimal effort.

Non redundant: Requirements should not be stated more than once in a document. This may improve the readability of requirements but the problem arises when the requirements are revised. If redundancy exists, then there is a possibility that the requirements can become inconsistent on revision.

Organized: The requirements are organized if the grouping of requirements are easily understood and the logical relationships between adjacent groupings and sections are apparent.

Complete: The requirements are complete if everything that the software is supposed to accomplish is included and is there are no "To be determined" requirements [Davis 90].

The attributes described form only a small portion of a long list of quality attributes [Davis et al. 93]. In addition to checking the requirements for the attributes mentioned, the quality analyst also has to confirm that during local analysis the requirements were checked for ambiguity, correctness, etc (Figure 3.9) and this is done to ensure that there is

no duplication of effort. The findings of this activity are documented so that any needed action can be taken by the requirements engineer. After checking for the adherence to quality attributes, the requirements list is used as input for the traceability analysis activity.

3.4.2 Traceability Analysis

Traceability analysis is the activity by which the life of a requirement is described and followed i.e. from its origins, through its development and specification, to its subsequent deployment and use [Gotel 95]. This activity is performed after checking the requirements for adherence to the quality attributes listed in Figure 3.15. The requirements engineer conducts traceability analysis, which addresses the following important questions:

- What need is addressed by a requirement?
- Are all requirements allocated?
- Has any need been overlooked?
- What is the impact of changing the requirement [SPS 94]?

Initially, the requirements engineer must determine dependencies or links between the requirements. In addition, the links between the requirements and needs are also identified. This linking of requirements is achieved by examining the results of the rationalization and justification activity (requirements capturing phase), which analyzes each requirement and identifies the rationale behind it. In effect, the rationale of the requirement points to the need from which the requirement is derived, and it also helps in identifying the links between the requirements.

Once the links have been identified, the approach for representing traceability must be determined. One approach is the use of general purpose tools (word processors, spreadsheets, etc.) which support cross linking of requirements among documents. However, this approach is not scalable and is suitable for only small projects. The second approach is the use of a dedicated workbench environment centered on a database management system for the storage of requirements. This environment would provide

tools for editing, storing, linking, organizing and managing requirements. The strengths and weaknesses of each of these approaches are presented in Table 3.3

Approach	Pros	Cons
General purpose tools	Readily available	Limited integration with other software tools
	Good for small projects	High maintenance cost for traceability
	Flexible	Tools have to be configured for supporting traceability
		Limited control on the traceability requirements
Requirement Workbenches (includes requirement management tools)	Provides a number of tools for traceability maintenance	Expensive
	Good for large projects	Learning curve is bigger than general purpose tools
	Provides visualizations for traceability	Rarely covers traceability in the other phases
	Integrates with a number of software tools	

Table 3.3 Comparison of traceability approaches [Kean 97]

Most of the office tools available in the market have database and spreadsheet capabilities, which can be configured to support requirements tracing. Moreover, there are several products under the workbench category which support traceability [STSC 98]. Some of the requirement management tools available in the market are DOORS, Requisite Pro, Caliber RTM, and so forth. The minimum functionality provided by these tools is listed below:

- Bidirectional requirements tracing

- Capture of requirements rationale and accountability
- Identification of inconsistencies
- History of requirement changes
- Verification of requirements
- Impact of requirements change

Traceability matrix and tree representations are the most commonly used in industry to show the dependencies of the requirements. Once the traceability diagrams have been created, the requirements engineer should review the traceability of the requirements for errors. This helps in identifying if the requirements have "dangling pointers", i.e. they do not trace back to any need. In addition, inspection of the traceability helps in detecting inconsistency problems in the requirements. The requirements engineer documents his/her observations and passes the traceable requirements list to the next activity, which is customer validation.

3.4.3 Customer Validation Meeting

Validation is a critical part of confirmational analysis as it determines if the customer expectations are met by the requirements. This activity differs from the validation in the local analysis in that the whole set of requirements are validated as compared to sets of requirements that are validated during local analysis. The objective of the customer validation meeting is to identify if there are disagreements between the customer needs and the requirements. Validation at this stage identifies any remaining discrepancies in the set of requirements. Upon completion of the customer validation activity, the requirements engineer has to decide whether the confirmational analysis phase is complete (Figure 3.17).

All validation discrepancies are recorded by the requirements engineer, and the necessary changes to the requirements are made in the reformulation activity. Validation of the whole set of requirements is accomplished using a number of techniques. The most common method is prototyping because the customer "sees" what the proposed system looks like, and because identifying flaws in the prototyped system is easier when

compared to the use of other techniques. Besides prototyping, reviews and walkthroughs are also popular methods for validation.

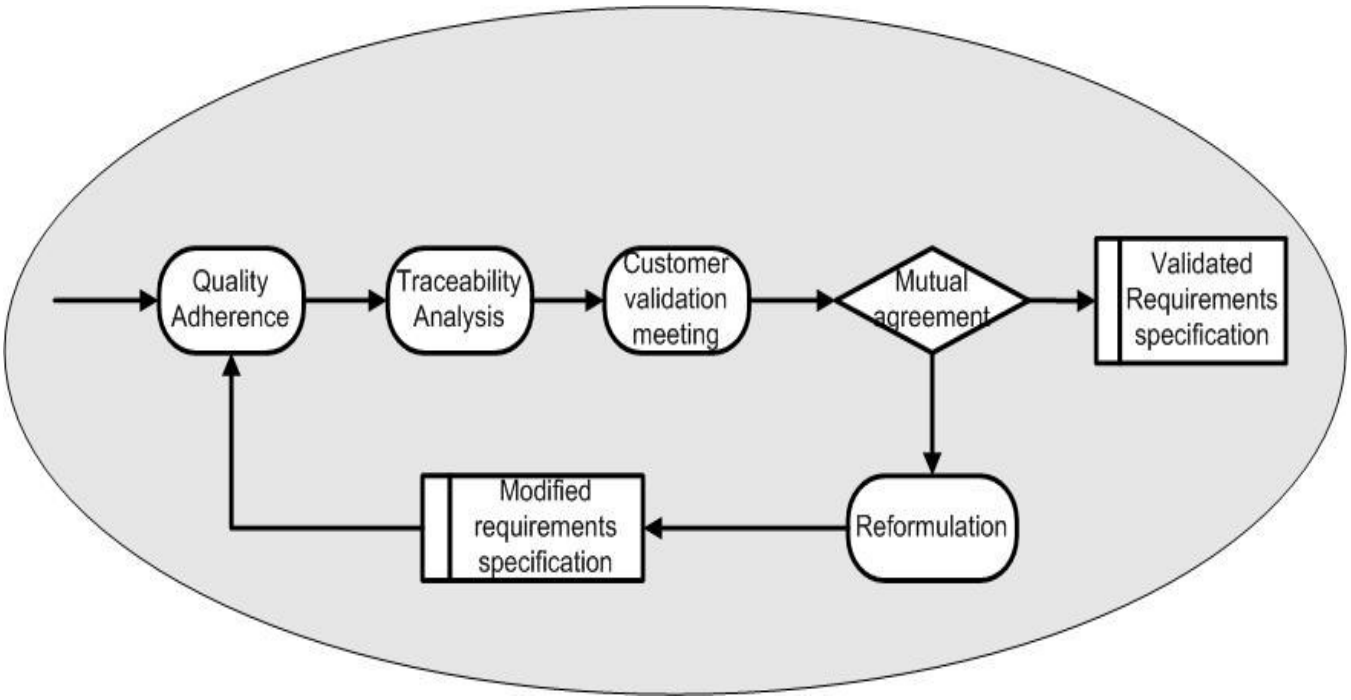


Figure 3.17 Customer validation and reformulation

The requirements engineer decides whether the confirmational analysis phase is complete on the basis of the output from the quality adherence and customer validation meeting activities. If the quality analyst determines that the requirements are incomplete or inconsistent, iteration to previous phases will be needed. The requirements are incomplete if some needs of the stakeholder are not addressed during elicitation. This error is usually identified by the validation activity during local analysis. But in case such an error does slip through, then the requirements engineer must perform an additional iteration starting from the elicitation meeting in order to capture the requirements for the needs that have been overlooked. The other possibility of iteration to previous phases is when the requirements are inconsistent i.e. the requirements have conflicts with each other. Even though the global analysis phase identifies conflicts and resolves them, there is a likelihood that requirements conflicts can pass to the next phase unnoticed. In such a situation, iteration back to the conflict resolution activity is necessary.

If the quality analyst is of the opinion that the requirements need some changes to meet the other quality attributes (Figure 3.16), then as shown in Figure 3.17 the requirements

document is passed to the reformulation activity. Similarly, if the customer is unhappy with the phrasing of the requirements or if s/he needs to introduce in some minor changes to the requirements, these problems are documented so that they can be addressed in the reformulation activity.

The confirmational analysis phase is complete when all of the requirements satisfy the quality attributes, and the customer agrees that his/her intent is captured by the requirements.

3.4.4 Requirements Reformulation

This activity is conducted by the requirements engineer in order to rectify the requirement problems identified by the quality analyst and the customer (Figure 3.17). Such problems pertain to requirements quality and customers disagreement with the requirements.

The requirements document may be organized in an improper fashion for the system being built or it may have redundant requirements, which makes maintenance of the document difficult. An additional quality concern is the verbosity of the requirements document and its non-modifiability. If these concerns are overlooked, the requirements engineer must modify the requirements in consultation with the quality expert.

Customers also play a role in the reformulation of the requirements. During validation, some of the requirements may be unclear to the customer, and s/he may want to change the requirements to make it more comprehensible. As the requirements generation process is conducted, the customer acquires more knowledge about the solution and his/her expectations also rise. Hence, while validation is performed using prototypes or other techniques, the customer may want to make some minor additions to the requirements. These changes to the document are performed during the requirements reformulation activity. Once the updates have been completed, the document goes through an iteration of the confirmational analysis phase, starting with the quality adherence activity, but building on the results from all previous activities.

3.5 Summary

This chapter focuses on the activities and their objectives in the Expanded Requirements Generation Model (x-RGM). The model begins with the iterative requirements capturing phase which elicits requirements and analyzes them from the local standpoint. This phase is followed by global analysis where the requirements are analyzed as a complete set and requirement conflicts are resolved. The organization and compilation phase structures the requirements as a part of the SRS; the confirmational analysis phase verifies and validates the complete set of requirements. The model terminates with the generation of the requirements specification, which forms a section of the SRS. Creation of the SRS, its validation and version control is not included in the x-RGM because the focus of this model is on the generation of requirements and not the SRS. However, if necessary the model can be easily extended to incorporate the generation of the SRS.

We are not aware of any shortcomings of the x-RGM. It was conceived as an expansion of the requirements phase in the conventional waterfall model as depicted in the RGM. The intent was to concentrate on identifying activities and objectives for the requirements phase with minimal overlap between other phases. Even though the x-RGM in its current form is incapable of addressing the other development paradigms such as OOA, XP, we conjecture that the x-RGM can be adapted to accommodate them.

Chapter 4 examines the methods mapped to the different activities in the x-RGM. In addition, the chapter explains the selection of method paths based on different "fitting" criteria for the requirements generation process as a whole.

Chapter 4

Synchronization of Methods and Activities

4. Introduction

Chapter 3 focused on the issues of developing a well-defined requirements engineering model and identifying the objectives of the activities in the proposed model (x-RGM). This chapter addresses the second phase of our solution approach and focuses on identifying methods for the activities in the x-RGM and determining a path of methods for the entire requirements generation process based on some commonly used selection criteria.

This chapter is organized such that Sections 4.1 – 4.4 describe the methods that can be used to achieve the objectives of the activities comprising the different requirement engineering phases (Requirements capturing phase, Global analysis phase, Organization and compilation phase, Confirmational analysis phase). Section 4.5 addresses the issue of identifying the selection criteria and the path of methods which optimize the different selection criteria. Appendix D provides a summary of the pros and cons of the methods mapped to the activities in the x-RGM.

4.1 Methods for Requirements Capturing Phase

The requirements capturing phase begins after the generation of the needs document in the problem analysis phase. This phase is iterative in nature and involves the elicitation, analysis, verification and validation of requirements as shown in Figure 4.1. During the requirements capturing phase, requirements are gathered and analyzed in increments, and on completion of this phase a complete set of requirements is obtained.

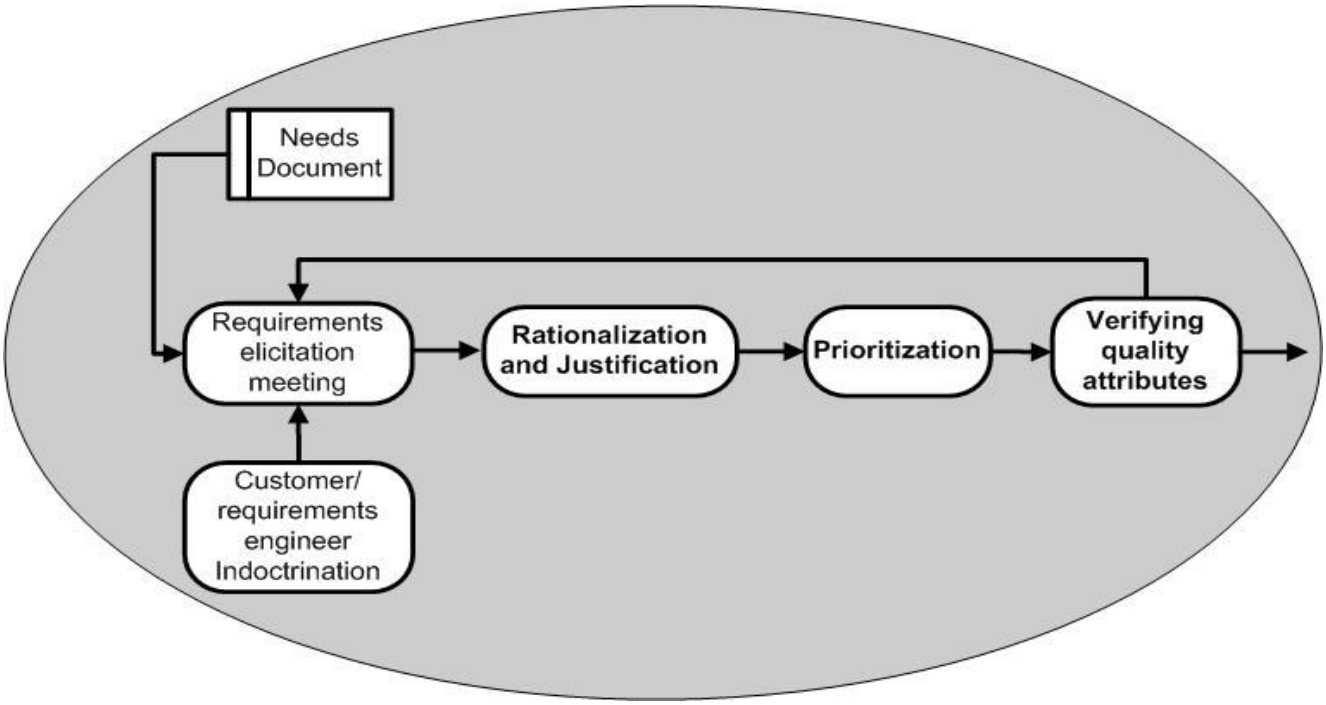


Figure 4.1 Requirements capturing phase

In the sections that follow, we discuss the methods used to achieve the objectives of the activities in the requirements capturing phase.

4.1.1 Customer/requirements engineer Indoctrination

Customer indoctrination is an optional activity, which is performed with the intention of educating the customer about the requirements engineering process. During this activity, the requirements engineer provides the following information to the customer:

- A description of the software development life cycle and the importance of requirements engineering.

- Explanation of what constitutes a good requirement and what does not.
- Overview of the requirements generation model and the description of responsibilities of each participant in the requirements process.

In addition, this activity involves the education of the requirements engineer about the problem domain and user needs. The communication of information in this activity is accomplished through techniques discussed in the subsequent sections.

4.1.1.1 Print Material

Print material is one of the most common methods used in the industry for the purpose of education. Printed material provides a comprehensive coverage of the information that needs to be understood by the readers.

The printed material should follow certain guidelines in order to convey the information effectively. It is crucial that the objective of the document is understood and stated in a clear and precise manner. In addition, the document should be organized so that the readers can easily follow the flow of information. Diagrams should be used to explain difficult concepts and font size should be large enough to read from a fair distance. The document should also include an index and appendix, which provides supplementary information to the data presented. Furthermore, the language level used in the document should be in harmony with the reader's expertise in the language. For example, if the readers' native language is not English, it is highly recommended to create a document using simple English vocabulary rather than complex terminology.

Well planned and worded documents are informative and cover a lot of information. Also, this method can reach large numbers of people at low cost, since the only effort needed is in creating the document [Stocks 99]. In addition, print material (documents) allows people time to digest information and return to it for future reference whenever necessary. The downside of this method is that it involves one way communication, which does not encourage questioning, clarification or feedback [EPA 2003]. In addition, it is difficult to create a document which interests every reader because different people respond to different writing styles, language and tone. There is also the risk that the reader may get frustrated with the bulk of information presented, and as a consequence, some of the

important details may be overlooked by the reader. Furthermore, this technique puts the burden of understanding the material on the readers. Hence, this method requires significant amount of time to convey the information to the audience / readers

4.1.1.2 Oral Presentation

The purpose of using the oral presentation technique is to eliminate, or greatly reduce, the need for written material, where information can be conveyed in a more meaningful and efficient way through visual and verbal means. Nothing has more impact, or is quite as impressive, as a well-delivered oral presentation [PAHO 2003].

During the customer indoctrination activity, the requirements engineer presents his/her knowledge about the requirements process and the life cycle models in general. However, for this presentation to be effective, proper planning and preparation is necessary. The following guidelines should be adhered to for a good presentation.

- Understand the context for the presentation
- Analyze the audience
- Understand and articulate the purpose of the presentation clearly
- Develop sufficient and appropriate supporting material
- Organize the material so it is easy for the audience to follow
- Choose a speaking style, level of language, approach to the subject, and tone suitable to the occasion and environment
- Select graphics that enhances the audience's understanding of the message.

The design of the slides is also crucial in getting the attention of the audience. Some of the design tips commonly followed in the industry are as follows [UTK 2003]:

- Avoid busy, confusing backgrounds
- Use a font large enough to be seen from the back of the room. Use a color for the text that has a very high contrast to the background. Background colors that transition from dark to light can make words difficult to read as the contrast changes.
- Keep the background simple.
- Animations should be minimal.

- Use bar graphs, pie charts and line graphs to show trends and statistics.
- Use contrasting, bright colors to delineate between categories.
- Simplify graphs, and only present one graph or figure per slide.
- Handouts of the presentation should include details or explanations.

The advantage of presentations is that they cover the essential points in a shorter time span than the document studies technique. In addition, the audience grasps more information as this technique allows for questioning and clarification of difficult concepts. Furthermore, this method is cost effective and is useful in establishing relationships with the audience. The disadvantage of presentations is that the information will not reach large numbers unless a series of presentations are scheduled. Also, the effectiveness of presentations depends heavily on the speakers, and hence, it is necessary that the presenters spend considerable time on their presentation. Furthermore, the speaker should be adept in managing the time in order to balance the audience needs for discussion and the speaker's needs to cover all the key issues. One more disadvantage is that the information coverage is not complete, and as a consequence, some of the important details may not reach the audience [EPA 2003a].

4.1.2 Requirements Elicitation Meeting

The requirements elicitation meeting focuses on correctly identifying and capturing the requirements of the stakeholders. During this activity, it is the stakeholder's responsibility to convey all the necessary information about the system to the requirements engineer. On the other hand, it is the responsibility of the requirements engineer to capture all the requirements along with their related information (contextual details). In order to achieve the objective of this activity, the requirements engineer can employ several techniques, which we describe in the sections that follow.

4.1.2.1 Interviews

Interviews are perhaps the most common technique for elicitation and have been effectively employed in a large number of domains [Moser 71]. If the stakeholders are asked the right questions, the interview technique can provide valuable information about

the system and its problems. While the questions play a critical role in the success of an interview, the social aspects of dealing with the stakeholders are also equally important [Zucconi 89].

The interview method begins by asking broad questions known as context free questions, which do not suggest a particular response from the stakeholder [Gause 89]. Context free questions pertain to day-to-day work, day-to-day problems, critical tasks, and so forth. For example, who is the client for this system? What is the real reason for wanting to solve this problem? What environment is this product likely to encounter? What kind of product precision is required? These questions enable the identification of critical issues, which are probed further through detailed questions at a later time.

Interviews can be conducted on a one to one or group basis. The advantage of interviewing a group of people is that they can inspire each participant to remember critical issues and describe day-to-day work [Lausen, 2002]. As a consequence, the requirements engineer can get more information about the system and its problems. However, it is important that a balance in participation is maintained so that no one person dominates the interaction process.

Interviews are advantageous because it is a mature technique and there is lots of literature on how to conduct them [Christel 92]. Also, this method requires little or no equipment except for the interviewer and an interviewee. As a result, the cost involved in conducting interviews is minimal. However, the time taken is considerably long because the requirements engineer has to interview the stakeholders on an individual basis. This holds for the group interviews too, because each interviewee is required to answer the question either by consenting to the previous answers or by adding to it. Another drawback of the interview technique is the tremendous responsibility placed on the requirements engineer, who has the critical task of framing the interview questions. Furthermore, this technique assumes that the interviewee has access to conscious accurate knowledge [Maiden 96]. However, a lot of information is tacit and is held back from the interviewer because the interviewees find it difficult to explain.

4.1.2.2 Observation

Observation is useful in understanding the users' domain, main tasks and priorities, and work habits that the users themselves are unaware of such as workarounds, failures, and exceptions. In addition, this technique helps in determining the context around the use of a particular system and the relationship of the system with the other systems in the environment [HExp 2001].

One example of a task that the user is unaware of is finding a section in a manual, novel or any book. It would seem logical that people would use the index to find a particular section. On the contrary, observation shows that in most cases, people skim through the book assuming that they know where the section is. Only when their efforts fail do they actually refer the index for a particular section.

This method is intended to obtain information by observing what actually transpires in the work environment. Hence, to conduct this technique, the observer / analyst visits the work site and takes notes about the system and its interactions. Observation is easy to perform and does not require much training and preparation. Furthermore, it does not require any special equipment and can be conducted by a single person. However, the use of technology such as a video camera is beneficial as it provides a better coverage of the system and also allows the analyst to examine the collected data later.

The main advantage of the observation technique is its simplicity and cost effectiveness. Though video cameras can be used in this method, it is not compulsory. Another aspect which brings down the cost further is the possibility of conducting this method by a single person. Another advantage is that this method effectively enhances the knowledge on the current system and the related work problems. The problem with the observation technique is that it usually cannot collect information about events / interactions that happen rarely, because the observer can spend only a specific amount of time in the work environment of the target system [Lauesen 2002]. Since this method requires that the analyst be present in the actual work environment of the system, there might be problems regarding access to the sites and workplaces. Another drawback of the observation

technique is that it can generate a lot of unnecessary information and take a long time to perform if complete coverage of the system is required [Maiden 96].

4.1.2.3 Task Demonstration

This method is a variant of the interview and observation technique and involves the study of what a user is required to do, in terms of actions and / or cognitive processes, to achieve a task objective [Kirwan 92]. In many situations, users cannot explain the tacit knowledge that they posses, but they are able to demonstrate how a particular task is performed - this enables the observer / analyst to get a better understanding of the user's knowledge. Task demonstration can be applied to studying how users use existing products. Such an analysis helps in identifying the difficulties the users face in using existing products, and improvements that might be needed [Rauterberg 2003].

Task demonstration technique requires the users to perform tasks while describing what they are doing and why. The other alternative is to have the analyst perform the tasks with the users commenting and guiding him/her. Video cameras may be used to record the session so that they can be referred for later analysis. The information collected by this method is usually evaluated by the requirements engineer to obtain the initial set of requirements for the system. This method has many similarities to the think aloud protocol technique used in usability engineering [Lindgaard 94] and typically produces the following information:

- Roles and related tasks
- Sequences of events and relationships between them
- Objects involved in tasks and their attributes
- Users' actions and resulting behavior
- Breakdowns and problems

The main benefit of the task demonstration technique is a better understanding of the user's mental model and interaction with the product. Thus, the use of this technique is largely limited to eliciting requirements for interactive applications. Another advantage is that this method takes less time to perform because the user usually performs all the tasks in one session. Furthermore, since no expensive equipment is employed, the cost of this technique is also less and is comparable to that of the observation method. The drawback

of this method is that the success of the technique depends heavily on the tasks assigned to the users [Dumas 93]. Hence, it is very important to create the right tasks for a particular application.

4.1.2.4 Document Studies

An effective elicitation activity often involves a certain level of the study of documents such as business plans, market studies, contracts, requests for proposals, statements of work, existing guidelines, analyses of existing systems, and procedures [Hofmann 2001]. Hence, document studies are essential in providing a complete coverage of the requirements for the system under development.

Documents provide information about the current system and its functionalities. In addition, the documents also explicate the need for a particular feature and the arguments against a rejected / delayed functionality. Furthermore, domain information such as the relationship and interaction of the system with the other components, and organizational work procedures are clearly outlined in the documents. Thus, the analyst can obtain considerable amounts of useful information from the study of documents.

The main advantage of the document studies technique is that it provides the analyst with useful insights about the system and its domain. This technique can be effectively used to cross check the information elicited from users through methods such as interviews, brainstorming, and so forth. In addition, this technique allows the analyst to study the documents at his/her own leisure. Document studies are usually conducted by a single analyst, and hence, is cost effective like the other elicitation methods described in the previous sections. However, this method can be time consuming depending on the number of documents examined by the analyst. The drawback of the document studies technique is that the communication is one sided and impeded the clarification of and questioning about the information presented. Another disadvantage is that the analyst may get overwhelmed by the available information and, as a result, may skip certain important aspects / details of the system. Furthermore, document studies are more useful as a supplementary technique than as a primary method for requirements elicitation.

4.1.2.5 Questionnaires

Questionnaires are written lists of questions that are distributed to a large number of people. Depending on the information that needs to be elicited, the analyst formulates the questions as either open-ended or closed. Questionnaires with closed questions can be statistically analyzed whereas open-ended questionnaires can be difficult to interpret [Lauesen 2002].

Closed question questionnaires are suited for situations where it is necessary to obtain statistical evidence for assumptions. The questions provide the respondents with a set of alternatives as answers, and hence, the results are easier to evaluate statistically. An example of a closed question is: "Is the length of time the most important problem at work: Yes / No". However, because the questions are closed, the respondents have no latitude in explaining their choices. Furthermore, it is also possible that the respondents can misunderstand the question and make a wrong selection.

Questionnaires with open-ended questions give the respondents the freedom to answer in any way that s/he chooses. This type of questionnaire is best suited for eliciting opinions and suggestions. Such questionnaires enable the respondents to convey their reasoning for the choice they make for a particular question. However, in this case there is not only the risk that the respondents misunderstand the questions, but also that the analyst misinterprets the answers [Berntsen 2003].

Even though the writer of the questions has a clear understanding, the respondents may perceive the questions in a different way. Hence, it is critical that the author is knowledgeable about the product domain and is skilled at writing clear and unambiguous questions. A precaution that is highly recommended for preventing misunderstandings is to use the questionnaire on a sample group before distributing it to the respondents.

Questionnaires are an effective way of reaching a large number of people quickly. Among the elicitation techniques, this method covers the largest number of subjects in order to collect information. In addition, this method is cost effective because the only effort involved is in creating the questionnaires and distributing it either through post or through the internet. The drawback is that the results may be misleading because the

respondents may misunderstand the questions and respond incorrectly. Moreover, misinterpretation of the answers by the analyst can also impact the reliability of the results.

4.1.2.6 Brainstorming

Brainstorming is a conference technique by which a group attempts to find a solution for a specific problem by amassing spontaneous ideas by its members [Osborn 53]. This method has been employed successfully by many industrial and research organizations involving business, engineering, scientific, and management problems.

The steps involved in a brainstorming session are given below [Lewis 2003]:

- The group leader writes the problem for which solutions are sought on the blackboard or conference pad. The problem should be brief, specific, and stimulating.
- The reasoning and background information for the problem is conveyed to the group.
- The Ground Rules for "brainstorming" are clearly explained. These include:
    - *Every* idea is acceptable.
    - Neither verbal evaluation nor nonverbal expressions of approval or disapproval is permitted during the brainstorming session.
    - The quantity of ideas is the main goal of brainstorming. This concept is called "freewheeling."
    - Building on the ideas of others, referred to as "hitchhiking," is encouraged.
    - A time limit for the "brainstorming" stage should be set.
- The brainstorming session usually begins with a spurt of ideas and then slows down as the meeting progresses. The group leader lists each idea on a board or pad as soon as it is mentioned and should not hesitate in his/her action as this can give the impression of disapproval. Furthermore, the ideas are written exactly as spoken by the group member. The brainstorming session continues till all ideas have been exhausted.

The brainstorming session is usually followed by a discussion where the most promising ideas are identified and ranked. Ideas should not be discarded as it is extremely demoralizing for the group members who have suggested those ideas.

Brainstorming is the most time efficient technique compared to the other elicitation methods. In addition, the brainstorming session is also one of the cheapest methods to perform because of its simple procedure. An added benefit is that this technique promotes creativity and co-operation among the group members. The drawback of this method is that it needs to be followed up by some additional effort to filter out the unrealistic ideas. Furthermore, the effectiveness of the technique depends largely on the knowledge and management skills of the leader / analyst.

4.1.2.7 Focus Groups

Focus groups are in-depth, qualitative interviews with a small number of carefully selected people brought together to discuss a host of topics [Patton 90]. Thus, focus groups combine elements of both interviewing and participant observation. Unlike the one-way flow of information in a one-to-one interview, focus groups generate data and insights through the give and take concept of group interaction [Templeton 94].

The questions posed during the focus group technique should be open-ended so that the participants can generate several ideas. Short answer questions that can be answered with "Yes / No" and leading questions that suggest the leaders opinion, should be avoided. Questions should be [ASA 97]:

- Clearly formulated and easily understood
- Neutral so that the question does not influence the answer
- Carefully sequenced with easier, general questions preceding more difficult ones
- Ordered so that less intimate topics precede the more personal questions

Focus groups are usually comprised of eight to twelve people. The discussion begins with the moderator's introduction which should include the following:

- Explanation of the purpose of the group
- Description of some basic ground rules for group participation and interaction
- Introduction of the moderator and any co-moderators

- Explanation of how and why the group members were invited to participate
- Description of the purpose of note-taking

After the introduction, the moderator presents a set of questions related to the problem. As the group responds to each question, the moderator can probe for detailed information, and ask follow up questions to elicit more discussion. Focus groups are generally scheduled for two hours and conclude with the moderator summing up the major points of the discussion [Morgan 88].

Focus groups are effective in collecting a wide range of information and are more flexible compared to interviews. In addition, this technique can be conducted in a short duration of time similar to that of the brainstorming method. Focus groups are beneficial to the organization because they ensure greater involvement and co-operation among the members. However, this technique is criticized because the information gathered is based on the views of a small sample, which may not be representative of the target population. Also, the quality of the data elicited is influenced by the skills and motivation of the moderator. Another drawback of this method is the high cost involved because the group members are carefully picked people, who need to be paid for their time, energy and creativity.

4.1.2.8 Requirements Workshops

Requirements workshop is perhaps the most powerful elicitation technique and is designed to encourage consensus on the requirements of a particular application in a very short time frame. This technique involves gathering the key stakeholders together for a short, intensive period, typically for one to two days. The workshop is best facilitated by an outside expert, who focuses on the elicitation of requirements [Young 2002]. The responsibilities of the facilitator are to:

- Establish a professional and objective tone for the meeting
- Establish and enforce the rules for the meeting
- Manage the timing of the meeting
- Facilitate the decision making process and avoid pushing his / her ideas
- Ensure that the meeting is on track
- Control disruptive or unproductive behavior

The most important part of the workshop is the elicitation of ideas; this is accomplished in a manner similar to brainstorming. It involves a group setting, where the moderator asks open-ended questions while the participants answer the questions with spontaneous ideas. The difference between the workshop and brainstorming is the preparation for the group session. Requirements workshop involves sending out background material in advance to the participants while brainstorming does not. On obtaining the ideas, the group focuses on classifying, filtering and prioritizing the ideas. After the workshop, the facilitator distributes the minutes and outputs of the meeting to all the attendees [Leffingwell 2000].

Requirements workshops are advantageous because they assist in building a co-operative team, having a sole purpose – the success of the project. It is one of the best methods compared to all the other elicitation techniques. In addition, requirements workshops require a smaller time frame compared to the interview and observation techniques. The drawback of this method is that it is cost intensive because a lot of effort and expense is needed in preparing and conducting the workshop. Moreover, if the facilitator is an outside expert, s/he has to be paid for services provided.

4.1.2.9 Prototyping

Prototyping is used to better understand the poorly defined and fuzzy requirements of the system. This technique involves creating a partial implementation of the system in order to help the developers, users, and customers understand the requirements.

A prototype should avoid implementing well-understood requirements as this is a waste of resources. For example, if a system is to be extended, there is no need for prototyping because it is clear what most of the new functionalities need to be. However, the well-defined requirements may have to be prototyped to understand the fuzzy needs of the customers and users.

Once the prototype is built, the users of the system should ‘play’ with the prototype in an environment which closely simulates the target setting of the final system. This enables observing the influence of the environmental and other external factors that affect the system [Leffingwell 2000]. Furthermore, for the results to be reliable it is recommended

that various types of users be selected for exercising the prototype. After using the prototype, the users usually give a "Yes, But" response, which makes the unknown user needs visible. In addition, the users and the analyst now have a better picture of what the system requirements are.

The result of prototyping can be two kinds of requirements [Lauesen 2002]:

- **Product-level requirements**: These are requirements for the product functionalities, which have been shown to be realistic and useful by the prototype
- **Design-level requirements**: These are requirements which specify that the real product should have an interface exactly or similar to that of the prototype

Prototyping is a useful technique in situations where the users are unclear about their needs and requirements. This method is also effective in eliciting requirements for new and innovative applications. The main drawbacks of this technique are the high demands of cost and time. This is because of the need to implement a rough version of the application. However, it is argued that since this technique involves the customer early in the development process, fewer change requests will be made at a later stage, and this might eventually reduce the project time and cost [Sommerville 2001].

4.1.3 Rationalization and Justification

This activity aims to find the rationale of the requirements and also justify the requirements identified during elicitation. In addition, if the requirements are found to be of a high level, they are decomposed or refined in consultation with the stakeholders. In this section, we describe the techniques that can be employed for achieving the objective of the 'rationalization and justification' activity.

4.1.3.1 Brainstorming

This method involves a group session, where the participants interact and provide ideas spontaneously without the fear of being ridiculed. When used in the rationalization and justification activity, the brainstorming technique raises questions about the rationale of the requirements identified by the stakeholders.

This technique is advantageous because of its cost-effectiveness, simplicity, and time efficiency. The drawbacks of this method include the dependency on the moderator's management skills for success, and the need to filter out unreasonable ideas through additional supplementary techniques.

A detailed description of this technique is provided in Section 4.1.2.6

4.1.3.2 I-Time

I-Time is commonly used for determining the rationale of the requirements and is referred to as individual time or introvert time. In this technique, the participants spend a few quiet moments reflecting on the question and problems. This method involves a group session that is usually non-interactive.

I-Time is conducted using the following steps [NYS 2003a]:

- Give a brief introduction of the topic / issue (requirements whose rationale is to be determined)
- Instruct team members to either sit quietly or leave the room briefly to find space where they can concentrate and focus
- Establish a time limit depending on the topic or question the team is considering
- Repeat the question or instructions, or display them on a slide or overhead during the break
- The participants present their ideas after the break and this process is repeated in subsequent rounds

This technique should be used depending on the characteristics of the group members. If the participants have not had the opportunity to think about the problem or issue at hand, then this method is effective in avoiding an embarrassing situation for the group members. Also, if the team members are diverse or introverts, I-Time allows the participants to be alone with their thoughts without feeling pressured to come up with ideas or push their way into a conversation.

I-Time is effective when participants need time to think about the question or when they are introverts. This method is easy to perform and requires almost the same amount of

time as brainstorming. Another benefit is the low cost involved in conducting this method because there is a minimal need for resources. On the downside, the success of this method depends heavily on the questions posed and the management skills of the facilitator.

4.1.3.3 Task Oriented Discussion

This technique, also known as directed or guided discussion, can be used to identify the rationale of the requirements and to justify them. Moreover, they are often used as a follow-up for techniques such as brainstorming and I-time, which only identify the rationale of the requirements and fail to justify them.

In a task-oriented discussion, the moderator (usually an external expert) plays an important role in guiding the group towards a goal, overcoming obstacles and disagreements, keeping to a schedule and reaching an agreeable conclusion. One of the important skills that the moderator must possess is the ability to ask the right questions, which [MAHR 2003]:

- increase comprehension
- monitor and evaluate the group's level of perception
- help guide the group, i.e. when the group doesn't understand something, additional questions may cover more territory in areas that require assistance
- focus the group's attention on the relevant topic

The guided discussion is conducted through the following steps [DoD 99]:

- Prepare an open-ended question for each of the topics to be discussed
- Give introductory background information and briefly mention each topic or issue that will be covered during the discussion. State the amount of time that will be allowed for each topic or issue
- Ask the first question and observe the proceedings intently. Guide the discussion without being involved in the content. Intervene whenever it is necessary to assist the discussion process
- Monitor the time and move to the next topic using a transition statement
- Ask the question for the next topic

- If discussion digresses from the topic, bring it back on track without stifling additional ideas
- After discussing all topics, give a quick summary of the ideas presented and decisions made. Express appreciation for the group's participation

The advantage of guided discussion is that it encourages co-operation and interaction, which in turn leads to better understanding and commitment to the decisions taken. In addition, this technique enables free interchange of ideas, stimulates and clarifies thinking. Task oriented discussion takes more time than brainstorming and I-Time because it not only identifies different ideas but also determines the solution. As a consequence, more effort is needed making this method more expensive than the brainstorming and I-Time techniques. Furthermore, discussions may suppress convictions resulting in the first solution being accepted [USMC 98].

4.1.3.4 IBIS

The Issues Based Information System (IBIS) method can be used effectively to achieve the objective of the rationalization and justification activity. It is similar to the task oriented discussion technique but is more structured with a number of guidelines.

This technique consists of the following steps [Armstrong 2001]:

- Discussions are led by a moderator
- Every issue begins with one or more questions
- More questions are asked whenever appropriate
- As answers are proposed, they are grouped under the question
- Pro's (arguments for) and con's (arguments against) are listed under each answer
- Additional information is added anywhere it makes sense
- A decision cannot be reached until all answers and arguments have been evaluated

When used for the rationalization and justification activity, this technique focuses on identifying the rationale of different requirements through discussions. Once the rationale is obtained, the technique attempts to justify the requirements by eliciting the positions / opinions of the participants on a particular requirement. The participants are also required

to justify their stand through arguments, which are discussed and analyzed to determine whether or not the requirement is necessary [Conklin 88].

IBIS discussions tend to be calm and rational without heated battles. This is mainly because ideas are not discarded and every argument is considered. In addition, a decision is never reached until all the arguments are evaluated. The IBIS method covers all aspects of the rationalization and justification activity and is the best technique to achieve the objective of this activity. On the downside, this method is time consuming because it involves the evaluation of all the generated ideas and arguments. As a result, the cost of conducting this method is also more than the other techniques for this activity.

4.1.4 Prioritization

The prioritization activity is intended to identify the attributes of the requirements and determine the values of these attributes. In addition, this activity also involves the ranking of the requirements based on the priority ratings given by the stakeholders. Thus, this section discusses techniques which are useful in identifying requirement attributes as well as methods which help in prioritizing requirements.

4.1.4.1 Interview / Guided Discussion

Interviews and guided discussions are effective in determining the value of the requirements attributes. Guided discussion or task oriented discussion is better suited if the stakeholders are participative and interactive. On the other hand, interviews appeal to people, who are comfortable when spoken to on an individual basis. Interviews are cost effective compared to discussions since there is no overhead cost involved in hiring an external moderator. However, interviews take a longer time to elicit information than guided discussions. The pros and cons of both the techniques should be taken into consideration while selecting a method for the prioritization activity.

A detailed description of the interview technique is provided in Section 4.1.2.1. Guided / task oriented discussion is explained in Section 4.1.3.3.

4.1.4.2 Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process can be used in prioritizing requirements if the complete set of requirements is obtained in one execution of the elicitation activity. It involves comparing all unique pairs of requirements to determine which of the two is of higher priority. Thus, if a software project consists of n requirements, the requirements engineer must make n(n-1)/2 pair wise comparisons to rank the requirements. This is feasible for a small project, but as n becomes large, the effort required dramatically increases. However, the resultant ranking is trustworthy and can be helpful to the management in deciding which features to implement first.

This technique consists of three major steps [Saaty 80]:

- Outline all unique pairs of requirements
- Compare the pairs using the scale in Table 4.1. The comparison results in a hierarchy structure.
- Estimate the relative priority of each requirement on the basis of the hierarchy.

Intensity of importance	Description
1	Of equal importance
3	Moderate difference in importance
5	Essential difference in importance
7	Major difference in importance
9	Extreme difference in importance
Reciprocals	If requirement ‘a’ has one of the above numbers assigned to it when compared with another requirement ‘b’, then ‘a’ has the reciprocal value of that of ‘b’.

Table 4.1 Scale for pair-wise comparison

The only advantage of this technique is that it provides the priorities of each requirement relative to every other requirement. The disadvantage is that it is time consuming and cost intensive. In addition, it is not applicable to project which elicit requirements in iterations.

4.1.4.3 Binary Search Tree

Like the AHP, the binary search tree is a ranking technique applicable to projects, whose requirements are not obtained in increments. Prioritizing n requirements using this technique involves the construction of a binary search tree consisting of n nodes. Initially, the tree is composed of one node representing the first requirement. The next requirement is then compared to the top node in the tree. If the requirement is of lower priority than the node, it is compared to the node's left child, and so forth. If the requirement is of higher priority than the node, it is compared to the node's right child, and so forth. The comparison continues until a position is reached where the requirement can be inserted into the tree.

This method uses three steps in determining the priorities of the requirements [Wohlin 97]:

- Outline the candidate requirements
- Create the binary search tree from the requirements
- Traverse the list inorder[13] and add it to a list. The requirements in the list are then given a priority value

The number of comparisons required by this technique to create the tree structure for n requirements is approximately (N log N), which is an improvement over the analytic hierarchy process method. Another advantage is that the requirements are ranked relative to one another. However, the relative ranking of requirements makes this technique unsuitable for projects whose requirements are obtained through several iterations of the elicitation activity. Furthermore, this method is still cost and time intensive even though the number of comparisons required is less than that of AHP.

4.1.4.4 Priority Groups

The drawback of AHP and binary search tree technique is overcome through the use of priority groups, where the requirements are categorized into different priority groups. Thus, there is no need to compare the requirements with each other and as a consequence

[13] Inorder refers to when the root is processed *in* between its two subtrees

this method is applicable to incrementally elicited requirements. The number of priority groups chosen depends on the situation and the knowledge of the stakeholders, who determine the priority of the requirements [Karlsson 96]. A simple strategy is to classify the requirements into three distinct priority groups: low, medium and high. Such a scale for the requirements illustrates the features which are critical for the success of the project.

Thus the prioritization of requirements using this technique is accomplished in three steps:

- Outline the candidate requirements
- Put each requirement into one of the priority groups.
- All the requirements in a particular group are assigned the same priority.

If there are a large number of requirements in a particular group, the requirements engineer can create a few more subgroups and allocate the requirements to each of these sub groups. To ensure that the stakeholders do not assign high priority to all the requirements, it is necessary to provide a sample requirement for each priority group. The stakeholders can then assign the priorities relative to the sample requirements provided by the requirements engineer.

The main advantage of this method is its applicability to projects which are developed incrementally. In addition, the priority groups technique requires very little effort and time to prioritize the requirements. As a result, the cost of this technique is the least among the methods for requirements prioritization. The disadvantage of this method is that the requirements within a particular priority group are unranked, which can lead to a lower priority requirement being implemented ahead of a higher priority requirement.

4.1.5 Verifying Quality Attributes

This objective of this activity is to ensure that the requirements adhere to the quality characteristics such as ambiguity, correctness, understandability, preciseness, and so forth. The subsequent sections elaborate on the techniques that are commonly used for the verification activity.

4.1.5.1 Round-Robin Review

This technique does not involve group discussions like the other verification techniques and it gives each reviewer an equal opportunity to study and present the evaluation of the product. It involves circulating the work product in round robin fashion among the reviewers for their comments [Hart 82]. Over the years, the round-robin review technique has undergone several changes spawning new review methods, most of which emphasize the importance of interaction during the meetings.

The usual number of personnel involved in this type of peer review is four to six. Each reviewer is given the work product two to three days prior to the meeting. Reviewers should make notes of any errors or inconsistencies, from the most minor details all the way up to major conceptual problems. In the requirements phase, the main focus of the reviewers is to identify requirements which do not satisfy the quality attributes. During the review meeting, each reviewer gets to present their comments on the product in a sequential order. On getting their turn, the reviewer should not mention issues that have already been raised. However, they are allowed to present related issues, or raise a different view of the same defect as an issue. If a reviewer has no additional issue, then s/he may pass when their turn comes around. At the end of the review, all the major comments are summarized and the group decides on one of the following recommendations [Leif 95]:

- **Accept**: to accept the product / requirements as is with no changes
- **Re-Review**: to reject the product and require another review before acceptance
- **Simple Check**: to reject the product and require a simple conformance check against any identified issues before acceptance

Round-robin reviews take less time to perform the quality check on the requirements because the method involves minimal discussions during the meeting. In addition, this technique is cost effective because it is conducted by peers, and as a result, no cost is incurred in arranging for the reviewers. The drawback of this method is that it does not provide any checklists to support the task of verification. As a consequence, the result of this technique solely depends on the expertise of the reviewers. Due to these disadvantages, this method is unsuitable for large or critical projects.

4.1.5.2 Inspections

Inspection is a formal technique, which was first performed by Fagan at IBM [Fagan 76]. This method is the most commonly used technique for the verification of requirements because it ensures the detection of a high percentage of errors. There are several variations of the inspection technique such as phased inspection, N-fold inspection, Gilb inspection, FTarm, etc, but they all retain the essence of the classical inspection technique, which is described here.

Inspections are conducted by a team of four to six members for any software development work product such as requirements specification, design specification, or code. The inspection process typically goes through the following phases:

1. **Overview:** In phase I, the members of the inspection team are given an overview of the work product / module to be inspected. The module characteristics such as purpose, logic and related documentation are distributed to all participants for study purposes.
2. **Preparation:** In phase II, the team members prepare individually for the inspection by examining the work product in detail. The moderator arranges the inspection meeting with an established agenda and chairs it in phase III.
3. **Inspection:** In phase III, one of the team members, referred to as the reader, summarizes the purpose of the meeting and briefly introduces the work product. The inspection team is aided by a checklist of queries during the fault finding process. Each of the faults that are identified is recorded in a report immediately after the meeting.

During the meeting, the team discusses the problems identified and attempts to determine the remedies. If there is an impasse, then it is the responsibility of the moderator to come up with a possible solution to the problem [Wixon 94]. Furthermore, as in the previous technique, the team also decides on one of the following recommendations: Accept, re-review and simple check.

Inspection is the most effective technique for identifying the faults in the requirements. In addition, it uses elaborate checklists which help in the preparation of the reviewers for the

meeting [Susan 94]. The main drawback of this technique is that it is cost and time intensive because it involves the rigorous analysis of the work product.

4.1.5.3 Audits

An audit is a technique through which the work product / system is checked for conformance to documented quality characteristics and standards. Unlike inspections, audits are performed by a single person, who is independent of the work product, process, or function being reviewed.

There are three different types of audits [NCCL 96]:

- **First party audits**: These are conducted by the company itself and the auditor is an employee of the company. The results of such audits are generally not trusted by the customer.
- **Second party audits**: These are performed by the customer or a representative of the customer. However, the developers tend to lack confidence in the results as the auditors could be biased in their review.
- **Third party audits**: These are performed by agencies, which are independent of the customer and the developer. Since these agencies have no stake in the project, the results are valued by both customer and developer.

Audits are usually performed by third party auditors, who use detailed checklist to identify the faults in the work products. The auditor also suggests possible fixes for the faults in his/her final report on the work product. In addition, s/he also recommends whether to accept or re-audit the product based on the number of faults detected and their seriousness.

This technique (third party audits) is advantageous because it gives a non-biased opinion which is unaffected by organizational politics. Moreover, customers tend to have more confidence in the results generated by third party audits. Furthermore, this method requires lesser time and cost to perform than the inspection method, yet these values (cost and time) are much higher than those of round-robin reviews.

4.1.6 Stakeholder Validation

The stakeholder validation activity attempts to uncover disagreements between what the stakeholder desires and what the requirements state. This objective can be achieved through several techniques, which we describe in the sections that follow.

4.1.6.1 Walkthroughs

Walkthroughs can be viewed as *presentation reviews* in which a review participant, usually the requirements engineer / developer, provides a narrative description of the software / work product and the rest of the group provides their feedback throughout the presentation. This technique is called a presentation review because feedback is obtained only for the material that is presented [Yourdon 78].

A walkthrough team consists of a moderator and four to eight other members. The roles of the different members are listed below:

- **Presenter**: most often is the software developer / requirements engineer
- **Coordinator**: Organizes, moderates, and follows up the walkthrough activities and is usually from the SQA department or an external expert
- **Scribe**: Documents the proceedings of the meeting
- **Maintenance Oracle**: Considers long-term implications
- **Standards Bearer**: Concerned with adherence to standards
- **User / Customer Representative**: Reflects the needs and concerns of the user and customer
- **Other Reviewers**: (e.g., auditors)

The coordinator contacts participants, prepares and distributes documentation, and selects a schedule for the walkthrough meeting. Participants spend time preparing for the walkthrough by examining the product and related information. Although the meeting is opened by the coordinator, the presenter is responsible for leading the group through the product [Freedman 82]. In the case of requirements walkthrough, the presenter has to present the requirements in such a way that each participant can comment on the product based on his/her areas of specialization. A list of problems is maintained, and at the end

of the meeting the participants sign the list indicating whether the product is accepted as is, accepted with recommended changes, or rejected.

Walkthroughs are effective in obtaining the feedback of all the stakeholders and not just the customer. Also, since all the stakeholders are involved, the participants can learn from each other, resulting in a better understanding of the product [Melo 2001]. The walkthrough meeting is time efficient and can be conducted in a few hours. However, it requires considerable preparation on the part of the participants and, as a result, this method is fairly expensive. Another drawback is that feedback is elicited for only the material that is presented, and hence, the advance preparation of the participants is often not detectable. In addition, this technique can be stressful to the presenter as s/he is the producer of the product.

4.1.6.2 Scenarios

Scenarios are descriptions of how the users can interact with the system in different situations. This method makes it easier for a user to visualize system interactions and provide feedback about them. When used for the validation of requirements, the analyst needs to create scenarios for the requirements which are often complex and difficult to understand by the user / customer.

A scenario provides the sequence of steps in the interaction between the system and the end user. Scenarios can be generated in different formats, but they should at least have the following information:

- A description of the state of the system before entering the scenario.
- The normal flow of events in the scenario.
- Exceptions to the normal flow of events.
- Information about other activities which might be going on at the same time.
- A description of the state of the system after completion of the scenario.

The cost of using scenarios include the cost of training the staff in writing scenarios and the cost of actually using scenarios. For large projects, the number of scenarios is

considerably large and it may take several months of work [Sawyer 97]. Hence, this technique is more suitable for smaller size projects.

The main advantage of scenarios is that it enables the users to understand the work product (system / requirements) better. As a consequence, the users provide better feedback about the work product and this reduces the occurrence of change requests in future. Furthermore, scenarios help the user to identify any features that have been overlooked by the requirements engineer. The drawback of scenarios is that it is time consuming and cost intensive because of the large amount of effort involved in creating the scenarios.

4.1.6.3 Storyboarding

Storyboarding involves creating drawings depicting a set of user activities that occurs in a particular system. In simpler words, a storyboard is a visual representation of a scenario. When employed in the stakeholder validation activity, the storyboarding technique involves representing the complex requirements through dialogs, toolbars, pictures, etc., for better user comprehension and feedback.

Storyboards are grouped into three types based on the mode of interaction with the user [Leffingwell 2000]:

- **Passive storyboard**: In this kind of storyboard, the requirements engineer simply walks the user through the interactions, with a "when you do this, this happens" explanation.
- **Active storyboard**: These provide an automated description of the way the system interacts in a typical usage scenario.
- **Interactive storyboard**: It allows the user to experience the system interactions and comes close to being a throwaway prototype.

While creating the storyboards, the requirements engineer should follow the guidelines listed below:

- Do not invest too much in a storyboard.
- Make the storyboards easy to modify to incorporate user feedback

- Whenever possible, make the storyboard interactive

Storyboarding is a simple and effective validation technique, which enhances the user comprehension of the requirements. Like scenarios, storyboarding also helps to identify features that have been missed by the requirements engineer through "Yes, But" responses. Furthermore, the time and cost involved in this method is comparable to that of the scenario technique.

4.1.6.4 Interview, Prototyping and Guided Discussion

Interviews, prototyping and guided discussions are other methods that can be employed for the stakeholder validation activity. We have grouped them together as these methods have been described in the previous sections (4.1.2.1, 4.1.2.9, 4.1.3.3).

Interviews are occasionally used for the validation of requirements. During the interview process, the requirements engineer asks the user whether the product requirements meet their needs. The framing of the questions, both open-ended as well as closed, is critical to the success of this technique.

Prototyping is the most effective validation technique and it allows the user to 'play' with a partial implementation of the system. At this stage in the requirements phase (stakeholder validation activity), it is beneficial to build a low fidelity prototype such as a paper prototype, rather than a high fidelity one.

Guided discussion involves all the stakeholders in the validation of the requirements. This technique results in obtaining a better feedback than interviews, because a group effort produces better results than an individual effort. However, guided discussions are more expensive than interviews because more work is involved in conducting this technique and also additional cost is incurred in payment to the moderator.

4.2 Methods for Global Analysis Phase

The global analysis phase, which comes after the requirements capturing phase, consists of activities that examine the requirements from the development, market, sales and management perspectives, as seen in Figure 4.2. During this phase, inconsistencies

among the requirements are identified and are resolved through the negotiation activity. Thus, the objective of the global analysis phase is to analyze factors that globally affect the system under development [Nord 2003].

In the sections that follow, we describe the methods for the different activities in the global analysis phase.

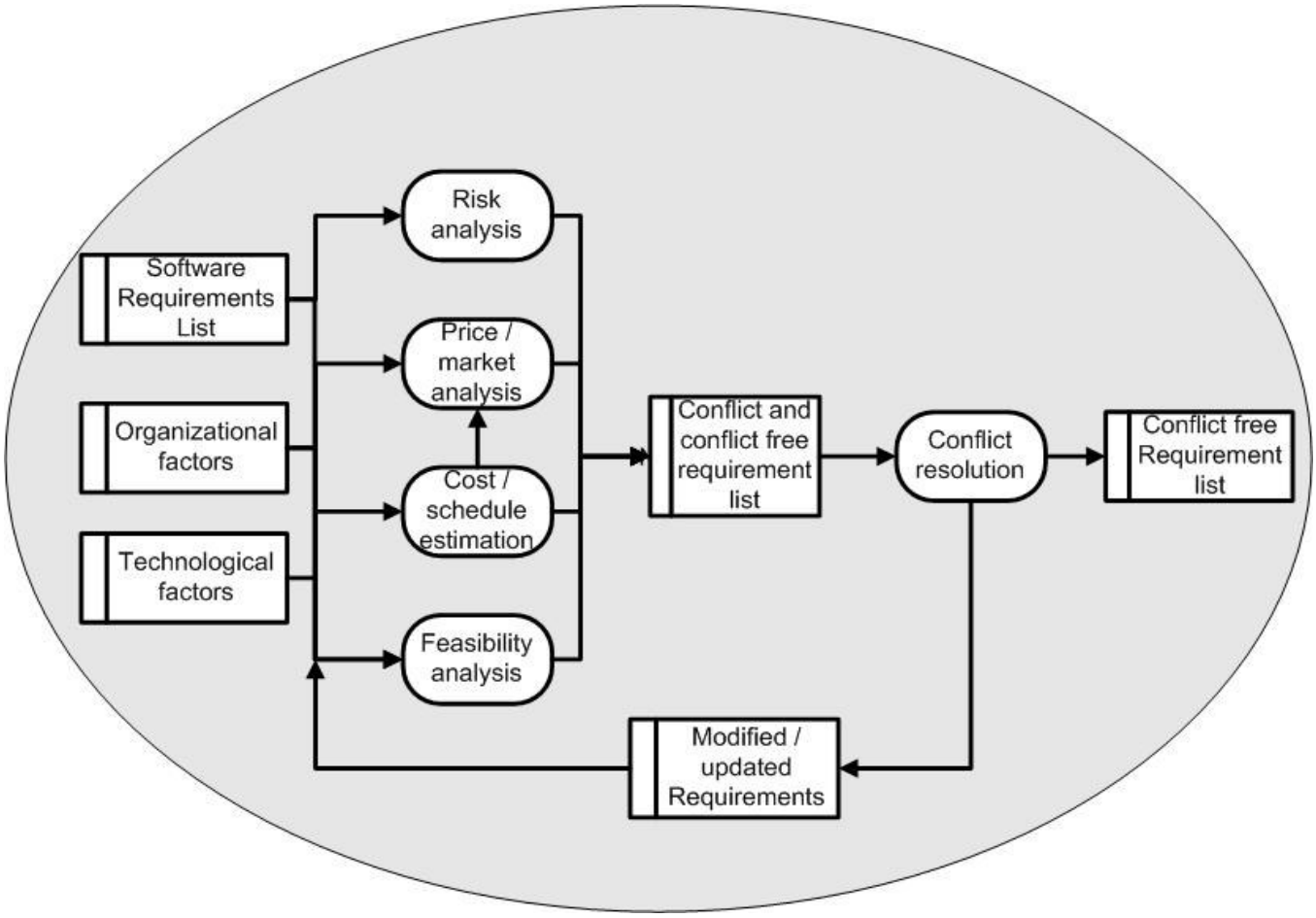


Figure 4.2 Global analysis phase

4.2.1 Risk Analysis

Risk analysis involves evaluating the complete set of requirements for risk factors identified during the prioritization activity of the previous phase. The risk factors are generally concerned with product engineering, development environment and program constraints [14][SEI 96]. The software engineering literature includes several techniques for performing the risk analysis activity. Each of these methods is explained in this section.

[14] Explanation of the different categories of risk factors is provided in Section 3.2.1

One or more of these methods can be utilized by the risk analyst to effectively achieve the objectives of this activity.

4.2.1.1 Criticality Analysis

Criticality analysis is a technique which ranks the item under consideration (requirements) according to the combined influence of the severity and probability of occurrence of the risk factors [MIL 77].

The MIL-STD-1629A document describes two types of criticality analysis: quantitative and qualitative. The steps involved in using the quantitative criticality analysis technique are as follows [Weibull 92]:

- Define the reliability/unreliability for each item
- Determine the portion of the item's unreliability that can be attributed to each risk factor.
- Rate the probability of loss that will result from each risk factor occurring.
- Calculate the criticality for each risk factor by:

  Risk factor criticality = Item unreliability x Ratio of unreliability associated with the risk factor x Probability of loss
- Calculate the criticality of each item by obtaining the sum of criticalities for each risk factor that has been identified for the item:

  Item Criticality = SUM of risk factor criticalities

The steps involved for the qualitative criticality analysis are:

- Rate the severity of the potential risk factors
- Rate the likelihood of occurrence of each risk factor.
- Compare the risk factors via a Criticality Matrix, which identifies severity on the horizontal axis and occurrence on the vertical axis.

Upon completion of this technique, the risk involved in the development of the requirements elicited is determined and the high risk requirements are identified.

The advantage of this technique is that it is easy to perform and time efficient. This method provides a good estimate of the risk, provided all the important risk factors are

identified and their values accurately estimated. Since it is difficult to obtain an exact estimate of the risk factors, a value close to the correct estimate is acceptable during risk analysis. A drawback of criticality analysis is that it relies heavily on the expertise of the risk analyst to provide suitable values for the risk factors. Furthermore, since each risk factor has a single estimate rather than a range of values, this technique is not considered as a rigorous risk analysis method. Another disadvantage of this method is that it assumes that all the risk sources / factors have been identified - this can reduce the effectiveness of the risk estimate if certain risk factors have been overlooked.

4.2.1.2 Failure Modes, Effects and Criticality Analysis (FMECA)

FMECA identifies all the sources of risk before attempting to determine the risk estimate. This overcomes one of the drawbacks of criticality analysis. The basic steps involves in FMECA are:

- Assemble the team of risk analysts
- Identify items (requirements) to be analyzed
- Identify failure (s), effect(s) of failure, cause(s) of failure for each item to be analyzed through discussions among the risk analysts and requirement engineers.
- Evaluate the risk associated with the items under analysis
- Prioritize and assign corrective actions

The standard MIL-STD-1629A provides the detailed guidelines for performing this technique [MIL 77]. In addition to calculating the risk through criticality analysis, FMECA proposes the use of risk priority numbers (RPN) to calculate risk, as an alternative to criticality analysis. The risk estimate for the requirements using RPNs is determined through the following steps:

- Rate the **severity** of each risk factor
- Rate the likelihood of **occurrence** of each risk factor
- Rate the likelihood of **detecting** the problem before it reaches the end user or customer
- Calculate the RPN using the formula:

  RPN = Severity x Occurrence x Detection

The risk estimate is obtained by the summation of the RPNs of all risk factors.

FMECA has the same drawbacks as criticality analysis except that the risk factors identified are more comprehensive. In addition, FMECA is costlier than criticality analysis because of the added effort in identifying the risk factors. This method is easy to perform and time efficient, although it takes longer to perform than criticality analysis.

4.2.1.3 Risk Reduction Leverage (RRL)

RRL is a technique which not only determines the risk of the items under consideration but also determines the risk of the various alternatives when the risk estimate is high. This technique involves the calculation of two values:

Risk Exposure (RE) = Probability (UO) x Loss (UO)
Risk Reduction Leverage (RRL) = ($RE_{Before} - RE_{After}$) / Risk Reduction Cost

Risk Exposure is the product of the probability of an unsatisfactory outcome (risk factor) occurring and the loss incurred due to the occurrence of the outcome. The requirements engineer has to calculate the Risk Exposure for each risk factor and determine an acceptable threshold. If the estimate crosses this ceiling, the requirements engineer has to reduce the probability of the risk factor occurring or / and the loss associated with the risk factor as shown in Figure 4.3 [Moores 96]. For each alternative, which reduces the risk, the Risk Reduction Leverage is calculated, which takes into account the Risk Exposure before and after risk resolution, and the cost incurred in the attempt to mitigate the risk. Thus, the overall risk estimate for an item is obtained by summing up the Risk Exposure values associated with all the risk factors. The Risk Reduction Leverage (RRL) illustrates how a large estimate coupled to a risk factor can be reduced. All the estimates calculated are documented for consideration by the management and the customer.

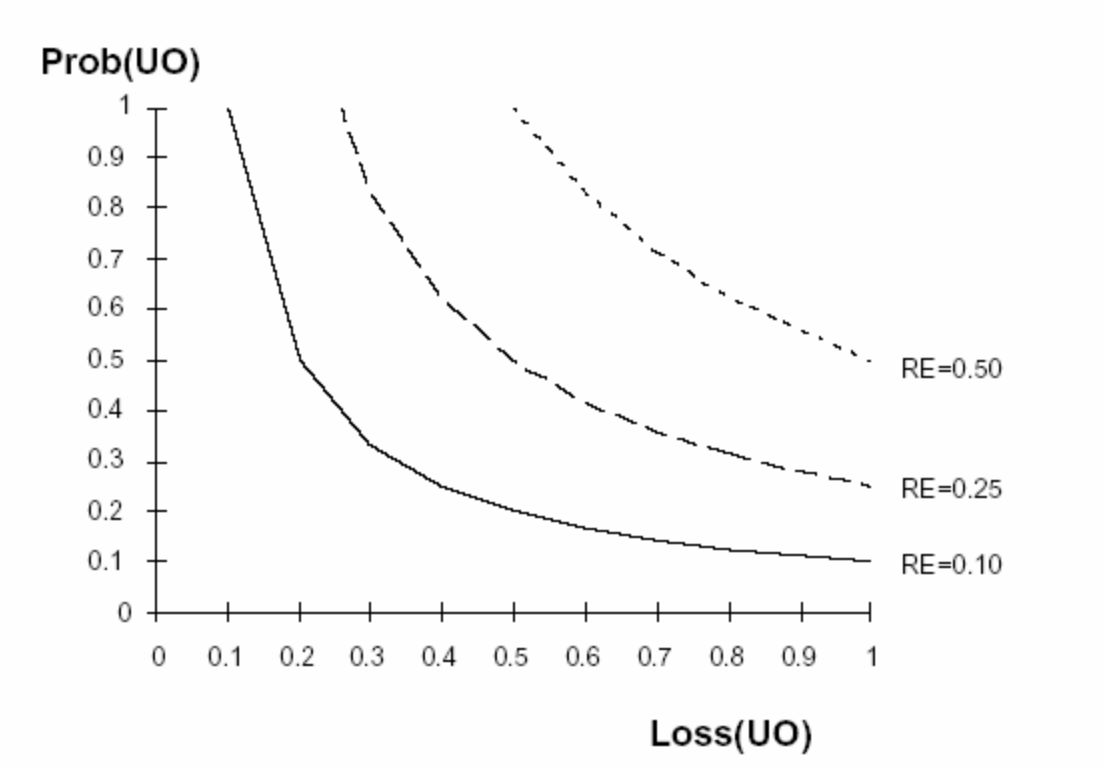


Figure 4.3 Risk exposure contours

An example of the usage Risk Reduction Leverage method is shown below [Boehm 89].

If the loss associated with having a particular type of interface error is estimated at US$1 million and from experience it is estimated that the probability of such a fault is 0.30, then the risk exposure is given as:

RE = 0.30 * 1000K = US$300K

Buying a requirements and design interface checker for US$20K would reduce the probability of this risk occurring to 0.1. Carrying out a detailed interface test for US$150K of manpower would reduce the same probability to 0.05. The RRL for these two approaches can be calculated as follows:

RRL1 = ([0.30] * 1000K - [0.10] * 1000K) / 20K = 10

RRL2 = ([0.30] * 1000K - [0.05] * 1000K) / 150K = 1.67

The RRL technique is useful in evaluating different ways of reducing the risk comparing the Reduction Leverage values with each other. This method is more time consuming than the previous techniques because in addition to determining the risk, it also evaluates

the alternatives for reducing the risk estimate. Similar to the other techniques, this method depends solely on the expertise of the analyst to obtain a good risk estimate and considers a single value for the probability of occurrence of each risk factor. Compared to FMECA and criticality analysis, this technique produces a weaker risk estimate since only two variables (probability of occurrence and loss) are considered in the risk estimation formula.

4.2.1.4 Fault Tree Analysis

Fault tree analysis was developed in 1962 at Bell Telephone Laboratories. A fault tree is a graphical representation of certain relations which traces an undesirable outcome (risk factor) backwards to search for all its possible causes. Such an outcome is named as the top event of the fault tree. Traditionally, quantitative analysis evaluates the probability of the occurrence of the top event in which case the probability of each basic event is already known or guesstimated. Thus, during the risk analysis of the requirements, a fault tree is created for each risk factor and the probability of the risk factor occurring is determined from the causes for this risk factor [Cheng 2000].

Fault tree analysis consists of the following steps [TWCC 2002]:

- Define the top event / risk factor
- Understand the system and its environment
- Construct the fault tree (Construction guidelines provided in [Zio 2002].
- Validate the tree for completeness and accuracy.
- Perform quantitative analysis (i.e. determine the probability).

The calculation of the probability for the top event in a simple fault tree (see Figure 4.4) is given below:

Top Event $T = X_1 \cup A_1 \cup A_2$ (Union of inputs due to the OR gate)

Where $A1 = X_2 \cap X_3$ (Intersection of inputs due to the AND gate)

$A2 = X_4 \cup X_5$ (Union of inputs due to the OR gate)

If P_{xi} denotes the probability of the occurrence of the cause x_i, then probability of the top event would be

$P_t = 1 - \{ (1 - P_{X1}) (1 - P_{A1}) (1 - P_{A2}) \}$ where

$P_{A1} = P_{X2}P_{X3}$

$P_{A2} = 1 - \{ (1 - P_{X4}) \ (1 - P_{X5}) \}$

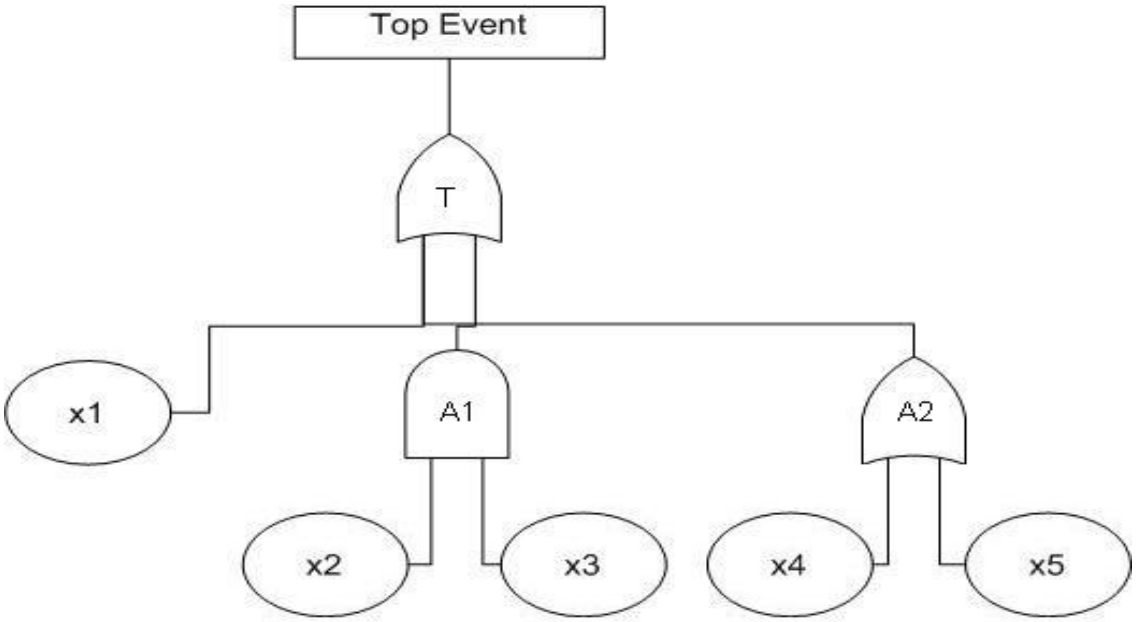


Figure 4.4 Simple fault tree

Fault tree analysis provides a better estimate of the risk compared to the previous techniques discussed because it considers several probability estimates in the risk calculation procedure. This technique is rigorous and involves construction of fault trees for each risk factor, which are assumed to be complete. Hence, fault tree analysis is more time consuming and costlier than the other techniques. The analyst is crucial in this method as s/he has to foresee all the causes for the undesirable events and also determine the probability estimates of these causes.

4.2.1.5 Event Tree Analysis

Event tree analysis is complementary to the fault tree analysis technique [Zio 2002a]. This technique provides an overview of the possible risk factors which affect the system under analysis. Thus, this method is useful in the scenario where the risk factors for the requirements are incomplete. Event tree analysis is based on binary logic, in which an event either has or has not happened or a component has or has not failed. It is valuable in analyzing the consequences arising from a failure or undesired event [Raafat 89].

An event tree is constructed by first identifying an initiating event or an undesirable outcome. This event is either absorbed (success state) or aggravated (failure state) by the system. The branches in the event tree represent the consequences as a result of the initiating event. Each of the failure states correspond to the risk factors, which are evaluated using fault trees[15] as shown in Figure 4.5.

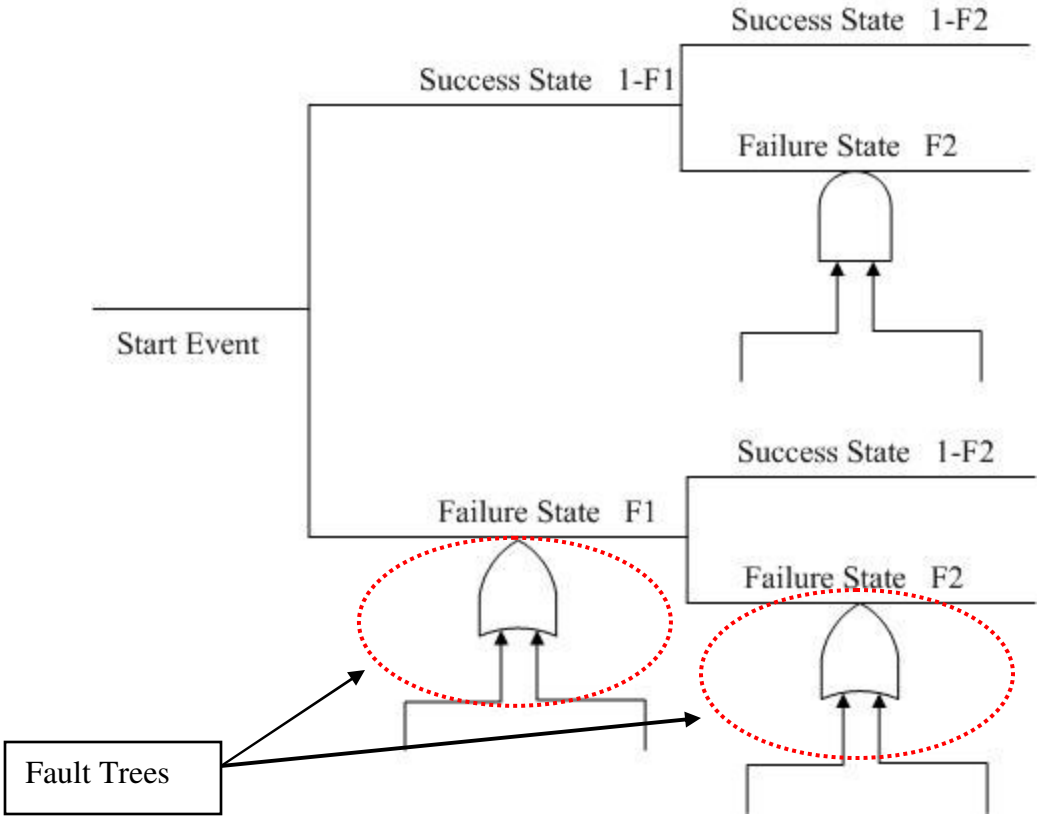


Figure 4.5 Event tree shown with fault trees used to evaluate probabilities of different risk factors

The advantage of this technique is that it gives on overview of all the risk factors affecting the system. Furthermore, since this method is easy to perform, a single risk analyst having knowledge about the system is sufficient for conducting this technique. By itself, this method fails to provide a good risk estimate and hence, this method is used along with the fault tree analysis technique. Another drawback of this technique is that the event trees can get very large and complicated to handle.

[15] Fault tree analysis explained in Section 4.2.1.4

4.2.1.6 Monte Carlo Simulation

Simulation is any analytical method meant to imitate a real-life system, especially when other analyses are too mathematically complex or too difficult to reproduce. Monte Carlo simulation is a form of simulation that randomly generates values for uncertain variables (risk factors) over and over to simulate a model [Goldman 2000].

For each risk factor, Monte Carlo simulation allows the requirements engineer to define a range of possible values with a probability distribution. A distribution is an equation that describes shape and range that represent the natural uncertainty around the input value. The type of distribution can be one of the following types:

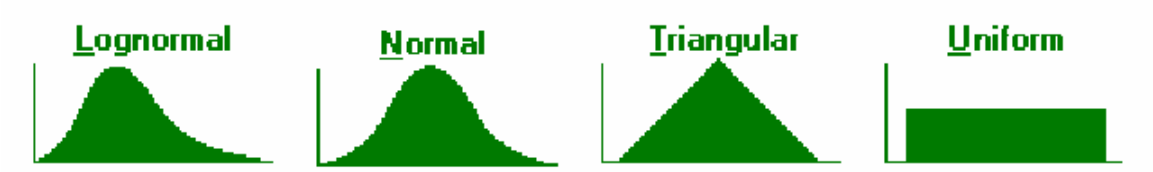


Figure 4.6 Types of probability distributions

During the simulation, the values generated for the different risk factors are evaluated and the overall risk estimate is calculated. This is repeated for several thousands of sample input values and the output is usually graphically displayed for better comprehension and analysis.

Monte Carlo simulation results in a far more rigorous risk analysis compared to other techniques discussed in this section. As the values are represented in ranges, this method is not completely dependent on the expertise of the risk analyst. However, this method needs reasonable range values for the risk factors from the analyst to perform effectively. Furthermore, this method is the fastest of all the risk analysis techniques because it is automated. A disadvantage of this method is its dependency on a large number of samples to provide accurate results. Hence, a wrong choice for the sample size can result in misleading risk estimates. Another drawback is that the effectiveness of the results generated by this method is dependent on the risk analyst's proficiency in analyzing the output. Furthermore, since Monte Carlo simulation is computer based, the initial investment in this technique is much larger than the other risk analysis methods. However, this investment is recovered in the long run and is beneficial to the organization.

4.2.2 Cost Schedule Estimation

Cost estimation is the process of determining the amount of work and effort needed to implement a system. It involves the evaluation of factors such as personnel experience, platform difficulty, etc., that affect the system development to determine whether the total cost estimate satisfies the customers' budget. The objective of the schedule estimation activity is to determine the development time of the components and to identify the critical components of the software system. This section focuses on the techniques which effectively achieve these objectives.

4.2.2.1 Software Life Cycle Management (SLIM)

Software Life Cycle Management (SLIM) is one of the first techniques for estimating the cost associated with the project [Putnam 78]. It is generally known as a macro estimation model and is based on the Norden/Rayleigh function.

SLIM uses the following formula to calculate the effort needed for the development of a system / component:

$$\mathbf{K = (LOC / (C * t^{4/3})) * ^{3}}$$

K → Total effort in terms of years

C → Technology constant, which combines the effect of using tools, languages, methodology, quality assurance procedures, standards etc. It is determined on the basis of historical data (past projects).

t → Development time in years

LOC → Size estimate in terms of lines of code

The value of the technology constant depends on the readiness of the project relative to existing technology and is assigned according to the scale:
C= 2000 -- poor, C = 8000 -- good, C = 11000 – excellent
Thus, for an assignment, which is easy or similar to a successfully completed project in the past, the value of C is high and is around 11000. Once the effort is calculated, the cost estimate is obtained by multiplying the effort with the cost per working year.

The SLIM technique is easy to perform as it involves few parameters in the calculation of the effort. In addition, this method consumes very little time and is suitable for large projects. On the downside, the SLIM technique produces a cost estimate which is extremely sensitive to the technology factor; this uncertainty in the cost makes it unsuitable for small projects.

4.2.2.2 Constructive Cost Model (COCOMO)

COCOMO is one of the most widely used techniques for cost and effort estimation [Boehm 81]. This method is also referred to as COCOMO ’81 and consists of three different variants: basic, intermediate and advanced.

- The **basic** COCOMO'81 computes software development effort (and cost) as a function of program size expressed in estimated thousand delivered source instructions (KDSI).
- The **intermediate** COCOMO'81 computes software development effort as a function of program size and a set of fifteen "cost drivers" that include subjective assessments of product, hardware, personnel, and project attributes.
- The **advanced** COCOMO'81 incorporates all characteristics of the intermediate version with an assessment of the cost driver’s impact on each step (analysis, design, etc.) of the software engineering process.

COCOMO depends on two main equations:

Development effort: MM = a * KDSI b

MM - man-month / person month / staff-month is one month of effort by one person. In COCOMO, there are 152 hours per Person month and this value may change by 10% to 20% depending on the organization

Effort and development time (TDEV): TDEV = 2.5 * MM c

The coefficients a, b and c depend one of the three modes of the development as shown in the Table 4.2. Once the development mode is identified, the values of a. b and c are

determined from the Table 4.3. The cost estimate is obtained by multiplying the effort estimate in terms of person months with the cost incurred for each person month.

Development Mode	**Project Characteristics**			
	Size	Innovation	Deadline / Constraints	Dev. Environment
Organic	Small	Little	Not tight	Stable
Semi-detached	Medium	Medium	Medium	Medium
Embedded	Large	Greater	Tight	Complex hardware / customer interfaces

Table 4.2 Modes of development

Basic COCOMO	**a**	**b**	**c**
Organic	2.4	1.05	0.38
Semi-detached	3.0	1.12	0.35
Embedded	3.6	1.2	0.32

Table 4.3 Values of a, b and c for the Basic COCOMO.

In the intermediate COCOMO, the same basic equation is used, but **fifteen** cost drivers are rated on a scale of 'very low' to 'very high' to calculate the total EAF (Effort Adjustment Factor). The adjustment factor is 1 for a cost driver that's judged as normal. Thus, for the intermediate COCOMO, we use the following formula:

MM = EAF * a * KDSI b

The Advanced COCOMO model computes the EAF by having the cost drivers weighted according to each phase of the software lifecycle.

The advantage of COCOMO is that it is simple, easy and time efficient. The cost drivers in the intermediate and advanced COCOMO identify factors affecting the project costs and help in obtaining a better cost estimate. The drawback of the COCOMO technique is

that it is hard to accurately estimate KDSI early on in the project. Also, the COCOMO defines KDSI as a length measure rather than a size measure. Furthermore, this technique is extremely vulnerable to misclassification of the development mode, resulting in misleading cost estimates.

4.2.2.3 COCOMO II

The COCOMO II method is the enhanced version of COCOMO '81 and it produces a better cost estimate. It defines the size of the project in terms of source lines of code (SLOC) such that:

- Only Source lines that are DELIVERED as part of the product are included -- test drivers and other support software is excluded
- SOURCE lines are created by the project staff -- code created by applications generators is excluded
- One SLOC is one logical line of code
- Declarations are counted as SLOC
- Comments are not counted as SLOC

The effort estimate is calculated using the formula:

Effort = 2.94 * EAF * (SLOC)^{E}

Where

EAF Is the Effort Adjustment Factor derived from the Cost Drivers

E Is an exponent derived from the five Scale Drivers

SLOC Is the source lines of code

COCOMO II replaces the development modes in COCOMO '81 with scale drivers, which are used in determining the exponent E. In addition, COCOMO II provides a set of 17 cost drivers[16], which help in calculating the EAF.

As an example [Softstar 2003], a project with all Nominal Cost Drivers and Scale Drivers would have an EAF of 1.00 and exponent, E, of 1.0997. Assuming that the project is

[16] See http://ksi.cpsc.ucalgary.ca/courses/451-96/mildred/451/CostEffort.html

projected to consist of 8,000 source lines of code, COCOMO II estimates that 28.9 Person-Months of effort is required to complete it:

$$\text{Effort} = 2.94 * (1.0) * (8)^{1.0997} = 28.9 \text{ Person-Months}$$

COCOMO II also calculates the duration of the project using the equation:

Duration = 3.67 * (Effort)^{SE}

Where

Effort	Is the effort from the COCOMO II effort equation
SE	Is the schedule exponent derived from the five Scale Drivers

Continuing with the example, and substituting the exponent of 0.3179 that is calculated from the scale drivers, we have an estimate of just below a year, and an average staffing of between 2 to 3 people:

$$\text{Duration} = 3.67 * (28.7)^{0.3179} = 10.66 \text{ months}$$

Average staffing = (28.7 Person-Months) / (10.6 Months) = 2.6 people

COCOMO II has the same advantages as COCOMO ’81 though it takes more time to perform the estimation than the latter. It also overcomes the drawbacks of COCOMO ’81 by including scale drivers and SLOC instead of development modes and KDSI. It provides a good cost estimate and a reasonable time estimate. A drawback is that the calculations can get very complicated because of the number of factors to be considered to obtain the estimate. Also, it has been shown that the duration estimate is unreasonable for small projects [Merlo 2002].

4.2.2.4 Functions Points

Allan Albrecht, in collaboration with John Gaffney, Jr., designed Function Points as a direct measure of functionality [Albrecht 83]. Function Points are used in two ways:

- As a measure of the "size", calculated from a functional, or user, point of view.
- As metrics used in conjunction with estimation variables to develop cost and effort projections.

In order to obtain the function points, the systems functionality is broken down into five basic categories [Heller 2002]. Two of these address the data requirements of an end user

and are referred to as Data Functions. The remaining three focus on the user's need to access data and are referred to as Transactional Functions.

Data Functions

- Internal Logical Files – Functions handling files/data invisible outside the system
- External Interface Files – Functions handling files shared with other software systems

Transactional Functions

- External Inputs – Functions allowing read / write capabilities
- External Outputs – Functions displaying reports, messages, etc
- External Inquiries – Functions handling interactive inputs needing a response

The Function point technique counts the functions under each category. These counts are then multiplied by a weighting scale (Table 4.4) based on the complexity of the functions (Table 4.5). On multiplying the counts with the weights, the resultant values are summed up to produce Unadjusted function points (UFP) estimate.

Function Type	Low	Average	High
Internal Logical Files	7	10	15
External Interface Files	5	7	10
External Input	3	4	6
External Input	4	5	7
External Inquiry	3	4	6

Table 4.4 Weighting scale for the function types

	1-5 Data element types	6-19 Data element types	20+ Data element types
0-1 File types referenced	Low	Low	Average
2-3 File types referenced	Low	Average	High
4+ File types referenced	Average	High	High

Table 4.5 Complexity of the function types

To obtain the overall function point estimate, three fundamental equations are used:

FP = UFP x TCF

TCF = 0.65 + 0.01 * DI

DI = Σ Fi

Where

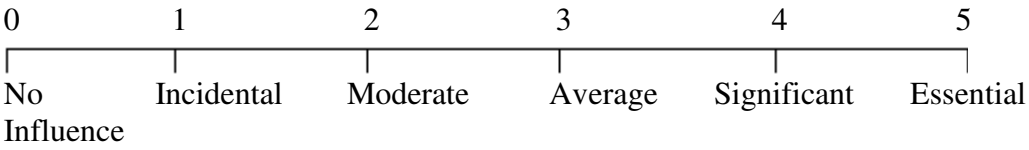
FP is the Function Points estimate

UFP is Unadjusted Function Points estimate

TCF is the Technical Complexity Factor

DI is the Degree of Influence, and Fi are the Factors of influence.

To calculate DI, the factors listed in Table 4.6 are rated on a scale of 0 to 5:



S/N	Question
1	Does the system require reliable backup and recovery?
2	Are data communications required?
3	Are there distributed processing functions?
4	Is performance critical?
5	Will the system run in an existing heavily utilized operational environment?
6	Does the system require online data entry?
7	Does the online data entry require the input transaction to be built over multiple screens or operations?
8	Are the master files updated online?
9	Are the inputs, outputs, files, or inquires complex?
10	Is the internal processing complex?

11	Is the code designed to be reusable?
12	Are conversion and installation included in the design?
13	Is the system designed for multiple installations in different organizations?
14	Is the application designed to facilitate change and ease of use by the user?

Table 4.6 Factors of influence

The function point estimate can be used to calculate the cost estimate in two ways. The first option is to assume a certain cost estimate for each function point. The second option is to convert the function point count into an equivalent number of lines of code and use a macro estimating model like COCOMO [Heller 2002].

The advantage of the function point method is that it is independent of the computer language, code, development methodology, technology or capability of the project team used to develop the application. In addition, it is more accurate than using the LOC estimate for size. The disadvantage is that this method is hard to automate and difficult to compute. Hence, compared to the other techniques discussed, this method is costlier and more time consuming. Furthermore, this technique is subjective in the counting of functions and is oriented more towards traditional data processing applications.

4.2.2.5 Work Breakdown Structure

The work breakdown structure is an expertise based technique which organizes the project elements / components into a hierarchy for budget estimation and control. If cost is associated with each element in the hierarchy, an overall cost estimate for the project development can be determined traversing the tree bottom up [Baird 89]. Expertise comes into play in this method when identifying the components of the hierarchy and determining the estimates of the individual elements.

A work break down structure consists of two hierarchies, one representing the product and the other illustrating the activities needed to develop the product [Boehm 81]. The product hierarchy identifies the components in the software product and describes the

basic structure of the overall system. The activity hierarchy shows the various activities that may be associated with a given software component.

The steps involved in defining the work breakdown structure hierarchy and then using it for estimation purposes are listed below:

1. Understand project related information such as project goals and objectives, the scope, etc.
2. Identify all major activities that will be required to achieve the goals and objectives (Activity hierarchy).
3. Identify all major components of the software product (product hierarchy)
4. Refine and decompose the hierarchies.
5. Continue step 4 until fairly sure that everything has been accounted for
6. Determine the effort required for each of the lowest level tasks / elements in the hierarchy. One practical way to do this is to have the people involved provide the following estimates of time:

   To = an optimistic estimate of how long the task will take

   Tp = a pessimistic estimate of how long the task will take

   Tm = the most probably estimate of how long the task will take

   Then determine the expected time **Te** by using the following formula

   Te = (To + 4 Tm + Tp) / 6
7. Multiply the estimates by either the cost of the actual person responsible or by an average staff cost and combine the estimates for all elements in the hierarchy.
8. Add the costs of equipment or any materials not covered by the tasks. This will provide the cost estimate for the entire project.

The work breakdown structure method provides a good schedule estimate and a reasonable cost estimate. This method is comparable to the COCOMO technique in terms of time efficiency. However, the work breakdown structure needs more effort than the COCOMO method because of the additional task of creating the hierarchies and hence, is costlier than the latter. The drawback of this technique is that it fails to provide factors (e.g. COCOMO II), which guide the analyst in his/her estimations.

4.2.2.6 Gantt Chart

The Gantt chart was developed as a production control technique in 1917 by Henry L. Gantt, an American engineer and social scientist. It provides a graphical illustration of a schedule that helps in the following tasks:

- Planning out the tasks that need to be completed
- Determining the schedule of the different tasks.
- Planning the allocation of resources needed to complete the project

A Gantt chart is a matrix, which lists on the vertical axis all the tasks to be performed as shown in Figure 4.7. The tasks include the activities necessary for the development of the system requirements / components. The horizontal axis is headed by columns indicating estimated duration for the completion of each task. Gantt charts may also include skill level needed to perform the task, as well as the name of the person assigned to the task. Task duration may be expressed in hours, days, weeks, months, and other time units.

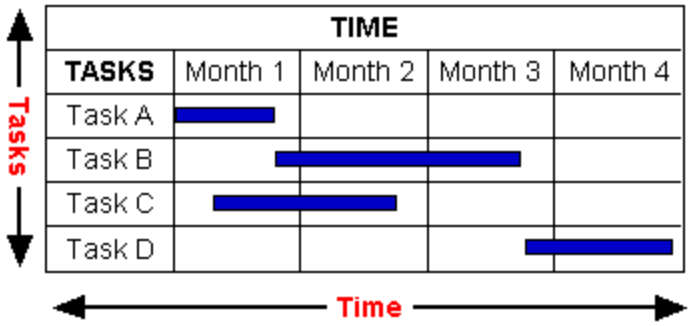


Figure 4.7 Gantt chart

The construction of the Gantt chart and the schedule estimation is accomplished through the following steps:

- List all the tasks of the system and identify whether they need to be developed in sequential order.
- Plot each task on a graph paper, starting on the earliest possible date length of the task bar being the duration of the task. Above the task bars, mark the time taken to complete them. This results in the rough draft of the Gantt chart.

- Schedule the tasks in such a way that sequential activities are carried out in the required sequence. Ensure that dependent activities do not start until the activities they depend on have been completed. In addition, schedule tasks in parallel without interfering with the other activities in the chart. The sum of all the durations along the horizontal axis gives the schedule estimate for the entire project

Gantt chart is a graphical scheduling technique, which is simple to use and understand. Hence, this method is time efficient as well as cost effective. Furthermore, Gantt charts show the sequence in which the tasks are conducted and this can be useful in project tracking. However, this method fails to show the interrelationships among the tasks and the critical path in a chain of activities. Another disadvantage is that the activity times are deterministic, which reduce the level of confidence in the overall schedule estimate, and hence, this technique is not recommended for systems with critical deadlines.

4.2.2.7 Program Evaluation and Review Technique (PERT)

A Program evaluation and review technique (PERT) chart is a project management technique developed by the U.S. Navy in the 1950s to manage the Polaris submarine missile program. PERT charts are used to schedule, organize, and coordinate tasks within a project.

The PERT technique for estimating the schedule consists of the following steps:

- Identify the tasks involved in developing the requirements.
- Determine the proper sequences of activities (sequential / parallel).
- Construct the PERT chart / activity diagram.
- Estimate the time for each activity
- Determine the critical path.

The PERT chart is drawn based on the knowledge of the serial and parallel activities. Each task in the chart is depicted by arrowed lines and milestones are represented by bubbles or circles as illustrated in Figure 4.8. In addition, each arrow (task) in the chart is

identified by a task name and duration. Software applications simplify this task of generating the PERT charts automatically converting the tabular activity information.

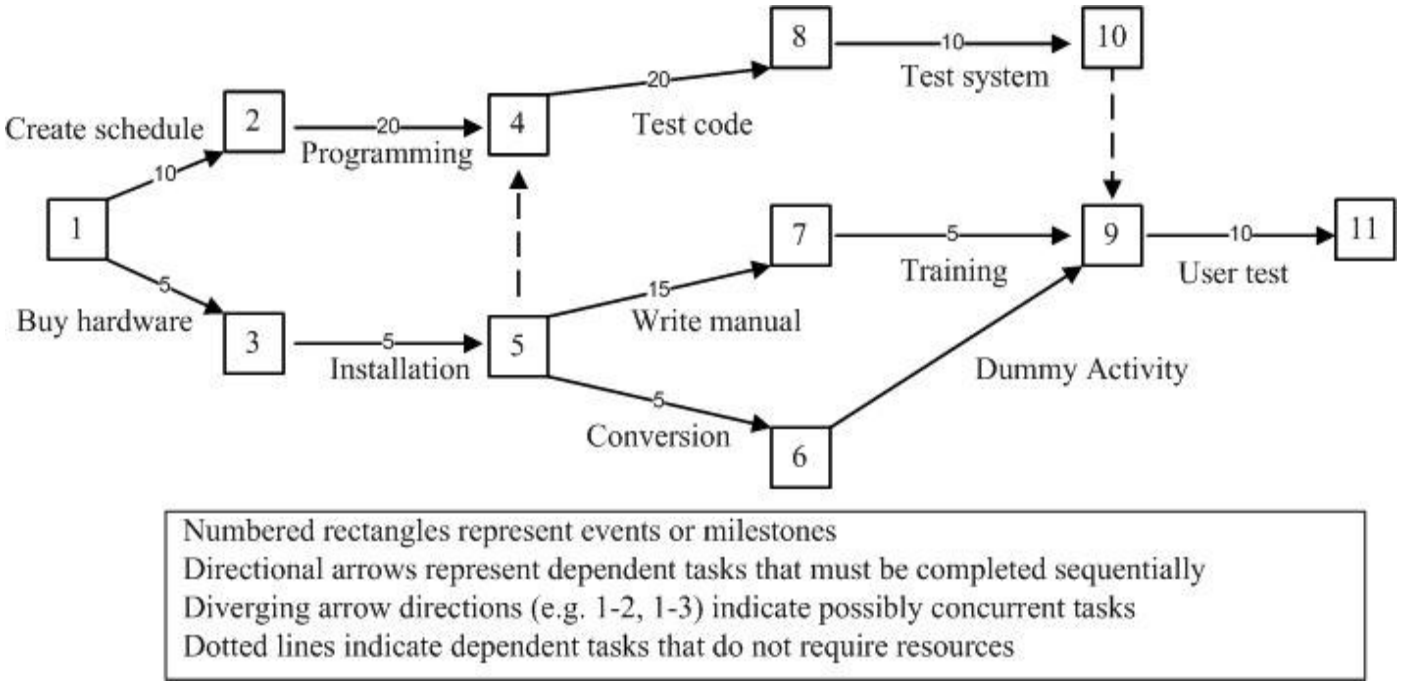


Figure 4.8 PERT chart

The duration of each task is calculated using the formula:

$$\text{Expected time } (t_e) = \frac{\text{Optimistic time} + 4 \times \text{likely time} + \text{longest time}}{6}$$

Optimistic time: Shortest time in which an activity can be completed. It can be obtained under unusual, good luck situations.

Likely time: Normal time that an activity will take, a result which is most likely to happen.

Pessimistic time: Maximum time that an activity will take, a result which can occur, only if unusually bad luck is experienced

The critical path in the PERT chart is obtained by summing up the times for the activities in each sequence and determining the longest path in the project. The duration of the critical path gives the time needed for the completion of the component / project. If any event on the critical path slips beyond its expected date of completion, then the final event can be expected to slip a similar amount. The amount of time that a non-critical path activity can be delayed without delaying the project is referred to as slack time, which is useful in the management of resources allocated to the activities [NetMBA 2002]. Thus, PERT not only estimates the overall schedule but also helps in better management and control of the activities.

PERT charts are advantageous because they show the dependencies of the various tasks and identify the critical activities of the project. This method enables management to use the resources wisely and improves control over complex and large development projects. Furthermore, PERT charts are easy to understand because they provide a visual representation of the tasks [Bedworth 87]. The drawback of this method is that considerable effort is involved in creating the activity diagrams and verifying them for non-existence of cycles (job 'a' is a predecessor for 'b', 'b' is a predecessor for 'c', and 'c' is a predecessor for 'a'). As a result, this technique is time consuming and costly. Another disadvantage is that the activity times are subjectively estimated and even if they are well-estimated, PERT assumes a beta distribution for the time estimates (t_e), but the actual distribution may be different [Stamatis 97]. In addition, this method fails to give attention to the calculation of the cost estimate, and hence is best used in combination with other techniques.

4.2.2.8 Critical Path Method (CPM)

Critical Path Method (CPM) charts are similar to PERT charts and are sometimes known as PERT/CPM. The critical-path method (CPM), developed by Du Pont and Remington Rand, is a powerful, but basically simple technique for analyzing, planning, and scheduling large, complex projects [Wickwire 89]. This method provides a means for determining:

- How long the project will take to complete

- Which jobs or activities are "critical" in their effect on the total project time?

If information about the cost of each activity and how much it costs to speed up each activity is provided, CPM can determine [Baker 2004]:

- Whether it is beneficial to speed up the project, and, if so,
- What is the optimal plan for speeding up the project?

The steps involved in the CPM method are similar to that of PERT and are as follows:

- Identify the tasks involved in developing the requirements.
- Determine the proper sequences of activities (sequential / parallel).
- Construct the network diagram.
- Estimate the completion time for each activity.
- Determine the critical path (longest path in the network).
- Determine how best to schedule all jobs in the project in order to meet a target date at minimum cost

Thus, CPM differs from PERT in two aspects:

- The use of a single time estimate for each activity
- The inclusion of a procedure for time/cost tradeoff to determine the scheduling of activities.

The advantages of the CPM technique are the same as PERT. An added benefit of this method is its ability to schedule the activities based on the costs. A drawback of CPM is that it fails to consider the effects of variability in path completion times, since it uses a single time estimate for the tasks [Hulett 95]. As a result, the schedule estimate of CPM is not as reliable as the one generated by PERT. Another disadvantage of CPM is that it is cost intensive and time consuming [Jaafari 84].

Since the PERT technique has a better schedule estimating process and CPM has a good time/cost tradeoff procedure, an ideal work strategy would be to combine the best features of both these methods to produce optimum project duration and cost.

4.2.3 Price Analysis

Price analysis is the process of determining the product price, which is fair and reasonable to the market as well as the management [FAST 2004]. It also entails determining the features which could be dropped for the current delivery but included in future releases, without affecting the product value. In order to achieve this objective, it is necessary to obtain information about the market needs. Hence, in this section we not only discuss techniques which help in determining the product price, but also examine methods which elicit market information.

4.2.3.1 Comparative Price Analysis

Comparative price analysis involves the comparison of the proposed product price with quotes or prices for the same or similar items. Several factors need to be considered by the analyst during the comparison of prices. Some of the factors are listed below:

- Number of competitors in the market
- Intensity of demand
- Inflation / deflation of the currency
- Market trends, etc.

For the purpose of comparison, this technique considers prices of:

- Older, similar / same functionality products (historical prices).
- Competitor's products
- Products' having a few features in common.

Hence, it is necessary to adjust these prices in order to make a fair direct comparison of prices. This method balances the prices through the use of indices, trends analysis, and product variance.

Price index numbers are ratios, usually expressed as percentages, indicating changes in values, quantities, or prices, with respect to the base year. These indices are useful in manipulating the prices to reflect the inflation / deflation of the currency to facilitate direct comparison. An example of the use of indices to inflate the price of a product for

comparison is shown below [FAST 2004]:

Use of Indices

Product: Computer Monitor
Objective: Adjust 2003 price to the 2004 price level by using ratio analysis

Available data: 2003 price (unadjusted)

$$\frac{\text{2004 price index}}{\text{2003 price index}} = \frac{\text{Adjusted price to 2004}}{\text{2003 price}}$$

$$\frac{110}{105} = \frac{\text{Adjusted price to 2004}}{100}$$

$104.76 = Adjusted price to 2004

Trends analysis is based on the assumption that the trends reported in the past will continue in the future. The analysis of the market can provide insights into the price patterns and this can be used in predicting the price of a product or service.

Product variance analyzes the technical differences among the various products (whose prices are being compared) and based on this evaluation the prices are compared. For example, consider a high resolution and a low resolution monitor. The price of the former will definitely be greater than the latter, and hence it is imperative to analyze the products technical aspects with respect to the costs, before weighing the product prices against each other.

This technique is the most commonly used method in the industry for predicting the prices of products / services. It is a comprehensive method and provides a good price estimate for the product. Furthermore, the comparative price analysis technique determines the prices for various combinations of product features to match different desirability levels of the users / market. The drawback of this technique is that it fails to determine whether a particular feature is desirable or not. In addition, this method can get complicated if several comparison factors and product prices are considered. Moreover, the comparative price analysis technique assumes that the market information already exists, and hence, this method needs to be supported by market analysis techniques. As a consequence, this method is time consuming and expensive.

4.2.3.2 Comparisons to Independent Cost Estimates

Independent cost estimate (ICE) is the assessment of the total cost incurred if the product is developed. The Comparison to independent cost estimates technique ensures that the proposed price is greater than the cost of development and, at the same time, is reasonable to the user. Since, obtaining cost estimates of similar/same products developed by other organizations is difficult, this method uses the cost estimates of products that have already been developed by the current organization. However, it is necessary that the product under analysis is compared with a very similar past product; otherwise the cost estimates of the previous project will not be applicable to the current one.

The Comparison to independent cost estimates technique is useful in situations where the current project is very similar to a previous one. The cost estimate of the previous project is utilized for the current project and the price is then tested for reasonability and fairness. As a consequence, it becomes unnecessary to conduct the cost analysis activity. For example, a company may develop e-commerce websites for its customers. The characteristics of all these websites are more or less the same. Hence, if the cost for the development of one website is done thoroughly, the estimate can then be used for subsequent efforts.

To determine if the basis of the independent cost estimate is reliable and can be used as a standard for comparison, the analyst must examine the following factors [FAST 2004]:

- Is the product comparable?
- What information and techniques were used?
- How reliable were earlier estimates?
- Is the cost estimate based upon the same technical approach as the current product or service?

The cost estimates may have to be adjusted due to the inflation of the currency, and this can be accomplished through the use of value indices explained in the previous section. Once the cost estimate is obtained, the analyst determines the reasonability of the proposed price by comparing it with the cost estimate and also accounting for factors such as the user demand, urgency of the user, and competitors in the market.

This technique can be used effectively for a particular set of situations such as the repetitive development of similar software. It is faster and more cost effective than comparative price analysis because there is no effort involved in comparing prices of several similar / same products. An added advantage is that this method proposes a price which is definitely profitable and reasonable. The drawback of this technique like the previous method is that it fails to determine whether a particular feature is desirable or not. In addition, the 'Comparison to independent cost estimates' technique assumes that the previous cost estimates are applicable to the current project. This may not hold true if there are changes to the technology, organizational procedures, and so forth.

4.2.3.3 Value Analysis

Value analysis is an auxiliary technique to the methods discussed above and attempts to overcome one of their drawbacks – determining whether a particular product feature is desirable or not. This method involves a systematic and objective evaluation of the functionality of the product and its related costs. The objective of value analysis is to eliminate the superfluous product features and thus reduce the costs involved. In order to achieve this objective, the analyst should be knowledgeable about the product, its features / functions, and its use.

Value analysis is performed after the market information has been elicited. It analyzes whether each functionality of the product is necessary and how desirable it is to the user. In addition, this method determines the contribution of each feature to the product's value. If a particular functionality provides no additional value, it is dropped from the product feature list. Furthermore, value analysis also attempts to reduce costs by examining various alternatives to perform the functions and the possibility of purchasing the software components of the product from an external organization.
Thus, the requirements engineer should consider the following factors during the analysis of the product [USAID 2002]:

- What must the product do?
- Which features are essential, desirable, and unwanted?
- What are the other ways that a function can be performed?
- Can any part of the product be eliminated without affecting its market appeal?

- Can a lower cost component be procured rather than developed?
- What are the product's operation and maintenance costs?
- What will the alternatives cost?

Value analysis is an effective technique in identifying features which do not add value to the product and thus, helps in reducing the product related costs. On the downside, this method cannot predict the product price and hence, is used as a supplementary method to other price analysis techniques. Another drawback of value analysis is that it assumes that the market information is available beforehand; thus making it necessary to precede this method with market analysis techniques. This adds to the cost and effort of conducting the value analysis method, and hence, it is considered to be one of the costliest price analysis techniques.

4.2.3.4 Written Surveys/Questionnaires

Written survey is one of the most commonly used technique for eliciting market information as it facilitates contacting a large section of the society/market [Angus 53]. A questionnaire, or written survey, can be a written document or an online questionnaire that is completed by the person being surveyed.

Written surveys are usually one of the following types:

- **Mail Surveys** – Involves sending the survey questions to the people through post [Bourque 95].
- **Drop-off Surveys** – Similar to mail surveys but involves meeting the person and giving the questionnaire.
- **Electronic surveys** – questionnaires distributed through the World Wide Web.

Questionnaires can be used in two ways – to get statistical evidence for an assumption, or to elicit opinions and suggestions. In the first case, the questionnaire includes closed questions such as: "How easy is it to get the precise information using product X: very difficult, difficult, easy, and very easy." For the second case, we include open ended questions such as: "what are your suggestions to improve the product X?". Closed questions have a high risk of misinterpretation and hence, the questions should be carefully examined before passing it on to the people [Converse 86]. The answers to open

ended questions can give good insights, but at the same time they can be vague and confusing [Weissberg 86].

The advantage of surveys is that they are cost-effective and allow responses to be obtained from a large number of people. In addition, many questions can be asked about a given topic, giving considerable flexibility to the analysis. The disadvantage of this method is that the results can be misleading because the respondents may misinterpret the questions and give wrong or inappropriate answers. Furthermore, a particular section of the contacted people may be more participative than the others, resulting in responses which cannot be generalized.

4.2.3.5 Oral Survey

Oral surveys are considered to be more personal than the written surveys / questionnaires. The oral survey technique can be administered in the following ways:

- **Group Interview**: It involves gathering a select group of people and instead of handing them a written questionnaire, the questions are posed verbally. The respondents are allowed to work in groups to answer these questions while one person takes notes of the proceedings.
- **Phone survey**: It involves contacting people over the telephone line, and is generally used to get short one word answers such as Yes/No and occasionally longer ones [Oishi 95].

As in written surveys, the questions that are posed can be either open ended or closed. However, compared to written surveys the information obtained is better understood as oral survey techniques provide the flexibility to react to the respondent's situation, probe for more detail, seek more reflective replies and ask questions which are complex or personally intrusive [Glastonbury 91]. Thus, oral surveys are communicative sessions, which need to be well managed since it is easy for the respondents to diverge from the topic under discussion.

Oral surveys are advantageous over written surveys as it gives the interviewer the ability to answer questions from the participant. If the participant, for example, misunderstands a question or needs further explanation on a particular issue, it is possible to converse with

the participant. Another advantage of this technique is that the requirements engineer has more control over the response rate compared to the written surveys. The main drawback of this method is the large amount of time needed to obtain complete results; as a result this technique is costly. Also, certain types of questions[17] are inconvenient for this type of survey, particularly for phone surveys where the respondent does not have a chance to look at the questionnaire [Dillman 78]. For example, if the respondent has a choice of five different answers, it will be very difficult for the respondents to remember all of the choices, as well as the question, without a visual reminder [CSU 97]. Another drawback is that a face-to-face interview survey may introduce bias, either from the interviewer or the respondent.

4.2.3.6 Study of Similar Companies/Products

Determining a reasonable and fair price for the product requires the knowledge of the competitors, their products and their development processes. A study of the competitor's procedures provides realistic ideas about handling various product related problems. In addition, the competitors may have more experience with the specific product and the knowledge about their processes may provide insights about how the current development process can be enhanced. This technique employs various strategies to obtain information about the competitor's processes and products.

Competitors may not be forthright with the information about the procedures they follow. In that case, the analyst can approach certain international auditing and consultancy firms, which have a benchmark database with performance figures for companies in the same field. Performance is measured for various internal processes such as IT support, maintenance, and so forth. These statistics of the competitors can indicate which processes need to be improved. Furthermore, the consultancy may give a clue about how the processes can be enhanced for a fee [Lauesen 2002].

This method also focuses on identifying the main features of the competitor's products and their appeal to the users. The analyst achieves this objective by analyzing the sales of different products and the marketing strategies of the competitors. On examining the ads

[17] See http://writing.colostate.edu/references/research/survey/com4a2a.cfm

of the products it is possible to determine the features which are emphasized by the competitor. Furthermore, the popular products and their features can be evaluated to determine the features which are desirable to the public.

The advantage of this method is that it provides realistic ways of enhancing the development procedures and handling product related problems. In addition, it determines the advantages and disadvantages of similar products in the market. In turn, this provides ideas for improving the product. The drawback of this method is that it is difficult to procure information of the competitor's development procedures. Furthermore, the analysis of various similar products and their features is time consuming. The difficulty in obtaining competitor information and the lengthy period of operation makes this method one of the costliest market analysis techniques.

4.2.3.7 Ask Suppliers

This technique gathers information about the suppliers of software components / functionalities in the market. It provides ideas about new functionalities and helps in deciding whether the functionality should be developed in-house or procured from a supplier. The 'Ask Suppliers' method supplements the value analysis technique, which focuses on reducing product related costs.

Suppliers know a great deal about how the customers use their products. This information may be helpful in identifying new functionality for the system, thereby increasing the value of the product [Lauesen 2002]. In addition, each supplier provides a long list of features of the product they sell. Comparing the list of features of several suppliers helps in determining the best product satisfying the budget. Furthermore, if the prices of the products are beyond the budget limit and the cost of in-house product development is lower, then the analyst may decide to develop the product internally. Thus, information collected from suppliers facilitates decision making on issues related to enhancement of product value and reduction in development costs (using COTS[18]).

[18] Commercial off the shelf components: commercial items already developed and readily available for purchase.

The advantage of this method is that it provides comprehensive information about the supplier's products and their features. In addition, this technique is an effective complementary method to value analysis. The 'Ask Suppliers' technique is cost effective even though it may take a long period to collect all the information. This is because the information collected is dependent on the supplier's response and the suppliers may take time to respond.

4.2.4 Feasibility Analysis

Feasibility analysis determines how beneficial or practical the development of a system will be to the customer, by evaluating for:

- Operational feasibility
- Technical feasibility
- Schedule feasibility
- Economic feasibility

Thus, feasibility analysis involves examining the requirements of the system through business, technological and cost perspectives and this evaluation is achievable through various techniques, which are discussed in this section.

4.2.4.1 Decision Analysis Under Uncertainty

Decision analysis under uncertainty is also known as the Expected monetary value (EMV) technique. It provides a highly organized structure within which various options can be laid out and investigated [Howard 88]. Hence, given an infeasible project, the requirements engineer can utilize the decision analysis method to choose the right alternative that is economically and practically sound.

Decision analysis begins with the construction of the decision tree, which consists of solution alternatives represented as lines [Clemen 96]. If the result of taking a decision / alternative is uncertain, a small circle is drawn. If the result is another decision that is to be taken then a square is drawn as shown in Figure 4.9 [Mindtools 95]. At each circle,

possible outcomes are drawn and the probability / cash value of each outcome is guesstimated.

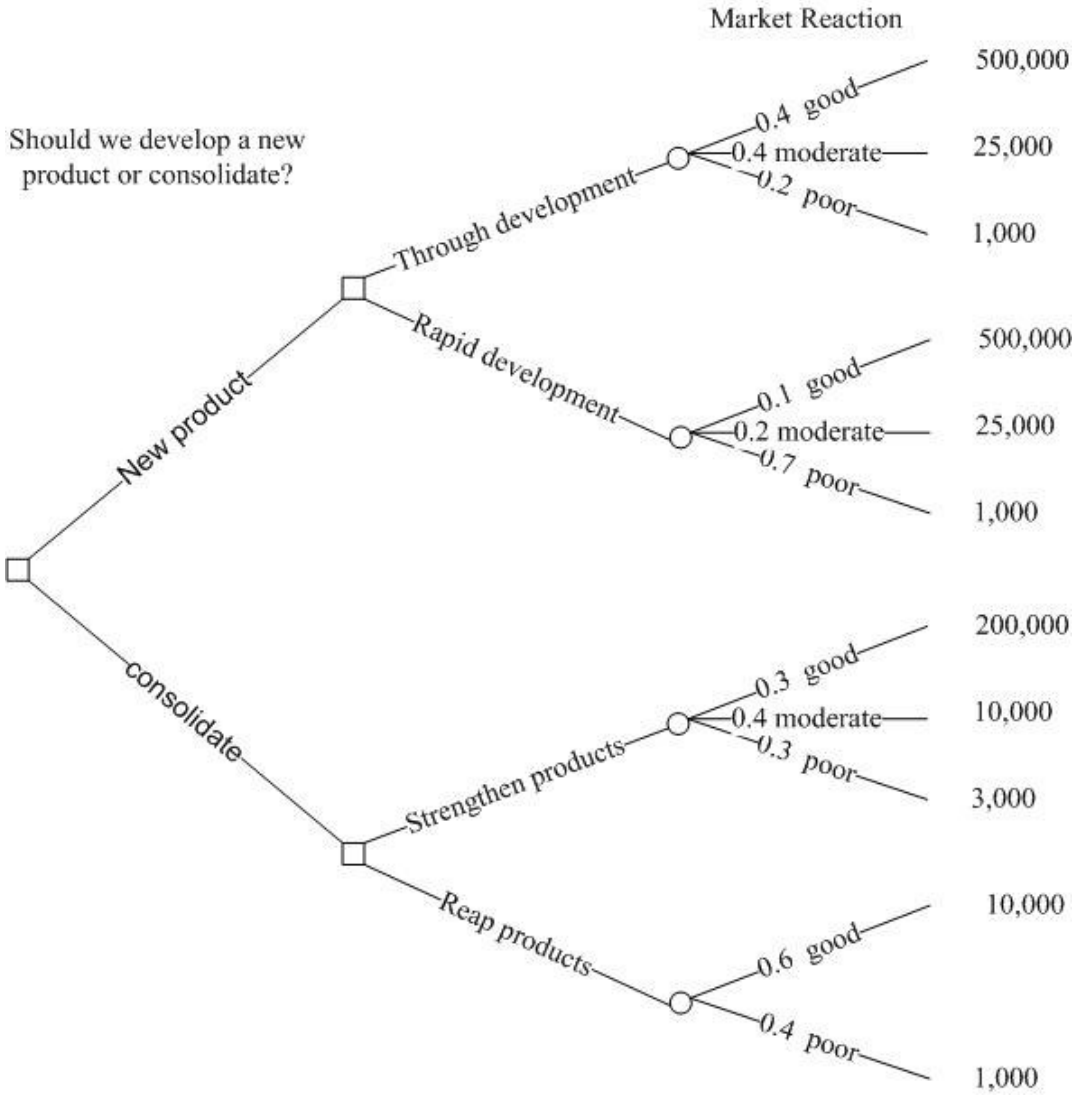


Figure 4.9 Example decision tree

Once the decision tree is constructed, it is evaluated backwards by multiplying the cash values of the outcomes with their probabilities. Thus from Figure 4.8, the value for 'new product' through development is:

0.4 (probability good outcome) x $500,000 (value) =	200,000
0.4 (probability moderate outcome) x $25,000 (value) =	10,000
0.2 (probability poor outcome) x $1,000 (value) =	200
Total value	**$210,200**

The value of a node/decision is obtained by subtracting the costs incurred in implementing the decision from the outcome value. Thus, the tree is evaluated bottom up until the root of the tree is reached. The propagation of costs up the decision tree is shown in Figure 4.10 [Mindtools 95].

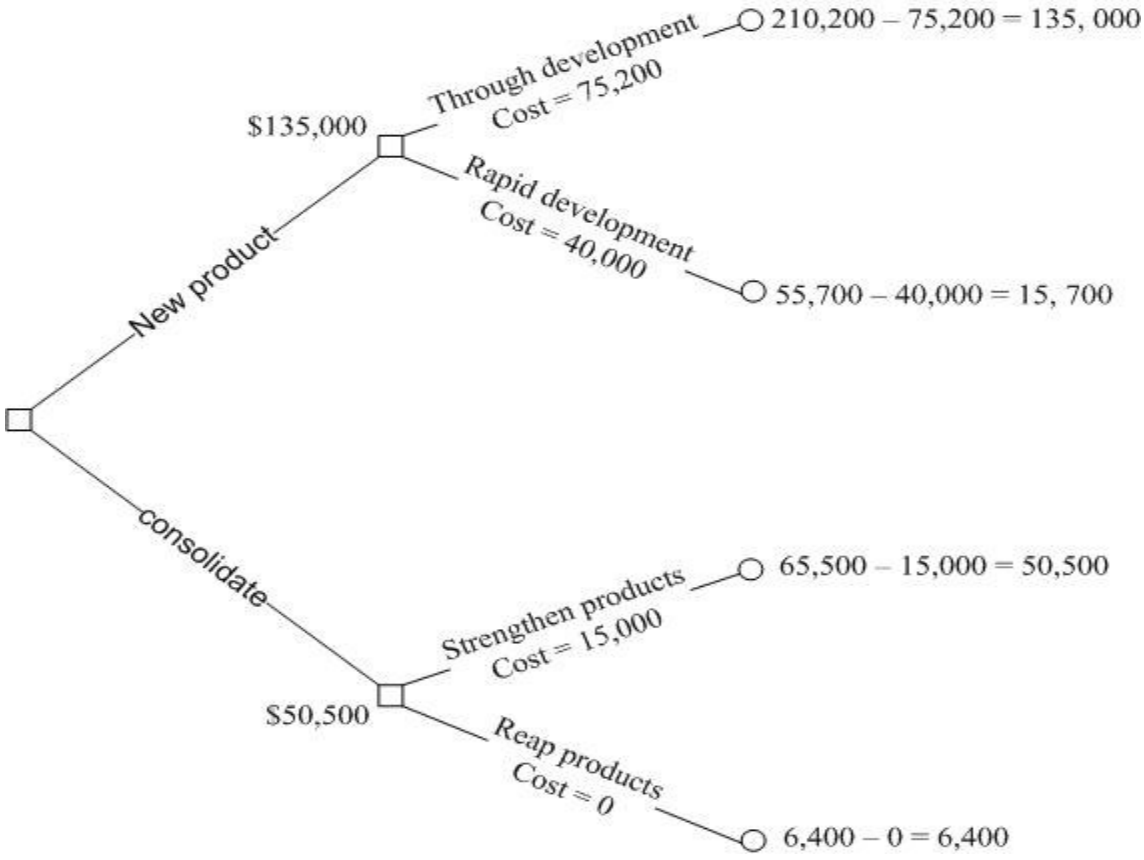


Figure 4.10 Propagation of costs in the decision tree

From Figure 4.9, it is clear that the best option is to develop a new product through development. Thus, decision trees are helpful in evaluating various alternatives and guiding the requirements engineer in the decision making process.

The decision analysis technique is advantageous because it clearly lays out the problem so that all options are challenged. In addition, it allows the analysis of all possible consequences of the decision and provides guidance in taking the best decision. The disadvantage of this method is that it relies on the requirements engineer for identifying the consequences of the decisions and the associated probabilities. This is a costly technique as considerable effort and time is required to perform a complete analysis of all the decisions [Ngatagize 86].

4.2.4.2 PMI

PMI stands for 'Plus/Minus/Implications' and is the most commonly used technique for feasibility analysis [Bono 92]. It is a decision making technique which helps evaluate the pros and cons of any item (requirements and its global factors[19]) under consideration.

The PMI technique starts with the drawing of a table with the headings: Plus, Minus and Implications. In the column underneath 'Plus' all the positive aspects of the item / project are included. For example, the requirements engineer may list out all points which make the project technically, operationally and economically feasible [Frame 2002]. Under the column 'Minus', the negative aspects of the project are listed. The last column, 'Implications', records the effects (either positive or negative) which are expected to occur when the product is completed and delivered. Examples of project implications could be: capturing a large percentage of the market share or the necessity to include localization features.

Once the table is filled, each of the points listed are subjectively assigned a positive or negative score. The scores are then added up to determine if the project is feasible or not. A strong positive tally indicates that the project is feasible while a high negative count alerts the requirements engineer about the non-practicality of the project [Mindtools 95]. On completion of the PMI technique, if a project is found to be infeasible, the decision analysis method can be employed to identify means by which the project can be made more attractive for development. An example of the usage of this technique is provided in the table below [McGuire 2002]:

Take up new post in London?		
Plus	**Minus**	**Implications**
Better social life +5	Have to sell house -6	Better promotion opportunities +2
Change of scenery +4	More pollution -5	Meet more people +2
Higher salary +4	Higher cost of living -6	

[19] Global factors include risk, price and schedule

	Further away from friend and family -5	Less disposable income -3
Total score = 17 – 25 = -8 (Analysis loaded against going to London)		

Table 4.7 Example of using PMI technique

The PMI technique is the most popular method in the software industry for feasibility analysis as it is simple, cost effective and time efficient. However, this method is unclear about the weighting of points and relies heavily on the experience of the analyst. As a consequence, the results obtained can be misleading if this method is performed by inexperienced analysts.

4.2.4.3 Payback Period

The payback period technique estimates the economic feasibility of the product by measuring the amount of time it would take to earn back the initial investment in the project. This is the simplest of the feasibility techniques and is usually used for small investments. The payback period is calculated using the following formula:

$$\textbf{Payback Period } \textit{(years)} = \frac{\textbf{Initial Investment}}{\textbf{Annual net benefits}}$$

A project is termed 'economically feasible' if the payback period is less than the critical value. In addition if there are mutually exclusive projects which achieve the same objective, the one with the lower payback period is selected for development [Bracker 2003]. An example of the usage of this technique is given below:

Let's assume that Jim's Printing is considering the purchase of a new printing press. The press will cost $2000 to produce and will generate cash flows of $900 per year for 3 years.

Payback Period = 2.22 years.

During the first year $900 of the $2000 is paid back. This leaves $1100. Then during the second year another $900 is paid back, leaving $200 of the initial investment yet to be recovered. Assuming the $900 comes in evenly throughout the year, it will take 2/9 or .22 of the last year to pay back the initial $2000.

Payback period is advantageous because of its simplicity and easiness of application. In addition, it is easy to understand and time efficient. Furthermore, this method provides information about how long the funds will be tied up in a project and this can be a useful statistic for the management. There are two primary situations when payback period can be useful. The first situation is when the distant cash flows are highly uncertain. For instance, the projected life span of a technology dependent project may be six years but after two years of development there is a possibility that the technology becomes obsolete. In a situation like this, it would be extremely helpful to have had the entire project paid back by the end of the second year. The second situation where Payback Period is extremely helpful is when the firm is facing significant financial problems. For example, a company having financial problems should preferably avoid investing in a project which has very low cash flows in the first couple years and high cash flows in the later years. Ideally, such an organization should look for early payback of the investment to prevent bankruptcy.

The disadvantage of this method is that it ignores cash flows after the payback period [deNeufville 90]. Moreover, this method assumes that cash flows come in evenly throughout the year and this may result in misleading estimates. Furthermore, the payback period method uses an arbitrarily chosen cut off period value for accepting or rejecting the project. Because of these limitations, this technique is biased against long term capital intensive projects.

4.2.4.4 Net Present Value

Net present value (NPV) is widely used by industry to determine the profitability of a project. The net present value of a project is the present value of all cash flows less the initial investment. Cash flow is defined as the benefits minus the cost incurred in each period. Net present value can be calculated as follows:

$$\mathbf{NPV = CF_0 + CF_1/(1+r) + CF_2/(1+r)^2 + \ldots + CF_n/(1+r)^n.}$$

Where NPV → Net present value (dollars)

CF → Cash flow

r → Discount rate

As seen in the formula, the cash flow for each year is discounted by a discount rate [r], which represents the conversion of future year money to current year money. Discount rate is the measure of the value of money over time, that is, a dollar today is worth more than a dollar tomorrow because one can invest the dollar today and have more tomorrow. The choice of the discount rate plays a critical role in the feasibility analysis of projects competing for funding. Low discount rates favor capital intensive projects with low operating costs while high discount rates support solutions with lower investment costs but higher operating costs [OMB 2000]. The rate for the commercial industry is typically between 10% and 15% depending on the risk and stability of the industry.

If a project has a positive Net present value, it indicates that the project is profitable and if funded, will increase the value of the company. If there are two projects competing for funding, then the one with greater Net present value should be selected. An example showing the calculations involved in the application of the Net present value technique is presented below [Williamson 2001]:

Year	**Cash Flows ($)**	**Discount Factors (15%)**	**Present Values ($)**
0	-25,000	1.0000	-25,000.00
1	20,000	0.8696	17,391.30
2	25,000	0.7561	18,903.59
3	12,500	0.6575	8,218.95
4	9,000	0.5718	5,145.78
Net Present Value			**24,659.63**

Table 4.8 Calculations in the Net Present Value technique

The Net Present Value method addresses the value of money over time, considers all cash flows, and acknowledges the risk involved in cash flows by incorporating discount rates. As a result, compared to other techniques for estimating economic feasibility, this technique is the most effective and widely used. The drawback is that this method requires more time and effort than the other techniques because of its comprehensive

evaluation. In addition, this technique fails to specify the size of the investment required to achieve the results [DoD 2001].

4.2.4.5 Internal Rate of Return

While the net present value technique estimates an absolute value for the returns, internal rate of return (IRR) provides a relative measure of the value. This technique calculates the discount rate at which the net present value becomes zero [Baker 97].

$$\mathbf{NPV = CF_0 + CF_1/(1+r) + CF_2/(1+r)^2 + \ldots + CF_n/(1+r)^n = 0}$$

Where NPV → Net present value (dollars)

CF → Cash flow

r → Discount rate

As seen from the above formula, the discounted cash flows (CF) together equal the present value of the investment in the project. The feasibility of the project is determined on the basis of the discount rate [r]. If the estimated rate is higher than the required rate of return, the project is said to be financially feasible. The computations involved in this technique are shown in the following table.

Year	Cash Flows ($)	Discount Factors (r=13.114%)	Present Values ($)
0	-$3,000	1.00	-3,000.00
1	1,500	.884063865	1,326.10
2	1,200	.781568917	937.88
3	800	.690956837	552.77
4	300	.610849972	183.25
Net Present Value			**0**

Table 4.9 Calculations in the Internal Rate of Return technique

The table is the same as that for net present value, but in this method the focus is on estimating the value of r in order to obtain a value of zero for the net present value. This difference is highlighted in Figure 4.9.

The IRR technique is an effective method for determining the economic feasibility of a project. It also provides the same advantages as that of the net present value technique. However, compared to the net present value method, this technique is more complicated and time consuming. Moreover, there is a possibility of dealing with multiple internal rates of return if there is a change in sign of the cash flows after the initial cash outflow [DSU 2003].

4.2.4.6 Pilot Experiments

In some projects, the main risk is whether the customer organization can adapt to the final product. For such projects, determining the operational feasibility is critical before developing the product. This objective is effectively achieved through pilot experiments.

In order to determine the operational feasibility using this technique, a working system needs to be developed, preferably through the use of COTS components. A small part of the target organization tries this system on a trial basis using real production data. In order to incorporate the system efficiently, the organization needs to make certain changes in the working procedures [Lauesen 2002]. The requirements engineer observes the results and evaluates the benefits and costs of deploying the real system. Analysis of the project feasibility is done in a way similar to that of the PMI technique.

Pilot experiments are useful in situations where the organizations adaptability to the system is a major risk factor. It is an elaborate technique which is time consuming as the requirements engineer has to observe the system in its real environment. Furthermore, this is an expensive method because the system has to be developed using COTS components and deployed in the customer organization.

4.2.5 Conflict Resolution

Conflict resolution is a process by which conflicts in requirements are resolved to reach a solution agreeable to all parties. This activity consists of three major steps: identify issues,

identify options and finalize agreements. Issues specify the conflicts in requirements along with the arguments from the stakeholders, who own the requirements. The options list various alternatives to resolve the identified conflicts. Agreements are the final solutions which are approved by all the stakeholders.

In this section, we discuss different techniques employed by the software industry to perform the three steps -identify issues, identify options and finalize agreements, which constitute the backbone of the conflict resolution activity.

4.2.5.1 Brainstorming/Interviews

Both of these techniques have been explained under the requirements elicitation meeting activity in Sections 4.1.2.1 and 4.1.2.6. Hence, in this section, we will provide a brief recapitulation of each method and highlight their pros and cons.

In the conflict resolution activity, brainstorming and interview techniques are effective in capturing the stakeholders' viewpoints and their solutions for the various conflicts. Both these methods have their own characteristics and should be employed based on the situation.

Brainstorming consists of gathering the stakeholders, creating a stimulating atmosphere, and letting the participants come up with spontaneous ideas without the fear of being ridiculed. On the contrary, interview is a face-to-face session, where the participant is briefed about the conflicting interests and his/her arguments are recorded.

Brainstorming takes lesser time and cost to perform compared to interviews and is effective in identifying innovative ideas / solutions. However, interviews are more personal than brainstorming and allow for discussion between the analyst and the stakeholder. Since brainstorming generates ideas that are not criticized, several unrealistic solutions may be proposed that need to be filtered out and this requires some additional effort. Furthermore, the success of the interview and brainstorming techniques depend on the questions asked and the management skills of the moderator / analyst.

4.2.5.2 Go-Around

This technique attempts to combine the positive features of interviewing and brainstorming methods. In a go-around, the facilitator sequentially asks each participant to submit his/her viewpoint. If a person doesn't have anything to say, s/he can pass during a round. Team members can also rejoin the process and contribute on subsequent rounds of the technique [NYS 2003b].

The Go-Around technique consists of the following steps during conflict resolution:

- Give a brief introduction to the conflicting items
- Give the members a break (around five minutes) to collect their thoughts
- In the first round, ask each member to state their position on the conflict and the arguments associated with their decision.
- Clarify / discuss the unclear arguments of the participants in the next round.
- In the subsequent rounds, assist and encourage people to find ways to overcome the conflict. The proceedings of each round are recorded by a scribe.

The industry uses several variations of the Go-Around technique such as Take five, Constructive response, and Nominal group technique[20] [DoD 99]. The 'take five' method proposes notifying the participants of the conflicting issues before the meeting takes place. It also includes a break of five minutes before commencing each round. Constructive response technique is very similar to Go-around with the addition being the use of chalkboards for a visual representation of the member viewpoints and concerns. The nominal group technique has the same steps as Go-around but in addition it provides a simple voting procedure to resolve the conflicts. Thus, we see that each of these methods build on top of the Go-Around technique, providing a few additional enhancements.

This technique allows introverted people the chance to provide input without having to "push" their way into the conversation. Furthermore, since the participants are given time to think about the conflicts, the ideas contributed are likely to be more realistic. This method requires more time than brainstorming but lesser time than interviewing. In

[20] See http://instruction.bus.wisc.edu/obdemo/readings/ngt.html

addition, this technique builds team spirit and requires lesser effort than the interview method. The drawback is that this method relies heavily on the facilitator for the success of the group session.

4.2.5.3 Positional Bargaining

Positional bargaining, also known as distributive negotiation, is a conflict resolution strategy which involves each party taking a stand and arguing for their position regardless of any underlying interests. This technique consists of three basic steps:

- take a position
- argue for this position
- make concessions to reach a compromise

Positional bargaining tends to be the first strategy employed by people when they enter into a negotiation. This can result in problems, because as the negotiation proceeds the participants get more committed to their positions, continually restating and defending them. A strong commitment to a position often results in lack of attention to the participants underlying interests. Therefore, any agreement that is reached will "probably reflect a mechanical splitting of the difference between final positions rather than a solution carefully crafted to meet the legitimate interests of the parties" [Fisher 81].

We see many examples in the real world that illustrate the use of this method [Spangler 2003]. For instance, at a flea market, a man offers a vendor $10 for a rug he has for sale. The vendor asks for $30, so the customer offers $15. The merchant then says he will accept $25, but the customer says the highest he will go is $20. The vendor agrees that $20 is acceptable and the sale is made at $20. So the customer pays $10 more than he originally wanted and the vendor receives $10 less.

Positional bargaining focuses on the issues rather than the interests of the parties involved in the negotiation. Issues are universal and are shared between each party in a conflict, while interests are specific to each party. In the example outlined above, what the customer wants is a bargain, while what the seller wants is a profit.

This technique is advantageous for situations that involve extremely conflicting interests [Lax 91]. For example, suppose two nations are in a dispute over water rights. They also

have a difference in opinion on issues such as trade, religion, etc. Broadening the debate to include all the underlying interests may further polarize the countries. It is much easier to reach an agreement by negotiating one particular issue at a time in terms of positions. The drawback of positional bargaining is the inflexibility of positions of both parties. This may result in bad feelings between the parties. This technique is inefficient because it may take a long time to reach a compromise in the event the opening positions are extreme. Furthermore, the method focuses on splitting the differences between parties rather than on the development of a solution beneficial to both sides.

4.2.5.4 Interest Based Bargaining

The main difference between positional bargaining and interest based bargaining is the underlying assumption that each party brings to the negotiation table. While the former focuses on position, the latter concentrated on the interests of the two sides. This technique attempts to create a win-win situation, where both sides have the impression of being on the winning side of the negotiation [Palmer 2000].

Interest-based bargaining goes by a host of names such as “consensus bargaining”, “problem-solving negotiations,” “win-win,” “mutual gains,” “collaborative bargaining,” and “principled negotiations”. This technique has the following characteristics [Hammond 95]:

- **People**: View the problem as that which needs to be resolved rather than viewing someone holding a contrary viewpoint as a person to be defeated [Cohen 2002]

  One specific technique that can work is to make both the parties face a flip chart or blackboard where the problem is presented, rather than facing each other as opponents.

- **Interests**: Take care of the human needs of the participants by identifying each side's needs, desires, concerns and fears.

- **Options**: Invent alternatives for mutual gain. The interests and options can be elicited from the participants through techniques such as interviewing, brainstorming or Go-around.

- **Criteria**: Develop objective criteria for judging merits of agreement such as market value, precedent, scientific judgment, professional standards, efficiency, costs, tradition, reciprocity, equal treatment, and time.

This technique examines all the identified options keeping in mind the interests of both parties and analyzes each option against the selection criteria. Once an option is selected, an agreement is prepared that clearly states the resolutions arrived at during the negotiation.

Interest based bargaining is an effective technique in finalizing an agreement for conflicts among different parties. This technique focuses on the underlying concerns of the disputing parties and hence, there is very little scope to develop bad feelings towards the other party [Sebenius 86]. In addition, this method fosters co-operation among the participants in an informal atmosphere. Compared to positional bargaining, this technique is more likely to reach an agreement, which is beneficial to both the sides. Furthermore, interest based bargaining requires lesser effort, cost and time than positional bargaining because it is more structured and has clear guidelines for identifying and finalizing agreements. A possible drawback of this method is that it requires the two parties to trust each other, which is not often the case.

4.3 Methods for Organization and Compilation Phase

This phase consists of a single activity, which is concerned with grouping the complete set of requirements in a manner which is optimal for understanding. Requirements can be classified based on user class, stimulus, response, system mode[21], etc. The organization and compilation phase / activity produces a structured requirements list, which represents a sections of the final SRS.

This section describes methods that can be employed for structuring the requirements list based on the type of classification.

[21] See Section 3.3 for more details.

4.3.1 Affinity Analysis

Affinity analysis is a categorization method where users sort various concepts into several groups. This is an effective technique to use when there is a large amount of data that needs to be classified. Basically this technique involves writing each concept on a Post-It note and sticking it on a wall or board. The team then moves the notes around to form groups based on how they feel the concept relates to the others.

The steps involved in affinity analysis are as follows [Brassard 88]:

- Form a team of four to six people so that there is good mix of experience and perspectives.
- Clearly state what the team is trying to accomplish and what the end result of the exercise should be.
- Use Post-It notes to record concepts (requirements) in whole and not just as a single word.
- Tack cards to wall or whiteboard in no particular order.
- The team members sort the cards into groups based on their intuition. No person should influence the other person's decision.
- For each group, create header cards which concisely describe what each group represents. The header cards should be single word titles and meaningful. Rite sub-header cards for subgroups, if necessary.
- Connect the related headers and sub-headers with lines to generate the affinity diagram.

Affinity analysis is an effective method for classifying requirements so that they are easy to comprehend. It is a simple technique which can be performed in a short time frame. The drawback of affinity analysis is that for large amount of data, a huge canvas is necessary to conduct this method. In addition, this method is fairly expensive because it involves approximately six people and a moderator, who manages the proceedings of the meeting.

4.3.2 Functional Hierarchy Decomposition

Functional hierarchy decomposition represents the data / requirements in terms of what the system must perform. Thus, this technique is applicable when the requirements are to be organized based on the functional hierarchy of the system. In order to facilitate the organization, this method necessitates the creation of a hierarchy diagram similar to the one illustrated in Figure 4.11

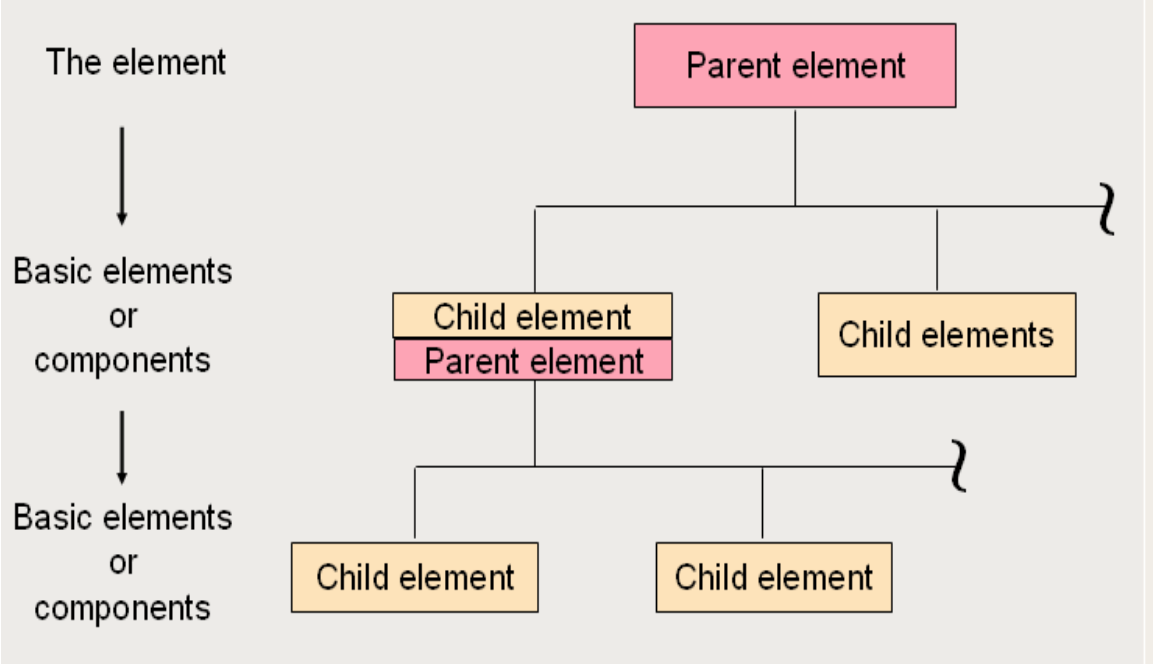


Figure 4.11 Functional hierarchy diagram

The overall functionality of a system can be structured into a hierarchy of functions to illustrate the information flow in the system. Thus, the root node in the hierarchy represents the system objective. The second tier of the hierarchy includes those components / functionalities that help in achieving the system objective [CMSD 2003]. For example, a high level functionality could be database manipulation while a sub-function of this functionality could be an authorization check. The functionalities are decomposed successively until the leaf nodes represent the smallest unit of functionality (requirements). Each high level node represents a grouping of lower level nodes. This hierarchy is used in organizing the requirements.

Functional hierarchy decomposition is beneficial only for the situation where requirements need to be organized in a hierarchy of functions. This technique is simple and is generally performed by a single person. It is cost effective, but time consuming because the task is performed by a single person. A disadvantage of this method is that its success is dependent on the product knowledge and expertise of the analyst / requirements engineer. Hence, it is imperative that s/he have a clear understanding of the system and its functions.

4.4 Methods for Confirmational analysis Phase

This phase creates the traceability diagrams and determines whether the requirements trace back to user needs. In addition, this phase performs the final verification and validation on the complete set of requirements. This phase concludes with the generation of the validated and structured requirements list, which is ready for inclusion in the SRS.

In the sections which follow, we describe the methods that achieve the objectives of this phase.

4.4.1 Quality Adherence

This activity verifies the total set of requirements for quality characteristics such as completeness and consistency. These quality characteristics cannot be checked earlier in the 'verifying quality attributes' activity because they can be determined only when the entire set of requirements is elicited. However, the techniques that are applicable to the 'verifying quality attributes' activity are effective for the 'quality adherence' activity too. Thus, the techniques that can be used to achieve the objectives of this activity are: Inspections, round robin reviews and audits (from Section 4.1.5)

Inspection is a formal technique, which is widely used to verify the requirements because it detects the most number of errors. Inspections are conducted using a group of about six people, who refer to elaborate checklists to determine the adherence of the requirements to the quality characteristics. The main drawback is that this technique is time consuming and cost intensive because of its rigorous nature.

Round robin reviews involves circulating the requirements among the reviewers for their comments on the quality attributes of the requirements. The unique feature of this method is the lack of discussion among the reviewers. Compared to the other verification techniques, round-robin reviews require the least amount of time and money for performing the quality check on the requirements. However, this method is not as effective as inspections in detecting faults.

Audits, unlike the previous methods, are performed by a single person, who is independent of the project being reviewed. Like inspections, audits use checklists during the verification of requirements. In terms of time and money required, this technique lies in between inspections and round-robin reviews. The main advantage of this technique is that the customers tend to have a strong belief / confidence in the generated results.

4.4.2 Traceability Analysis

Traceability analysis involves the creation of traceability diagrams, which show the function decomposition dependencies among the elicited requirements. In addition, once the traceability diagrams have been generated, the requirements engineer should verify the traceability of the requirements for errors. Hence, in this section we describe techniques which help in depicting the traceability as well as for verifying the requirements dependencies.

4.4.2.1 Traceability Matrix

A traceability matrix illustrates the dependency relationship between two requirements in the form of a matrix. Each requirement in the matrix should have the following information [DoE 2002]:

- A unique identification number by which it can be referred to.
- The requirement statement.
- Requirement source (Developer, customer, Configuration Control Board, etc.).
- Software Requirements Specification paragraph number containing the requirement.
- Design Specification paragraph number containing the requirement.

- Program Module containing the requirement.
- Test Specification containing the requirement test.
- Test Case number(s) where requirement is to be tested (optional).
- Verification of successful testing of requirements.
- Modification field - Requirement changed, eliminated, or replaced
- Remarks

All the above information cannot be obtained in the requirements phase and is incorporated into the matrix throughout the product development life cycle. In the requirements phase, the analyst creates the matrix and identifies the links between the requirements. The ID number and requirements statement is also incorporated into the matrix. The software industry uses several different formats of the traceability matrix. One of the most popular formats for the matrix is the one included in Requisite Pro and is shown in Figure 4.12

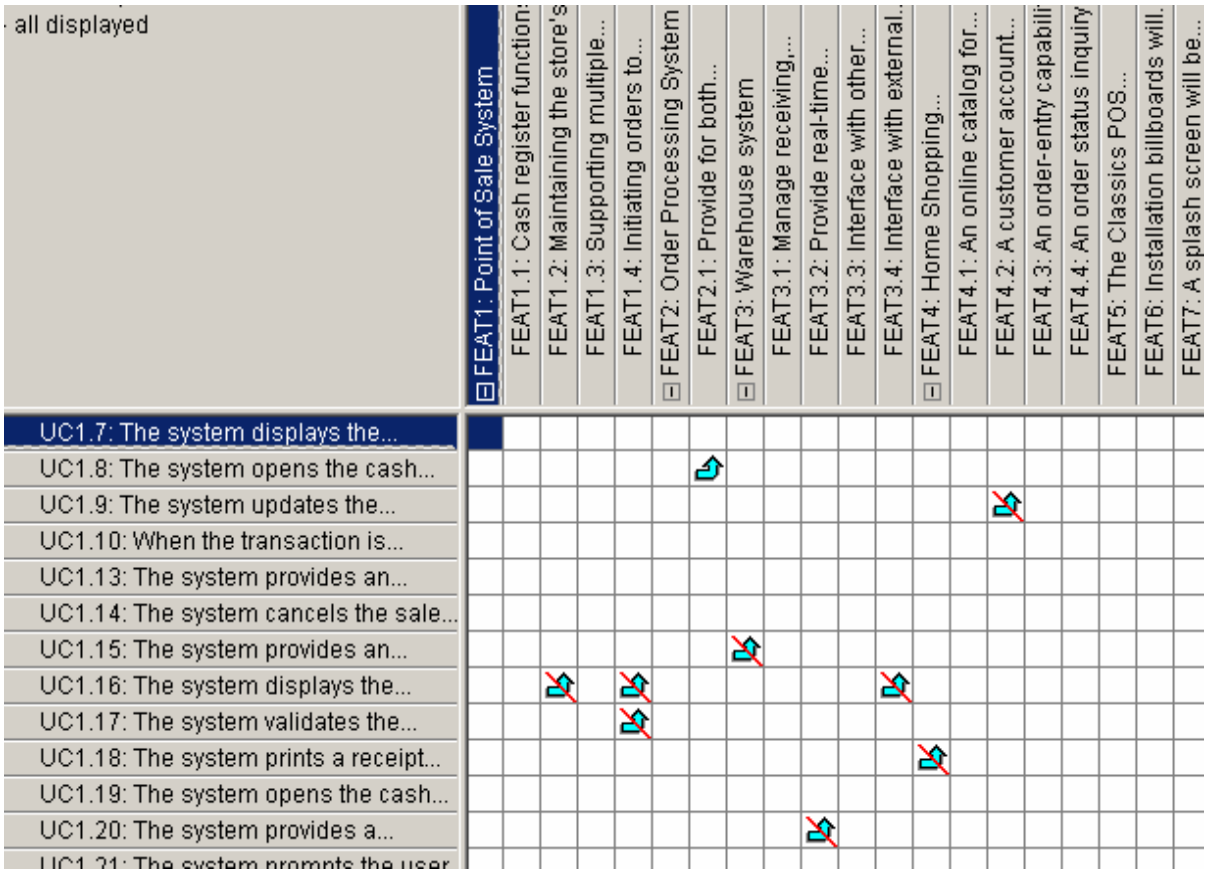


Figure 4.12 Traceability matrix in Requisite Pro

The advantage of the traceability matrix is that it shows all the requirements on the matrix and is very comprehensive. Moreover, the matrix shows the same requirements along the rows and columns and this ensures that no dependency is overlooked. The drawback of this method is that the matrix can get very large and difficult to handle. Also, this technique is time consuming because each requirement is checked against every other requirement for dependencies.

4.4.2.2 Traceability Tree

Traceability tree is another technique for representing the dependencies among the requirements. Each requirement in the traceability tree possesses the same information as that in the traceability matrix. The only modification is in the representation of the links so that the diagram becomes more manageable [Letelier 2003]. Thus, instead of having the matrix structure, the dependencies are represented in the form of a tree. An example of the traceability tree used in Requisite Pro[22] is shown in Figure 4.13.

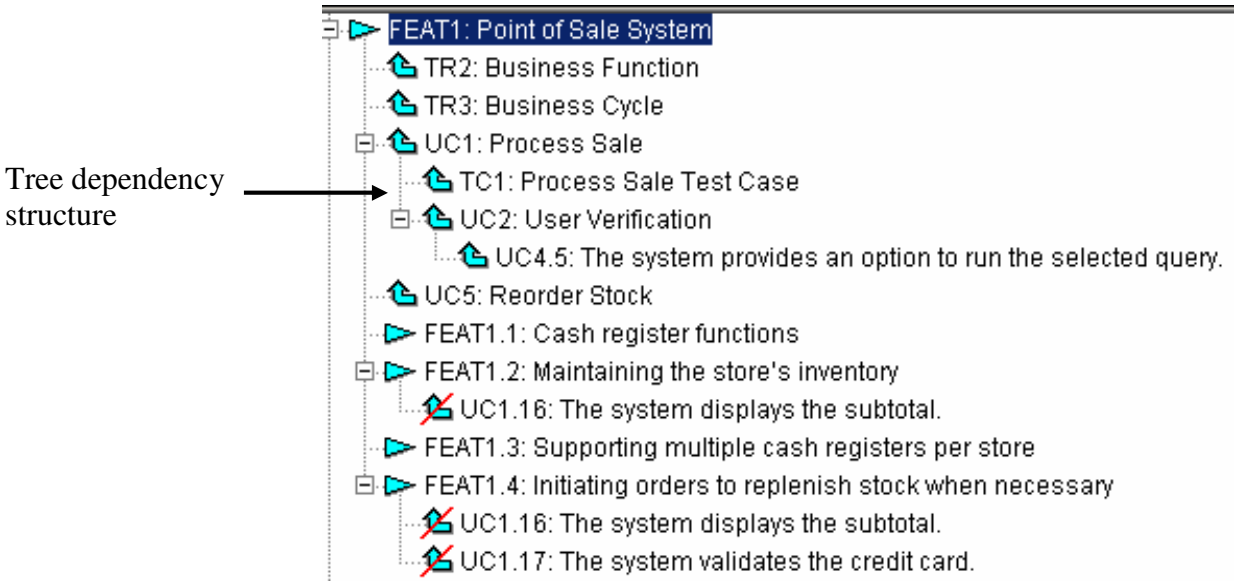


Figure 4.13 Traceability tree in Requisite Pro

The advantage of this technique is that the diagram is smaller than the traceability matrix and hence, is more manageable. Also, this method requires lesser time to create the tree structure because the links are created by the analyst based on his/her understanding of

[22] For more details see www.ibm.com/software/awdtools/reqpro

the system. However, this can be disadvantageous because the analyst may now unknowingly overlook certain dependencies. The cost of using this technique is almost the same as that of the traceability matrix because the main investment is in the software which facilitates the creation of these diagrams.

4.4.2.3 Inspections/Round-Robin Review

Inspections and round robin reviews are effective in verifying the traceability of requirements in the traceability diagrams. Sections 4.1.5.1 and 4.1.5.2 describe these techniques in detail.

Inspection is the commonly used technique for identifying errors in a work product (traceability diagrams.). It involves several people, who use detailed checklists for identifying faults in the traceability diagrams. However, the drawback of inspections is that it is time consuming and cost intensive.

Round robin reviews involves the verification of the product individually and not as a group. This technique is not as rigorous as inspections and hence, involves lesser cost and time. Also, this technique does not employ checklists - it depends entirely on the expertise of the reviewer to identify the errors.

4.4.3 Customer Validation Meeting

This activity differs from the validation in local analysis in that the whole set of requirements are validated, compared to component sets of requirements that are validated during local analysis. The objective of the customer validation meeting is to identify disagreements between the customer needs and the requirements. The techniques applicable to the ‘stakeholder validation’ activity of the requirements capturing phase can be used for this activity, too. Detailed explanations of the methods are provided in Section 4.1.6. In this section, we present only a brief description of these methods.

Walkthroughs, also referred to as presentation reviews, involve a group meeting in which the requirements engineer presents the requirements to the participants. The group consists of company employees, managers, users, customers and reviewers.

Walkthroughs require a lot of preparation before the group meeting and this is responsible for high cost involved. In addition, the feedback is obtained only for the material presented by the requirements engineer. The main advantage of this method is that its time efficiency and involvement of all the stakeholders.

Scenarios describe how the users can interact with the system in different situations while **storyboarding** transforms the textual scenarios into pictures, drawings, etc. Both of these techniques make it easier for the user to visual the interactions with the system. However, both methods are time consuming and cost intensive because of the large amount of work involved in creating scenarios and storyboards.

Interviews and **guided discussions** are occasionally used for validating requirements. While interviews involve individual face-to-face sessions, guided discussions involve interactive group meetings. Guided discussions require lesser time to validate the product compared to interviews. However, cost wise guided discussions are more expensive to conduct than interviews.

Prototyping is the most commonly used technique for validating a product / requirements. It allows the user to visualize how the final system will look like. This enhances the user understanding of the system requirements. The prototype developed at this stage of the requirements phase is usually a high fidelity prototype. As a result, prototyping is the most expensive and time consuming validation technique.

4.4.4 Requirements Reformulation

This activity is conducted by the requirements engineer in order to rectify the requirement problems identified by the quality analyst and the customer. These problems should be relatively minor and pertain to requirements quality and customer disagreement with the requirements. Requirements are often reformulated to overcome identified problems.

Guided discussion is the commonly used technique for this activity to resolve the minor problems of the customer. The discussion occurs in an informal atmosphere and the various solutions (reformulation) to the problems are analyzed. Guided discussion takes around two hours to perform and hence, is time efficient. The technique is fairly

expensive if the moderator is from an external agency. Several other techniques may be employed, but they all include some form of a discussion to resolve the customer problems.

4.5 Selection of Methods for Optimization of Common Criteria

The previous sections described the techniques that can be used to achieve the objectives of the activities defined by the x-RGM. Each activity can be performed by any of several methods and the choice of a particular method is a difficult task. We aim to simplify this task of the requirements engineer by identifying commonly used selection criteria and filtering out methods which do not satisfy these criteria. We choose to illustrate the selection process by example. In particular, for each selection criteria, we identify the set of methods for all activities defined by the x-RGM that best meet the selection criteria goal. Furthermore, the requirements engineer may have to employ one or more of the prescribed set of methods in order to achieve the objective of a particular activity.

We chose the following four criteria for the selection of methods:

- **Time** - Selection based on the amount of time needed to perform the technique.
- **Cost** - Selection based on the expenses involved in conducting the method
- **Personnel** - Selection based on the number of staff needed and their expertise.
- **Completeness** - Selection based on the coverage of the activity objectives

In the subsequent sections, we list the methods for each activity in the x-RGM based on the selection criteria and record the pros and cons of each approach.

4.5.1 Methods Based on Time Criteria

Often the requirements engineer has very limited time to perform a particular activity. In such a situation, it is necessary to employ the best possible technique, which achieves the objective in the least amount of time. However, many of the methods which satisfy the time criteria introduce compromises on other factors such as cost and completeness.

In this section, we record the methods that achieve the activity objectives in the least amount of time along with their benefits and drawbacks.

Activity Name	Methods	Pros / Cons
Requirements Capturing Phase		
Customer Indoctrination	Oral Presentation	+ Cost effective
		Better comprehension
		- May skip necessary information
		Audience coverage is limited
		Dependent on moderators skills
Requirements Elicitation Meeting	Task Demonstration	+ Suited for interactive applications
		Cost effective, simple
		- Success dependent on tasks assigned
	Questionnaires	+ Large user coverage
		Cost effective, simple
		- Results may be misleading
		Success dependent on the questions
	Brainstorming	+ Elicits news ideas, cost effective, simple
		Promotes creativity, team spirit
		- Needs good management
		Should be followed by idea reduction techniques
	Focus groups	+ Promotes co-operation
		- Participants may not be representative of users
		Needs management, cost intensive
	Requirements Workshops	+ Elicits maximum information
		Promotes co-operation
		- Cost intensive
		Needs management

Activity Name	Methods	Pros / Cons
Rationalization and Justification	Brainstorming (elicits only rationale)	+ Elicits news ideas , cost effective, simple
		Promotes creativity, team spirit
		- Needs good management
		Should be followed by idea reduction techniques / discussion
	I-Time (elicits only rationale)	+ Effective on closed participants
		Cost effective, simple
		- Questions posed are critical to success
		Needs to be followed by a discussion
	Task oriented discussion	+ Encourages co-operation
		Cost effective
		- May opt for first available solution
		Needs management
Prioritization	Guided discussion (elicits requirement attributes)	+ Encourages co-operation
		Cost effective
		- May opt for first available solution
		Needs management
		Followed by ranking techniques
	Priority Groups	+ Simple, Cost effective
		- Priorities not relative to each other
Verifying Quality Attributes	Round – Robin Review	+ Cost effective
		- Cannot detect all errors
		Dependent on reviewer's expertise
		Minimal discussion among reviewers
Stakeholder validation	Walkthroughs	+ Participation of all stakeholders
		- Cost intensive
		Validation only for material presented

Activity Name	Methods	Pros / Cons
	Guided discussion	+ Encourages co-operation
		Cost effective
		- Needs management
		May suppress convictions
Global Analysis Phase		
Risk Analysis	FMECA	+ Simple analysis
		Cost effective
		- Not a rigorous technique
		Single estimate for risk factors
	Monte Carlo simulation	+ Rigorous risk analysis
		Consider range of values for risk factors
		- Cost intensive
Cost / schedule estimation	SLIM (cost estimation)	+ Simple, cost effective
		- Extremely sensitive to technology factor
		Unsuitable for small projects
	COCOMO (cost estimation)	+ Simple, cost effective
		- KDSI is not a size measure
		vulnerable to misclassification of the development mode
	Gantt Chart (schedule estimation)	+ Simple, easy to use
		Cost effective
		Visual representation
		- Does not show the critical path in a chain of activities
		activity times are deterministic
		fails to show the interrelationships among the tasks

Activity Name	Methods	Pros / Cons
Price Analysis	Comparison to independent cost estimates	+ Cost effective
		Provides a good estimate
		- Not applicable to innovative projects
		Previous estimate may not hold
		Cannot elicit market information
	Questionnaires (market information)	+ Large user coverage
		Cost effective, simple
		- Results may be misleading
		Success dependent on the questions
Feasibility Analysis	PMI	+ Cost effective
		Easy, simple
		- Weighing of points is not clear
		Can be misleading if not done with a unbiased mind
		Needs to determine cost feasibility through other methods
	Payback Period (cost feasibility)	+ Cost effective
		Provides a good estimate for small investments
		- Ignores cash flows after the payback period
		Results can be misleading
Conflict Resolution	Brainstorming (elicits arguments and options)	+ Elicits news ideas, cost effective, simple
		Promotes creativity, team spirit
		- Needs good management
		Should be followed by idea reduction
	Interest Based Bargaining (finalizes agreements)	+ Focuses on concerns
		Fosters co-operation
		- Requires both parties to trust each other

Activity Name	Methods	Pros / Cons
Organization and Compilation Phase		
Organization and Compilation	Affinity analysis	+ Simple, Fosters team spirit
		- Difficult to manage for large amount of data
		Fairly expensive
Confirmational analysis Phase		
Quality Adherence	Same as the '*Verifying quality attributes*' activity	
Traceability Analysis	Traceability Tree (dependency creation)	+ Easy to comprehend and use
		Easily manageable structure
		- Certain links may be overlooked
	Round – Robin Review (traceability verification)	+ Cost effective
		- Cannot detect all errors
		Dependent on reviewer's expertise
		Minimal discussion among reviewers
Customer Validation Meeting	Same as the '*Stakeholder validation*' activity	
Requirements Reformulation	Guided discussion	+ Encourages co-operation
		Cost effective
		- May suppress participant convictions
		Needs management

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4.5.2 Methods Based on Personnel Criteria

Personnel is a common criteria used in the industry for the selection of methods because a project usually has limited work staff. Hence, in this section, we list those techniques which require minimum staff and expertise, and thus, aim to provide the necessary guidance to the requirements engineer. Most of the techniques listed below are conducted / supported by a single person (requirements engineer), unless explicitly stated.

Activity Name	Methods	Pros / Cons
Requirements Capturing Phase		
Customer Indoctrination	Oral Presentation	+ Cost effective, Time efficient
		- May skip necessary information
		Audience coverage is limited
		Dependent on moderators skills
	Print material	+ Provides comprehensive information
		Cost effective
		Documents can be read in leisure
		- Involves one-way communication
		Reader may get frustrated
		Takes a long time to read the documents
Requirements Elicitation Meeting	Questionnaires	+ Large user coverage
		Cost effective, fast to perform
		- Results may be misleading
		Success dependent on the questions
	Brainstorming	+ Elicits new ideas
		Promotes creativity, team spirit
		Cost effective, time efficient
		- Needs good management
		Should be followed by idea reduction techniques
	Interviews	+ Cost effective
		Provides opportunity to explore topics in depth
		- Time consuming
		Interview questions are critical for success
		Assumes interviewee has access to accurate knowledge

Activity Name	Methods	Pros / Cons
	Document studies	+ Simple, cost effective
		Can study documents in leisure
		- Involves one-way communication
		Reader may get frustrated
		Takes a long time to read the documents
Rationalization and Justification	Brainstorming (elicits only rationale)	+ Elicits news ideas , cost effective, simple
		Promotes creativity, team spirit
		Time efficient
		- Needs good management
		Should be followed by idea reduction techniques / discussion
	Task oriented discussion	+ Encourages co-operation
		Cost effective, time efficient
		- May opt for first available solution
		Needs management
Prioritization	Interviews	+ Cost effective
		Provides opportunity to explore topics in depth
		- Time consuming
		Interview questions are critical for success
		Assumes interviewee has access to accurate knowledge
		Cannot perform ranking of requirements
	Priority Groups	+ Simple, Cost effective
		- Priorities not relative to each other
	AHP or Binary Search Tree	+ Provides relative priorities
		- Time consuming, cost intensive
		Applicable if requirements obtained in a single iteration

Activity Name	Methods	Pros / Cons
Verifying Quality Attributes	Round – Robin Review (4-6 peers)	+ Cost effective, time efficient
		- Cannot detect all errors
		Dependent on reviewer's expertise
		Minimal discussion among reviewers
	Inspections (4-6 peers)	+ Detects maximum errors
		- Time consuming
		Cost intensive
	Audits (single expert)	+ Customers have confidence in the results
		Non biased opinion
		- Auditors need to be highly experienced
		Cost and time intensive
Stakeholder validation	Interviews	+ Cost effective
		Provides opportunity to explore topics in depth
		- Time consuming
		Interview questions are critical for success
	Scenarios or storyboarding	+ Easy to comprehend
		Better feedback from users
		- Cost and time intensive
Global Analysis Phase		
Risk Analysis	Monte Carlo simulation	+ Rigorous technique, time efficient
		Consider range of values for risk factors
		- Cost intensive
	Criticality Analysis	+ Simple, cost effective, time efficient
		- Assumes all risk factors are known before analysis
		Single estimate for risk factors

Activity Name	Methods	Pros / Cons
Cost / schedule estimation	SLIM (cost estimation)	+ Simple, cost effective
		Time efficient
		- Extremely sensitive to technology factor
		Unsuitable for small projects
	COCOMO (cost estimation)	+ Simple, cost effective
		Time efficient
		- KDSI is not a size measure
		Vulnerable to misclassification of the development mode
	Functions Points (cost estimation)	+ Independent of language and code
		More accurate than LOC estimate of size
		- Cost and time intensive
		Difficult to automate
	Gantt Chart (schedule estimation)	+ Simple, cost effective
		Visual representation
		- Does not show the critical path in a chain of activities
		Activity times are deterministic
		Fails to show the interrelationships among the tasks
Price Analysis	Comparison to independent cost estimates	+ Cost effective, Time efficient
		Provides a good estimate
		- Not applicable to innovative projects
		Previous estimate may not hold
		Assumes market information already exists
	Comparative Price Analysis	+ Produces a good price estimate
		- Cannot determine if a feature is desirable
		Assumes market information already exists
		Time consuming and expensive

Activity Name	Methods	Pros / Cons
	Value Analysis	+ Determines if a feature is desirable or not
		- Auxiliary technique, time consuming
		Assumes market information already exists
	Questionnaires (market information)	+ Large user coverage
		Cost effective, Time efficient
		- Results may be misleading
		Success dependent on the questions
	Study of similar companies / products (market information)	+ Provides information about product alternatives
		- Difficult to obtain information
		Time consuming
Feasibility Analysis	PMI	+ Cost effective, simple
		- Weighing of points is not clear
		Can be misleading if not done with a unbiased mind
		Needs to determine cost feasibility through other methods
	Payback Period (cost feasibility)	+ Cost effective
		Provides a good estimate for small investments
		- Ignores cash flows after the payback period
		Results can be misleading
	Internal Rate of Return (or) Net Present Value (cost feasibility)	+ Generates good estimates
		- Cost and time intensive
		Calculation can get complex
Conflict Resolution	Brainstorming (elicits arguments and options)	+ Elicits news ideas, cost effective, simple
		Promotes creativity, team spirit
		- Needs good management
		Should be followed by idea reduction

Activity Name	Methods	Pros / Cons
	Interviews (elicits arguments and options)	+ Cost effective
		Provides opportunity to explore topics in depth
		- Time consuming
		Interview questions are critical for success
	Positional Bargaining (finalizes agreements)	+ Applicable to situations that involve extremely conflicting interests
		- inflexibility of positions
		Time consuming
		Focus on splitting differences between parties
	Interest Based Bargaining (finalizes agreements)	+ Focuses on concerns
		Fosters co-operation
		Can be conducted in a shorter time frame than positional bargaining
		- Requires both parties to trust each other
Organization and Compilation Phase		
Organization and Compilation	Affinity analysis (4-6 peers)	+ Simple, Fosters team spirit
		Can be conducted in a short time frame
		- Difficult to manage for large amount of data
		Fairly expensive
	Functional Hierarchy Decomposition (single expert)	+ Applicable for organizing requirements into a hierarchy of functions
		Cost effective
		- Time consuming
		Dependent on expertise of analyst
Confirmational analysis Phase		
Quality Adherence	Same as the '*Verifying quality attributes*' activity	

Activity Name	Methods	Pros / Cons
Traceability Analysis	Traceability Tree (dependency creation)	+ Easy to comprehend and use
		Time efficient
		Easily manageable structure
		- Certain links may be overlooked
	Traceability Matrix (dependency creation)	+ Easy to comprehend and use
		Ensures links are not overlooked
		- Difficult to manage
		Time consuming
	Round – Robin Review (4-6 peers) [Traceability verification]	+ Cost effective, time efficient
		- Cannot detect all errors
		Dependent on reviewer's expertise
		Minimal discussion among reviewers
	Inspections (4-6 peers) [Traceability verification]	+ Detects maximum errors
		- Time consuming
		Cost intensive
Customer Validation Meeting	Same as the '*Stakeholder validation*' activity	
Requirements Reformulation	Guided discussion	+ Encourages co-operation
		Cost effective
		- May suppress participant convictions
		Needs management

4.5.3 Methods Based on Cost Criteria

Cost involved in conducting a method is another important criterion for selecting a particular method for an activity. This section lists the methods, which achieve the objectives of the activities in the x-RGM at a minimal cost.

Activity Name	Methods	Pros / Cons
Requirements Capturing Phase		
Customer Indoctrination	Oral Presentation	+ Time efficient
		Better comprehension
		- May skip necessary information
		Audience coverage is limited
		Dependent on moderators skills
	Print material	+ Provides comprehensive information
		Documents can be read in leisure
		- Involves one-way communication
		Reader may get frustrated
		Takes a long time to read the documents
Requirements Elicitation Meeting	Questionnaires	+ Large user coverage
		Time efficient
		- Results may be misleading
		Success dependent on the questions
	Brainstorming	+ Elicits news ideas
		Promotes creativity, team spirit
		Time efficient
		- Needs good management
		Should be followed by idea reduction techniques
	Interviews	+ Provides opportunity to explore topics in depth
		- Long execution time frame
		Interview questions are critical for success
		Assumes interviewee has access to accurate knowledge

Activity Name	Methods	Pros / Cons
	Document studies	+ Provide comprehensive information
		Can study documents in leisure
		- Involves one-way communication
		Reader may get frustrated
		Takes a long time to read the documents
	Task Demonstration	+ Suited for interactive applications
		Time efficient
		- Success dependent on tasks assigned
Rationalization and Justification	Brainstorming (elicits only rationale)	+ Elicits news ideas , simple, time efficient
		Promotes creativity, team spirit
		- Needs good management
		Should be followed by idea reduction techniques / discussion
	I-Time (elicits only rationale)	+ Effective on closed participants
		Time efficient
		- Questions posed are critical to success
		Needs to be followed by a discussion
	Task oriented discussion	+ Encourages co-operation
		Time efficient
		- May opt for first available solution
		Needs management
Prioritization	Interviews (elicits requirement attributes)	+ Provides opportunity to explore topics in depth
		Allows clarification of answers
		- Time consuming
		Interview questions are critical for success
		Cannot perform ranking of requirements

Activity Name	Methods	Pros / Cons
	Guided discussion (elicits requirement attributes)	+ Encourages co-operation
		Time efficient
		- May opt for first available solution
		Needs management
		Cannot perform ranking of requirements
	Priority Groups	+ Simple, time efficient
		- Priorities not relative to each other
Verifying Quality Attributes	Round – Robin Review	+ time efficient
		- Cannot detect all errors
		Dependent on reviewer's expertise
		Minimal discussion among reviewers
Stakeholder validation	Interviews	+ Provides opportunity to explore topics in depth
		Allows clarification of answers
		- Time consuming
		Interview questions are critical for success
	Guided discussions	+ Encourages co-operation
		Time efficient
		- Needs management
		May suppress convictions
Global Analysis Phase		
Risk Analysis	FMECA	+ Simple, time efficient
		- Provides a reasonable estimate
		Single estimate for risk factors
	Criticality Analysis	+ Simple, cost effective, time efficient
		- Assumes all risk factors are known before analysis
		Single estimate for risk factors

Activity Name	Methods	Pros / Cons
Cost / schedule estimation	SLIM (cost estimation)	+ Simple, time efficient
		- Extremely sensitive to technology factor
		Unsuitable for small projects
	COCOMO (cost estimation)	+ Simple, time efficient
		- KDSI is not a size measure
		vulnerable to misclassification of the development mode
	Gantt Chart (schedule estimation)	+ Simple, easy to use
		Time efficient
		Visual representation
		- Does not show the critical path in a chain of activities
		activity times are deterministic
		fails to show the interrelationships among the tasks
Price Analysis	Comparison to independent cost estimates	+ Time efficient
		Provides a good estimate
		- Not applicable to innovative projects
		Previous estimate may not hold
		Cannot elicit market information
	Questionnaires (market information)	+ Large user coverage
		Cost effective, simple
		- Results may be misleading
		Success dependent on the questions
	Value Analysis	+ Determines if a feature is desirable or not
		- Cannot predict the price estimate
		Auxiliary technique
		Assumes market information already exists

Activity Name	Methods	Pros / Cons
Feasibility Analysis	PMI	+ Time efficient
		Easy, simple
		- Weighing of points is not clear
		Can be misleading if not done with a unbiased mind
		Needs to determine cost feasibility through other methods
	Payback Period (cost feasibility)	+ Time efficient
		Provides a good estimate for small investments
		- Ignores cash flows after the payback period
		Results can be misleading
Conflict Resolution	Brainstorming (elicits arguments and options)	+ Elicits news ideas, cost effective, simple
		Promotes creativity, team spirit
		- Needs good management
		Should be followed by idea reduction
	Interviews (elicits arguments and options)	+ Allows clarification of interviewee answers
		Provides opportunity to explore topics in depth
		- Time consuming
		Interview questions are critical for success
	Interest Based Bargaining (finalizes agreements)	+ Focuses on concerns
		Fosters co-operation
		- Requires both parties to trust each other
Organization and Compilation Phase		
Organization and Compilation	Affinity analysis	+ Simple, Fosters team spirit
		Time efficient
		- Difficult to manage for large amount of data
		Fairly expensive

Activity Name	Methods	Pros / Cons
	Functional Hierarchy Decomposition	+ Applicable for organizing requirements into a hierarchy of functions
		- Time consuming
		Dependent on expertise of analyst
Confirmational analysis Phase		
Quality Adherence	Same as the '*Verifying quality attributes*' activity	
Traceability Analysis	Traceability Tree (dependency creation)	+ Easy to comprehend and use
		Easily manageable structure
		- Certain links may be overlooked
	Round – Robin Review (traceability verification)	+ Time efficient
		- Cannot detect all errors
		Dependent on reviewer's expertise
		Minimal discussion among reviewers
Customer Validation Meeting	Same as the '*Stakeholder validation*' activity	
Requirements Reformulation	Guided discussion	+ Encourages co-operation
		Time efficient
		- May suppress participant convictions
		Needs management

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4.5.4 Methods Based on Completeness Criteria

In some projects, it is necessary that the objective of each activity is completely met before proceeding to the next activity. In such situations, the completeness criterion is used to determine the methods that will be employed in the project. This section attempts to facilitate the above cause by providing a list of methods that will satisfy the objective of the requirements engineering activities to the maximum extent.

Activity Name	Methods	Pros / Cons
Requirements Capturing Phase		
Customer Indoctrination	Print material	+ Provides comprehensive information
		Cost effective
		Documents can be read in leisure
		- Involves one-way communication
		Reader may get frustrated
		Takes a long time to read the documents
Requirements Elicitation Meeting	Focus groups	+ Promotes co-operation
		- Participants may not be representative of users
		Needs management
		Cost intensive
	Requirements Workshops	+ Elicits maximum information
		Promotes co-operation
		- Cost intensive
		Needs management
	Interviews	+ Cost effective
		Provides opportunity to explore topics in depth
		- Time consuming
		Interview questions are critical for success
		Assumes interviewee has access to accurate knowledge
Rationalization and Justification	IBIS	+ Rigorous technique
		Fosters co-operation and team spirit
		- Cost and time intensive
		Need management
		Dependent on expertise of the analyst

Activity Name	Methods	Pros / Cons
	Task oriented discussion	+ Encourages co-operation
		Cost effective, time efficient
		- May opt for first available solution
		Needs management
Prioritization	Interviews (elicits requirements attributes)	+ Cost effective
		Provides opportunity to explore topics in depth
		- Time consuming
		Interview questions are critical for success
		Assumes interviewee has access to accurate knowledge
		Cannot perform ranking of requirements
	Guided discussion (elicits requirements attributes)	+ Provides opportunity to explore topics in depth
		Allows clarification of answers
		- Time consuming
		Interview questions are critical for success
		Cannot perform ranking of requirements
	Priority Groups	+ Simple, Cost effective
		Time efficient
		- Priorities not relative to each other
Verifying Quality Attributes	Inspections (4-6 peers)	+ Detects maximum errors
		- Time consuming
		Cost intensive
	Audits (single expert)	+ Customers have confidence in the results
		Non biased opinion
		- Auditors need to be highly experienced
		Cost and time intensive

Activity Name	Methods	Pros / Cons
Stakeholder validation	Walkthroughs	+ Involves the participation of all stakeholders
		Time efficient
		- Cost intensive
		Validation only for material presented
	Prototyping	+ Provides good user feedback
		Helps user in comprehending the requirements
		- Cost and time intensive
	Scenarios or storyboarding	+ Easy to comprehend
		Useful for interactive applications
		Better feedback from users
		- Cost and time intensive
Global Analysis Phase		
Risk Analysis	Monte Carlo simulation	+ Rigorous technique
		Time efficient
		Consider range of values for risk factors
		- Cost intensive
	Fault Tree analysis	+ Considers several probability values in calculating the estimate
		- Time and cost intensive
		Dependent on expertise of analyst
		Assumes all risk factors are identified
	Event Tree Analysis	+ Identifies most of the risk factors
		Easy to perform
		- Auxiliary technique to FTA
		Cannot estimate risk by itself
		Event trees can get large and complicated

Activity Name	Methods	Pros / Cons
Cost / schedule estimation	COCOMO II (cost estimate)	+ Cost effective, time efficient
		- Calculations can get complicated
		Schedule estimate is not accurate
	PERT (schedule estimate)	+ Focuses attention on critical aspects
		Enables management to use resources more wisely
		Shows the dependencies of the various tasks
		- Time and cost intensive
		beta distribution formula for the time estimate may not hold true
	CPM (schedule estimation)	+ Schedule the activities based on the costs
		Identifies critical activities
		Shows the dependencies of the various tasks
		- Time and cost intensive
		Schedule estimate is not as reliable as that of PERT
Price Analysis	Comparative Price Analysis (CPA)	+ Produces a good price estimate
		- Cannot determine if a feature is desirable
		Assumes market information already exists
		Time consuming and expensive
	Value Analysis	+ Determines if a feature is desirable or not
		- Auxiliary technique to CPA
		Assumes market information already exists
	Questionnaires (market information)	+ Large user coverage
		Cost effective
		Time efficient
		- Results may be misleading
		Success dependent on the questions

Activity Name	Methods	Pros / Cons
	Study of similar companies / products (market information)	+ Provides information about product alternatives
		Often used with Value analysis method
		- Difficult to obtain information
		Time consuming
	Oral Survey (market information)	+ Covers a large number of users
		Users misunderstandings can be clarified
		Cost effective
		- Time consuming
		Responses could be influenced
Feasibility Analysis	PMI	+ Cost effective, simple
		- Weighing of points is not clear
		Can be misleading if not done with a unbiased mind
		Needs to determine cost feasibility through other methods
	Decision Analysis	+ Rigorous technique
		Evaluates all consequences of a decision
		- Time and cost intensive
		Dependent on the expertise of the analyst(s)
		Needs to determine cost feasibility through other methods
	Internal Rate of Return (or) Net Present Value (cost feasibility)	+ Generates good estimates
		- Cost and time intensive
		Calculations can get complex
Conflict Resolution	Brainstorming (elicits arguments and options)	+ Elicits news ideas, cost effective, simple
		Promotes creativity, team spirit
		- Needs good management
		Should be followed by idea reduction

Activity Name	Methods	Pros / Cons
	Go-Around (elicits arguments and options)	+ Fosters co-operation
		Effective with closed participants
		- Requires more time than brainstorming
		Dependent on the expertise of the moderator
		Needs management
	Interest Based Bargaining (finalizes agreements)	+ Focuses on concerns
		Fosters co-operation
		Can be conducted in a shorter time frame than positional bargaining
		- Requires both parties to trust each other
Organization and Compilation Phase		
Organization and Compilation	Affinity analysis (4-6 peers)	+ Simple, Fosters team spirit
		Can be conducted in a short time frame
		- Difficult to manage for large amount of data
		Fairly expensive
Confirmational analysis Phase		
Quality Adherence	Same as the '*Verifying quality attributes*' activity	
Activity Name	**Methods**	**Pros / Cons**
Traceability Analysis	Traceability Tree (dependency creation)	+ Easy to comprehend and use
		Time efficient
		Easily manageable structure
		- Certain links may be overlooked
	Traceability Matrix (dependency creation)	+ Easy to comprehend and use
		Ensures links are not overlooked
		- Difficult to manage
		Time consuming

Activity Name	Methods	Pros / Cons
	Inspections (4-6 peers) [Traceability verification]	+ Detects maximum errors
		- Time consuming
		Cost intensive
Customer Validation Meeting	Same as the '*Stakeholder validation*' activity	
Requirements Reformulation	Guided discussion	+ Encourages co-operation
		Cost effective
		- May suppress participant convictions
		Needs management

4.6 Summary

This chapter addressed the issue of mapping methods to the activities in the x-RGM. Sections 4.1 to 4.4 describe in detail the techniques that achieve the objectives of the various activities. In order to facilitate the task of selecting methods for the activities, we have listed a set of techniques for each activity based on certain criteria, which are widely used in the industry. This list includes the popular as well as several other techniques and is NOT a comprehensive list. The intention behind creating this list is to provide the requirements engineer with some reference for selecting methods since the current RE literature fails to provide the necessary guidance.

Chapter 5

Summary and Future Work

5. Introduction

This research describes a solution to the problem in the field of requirements engineering that is concerned with the mapping of methods to activities in the requirements generation process. Chapter 1 motivates the need for this research, defines the problem and highlights the research issues. In Chapter 2, we discussed the relevant background, which reveals the absence of a well defined requirements process model. Furthermore, the literature illustrates the unsynchronized and inadequate attempts at mapping methods to the right level of activities in the requirements engineering process. Chapter 3 presented the x-RGM as the solution for a structured and well-defined requirements engineering model. Finally, in Chapter 4, we describe various methods for achieving the objectives of the activities in the requirements generation model, and prescribe a list of methods for the entire requirements engineering process on the basis of some common selection criteria. This chapter summarizes the research work conducted and presents the future opportunities of work.

5.1 Summary

This research is motivated by the problems faced by the requirements engineer in implementing the requirements engineering process. The main problem is the absence of a well-defined and comprehensive requirements process model. Adding to that problem list is the lack of coordination between methods and activities in the requirements model. As a consequence of these obstacles, the requirements engineer is often hindered in the effective application of the requirements generation process to the real world projects.

The solution of the problems listed above needs to consider several issues such as[23]:

- Incomplete requirements engineering model
- Inadequate level of activity abstraction
- Implicit activity objectives implicit
- Methods mapped primarily to high level activities
- Lack of reasoned guidance in selecting methods to achieve activity objectives

The solution was deployed in two phases. In the first phase, the focus was on developing a well-defined process model (addresses first three issues), and in the second phase, the emphasis was on synchronizing methods to activities (addresses last two issues).

The Requirements Generation Model (RGM) serves as the foundation for our research and has been decomposed to a more appropriate activity level based on the concept of "Separation of concerns" [ICSE 2001, OOPSLA 99, Hursh 95], which stresses on identifying and satisfying a small set of concerns for the purpose of organizing and decomposing different processes. In designing the proposed model (expanded Requirements Generation Model [x-RGM]), we evaluated several existing requirements engineering processes and approaches. The best features of these models are incorporated in the x-RGM. The x-RGM is composed of four main phases:

- **Requirements capturing**: elicits requirements and analyzes them from the local standpoint
- **Global analysis**: analyzes the complete set of requirements and resolves any requirement conflicts

[23] See Section 1.4.1 for detailed description of the issues

- **Organization and Compilation**: structures the requirements as a part of the SRS
- **Confirmational analysis**: implements traceability and performs the final verification and validation on the complete set of requirements

Each of these phases is decomposed into a detailed set of activities; the objectives of these activities are also identified and explicitly stated.

In order to map methods to activities, we conducted a literature review on the methods used in various disciplines for the purpose of generating requirements. These methods have been mapped to the activities defined by the x-RGM based on their objectives. Furthermore, in order to simplify the task of choosing methods for the activities, we prescribed a smaller set of methods for each activity on the basis of commonly used selection criteria such as time, cost, and so forth.

The x-RGM was conceived as the expansion of the requirements phase in the conventional waterfall model. The intent was to concentrate on identifying activities and objectives for the requirements engineering phase while attempting to minimize the impact on the other phases. Even though the x-RGM in its current form is not designed to accommodate other development paradigms such as OOA, XP, etc. we do conjecture that it can be adapted for them. We also note that the list of methods included in this research is not intended to be comprehensive; the intention is to provide the requirements engineer with some basic reference to and an approach for selecting methods.

5.2 Contributions

The contributions of this research to the field of requirements engineering and computer science in general are:

- **The expanded Requirements Generation Model (x-RGM):** As seen from the literature review, the current requirements engineering models either provide a high level of abstraction or focus on only portions of the entire requirements engineering process. Hence, it was necessary to develop a model having the right level of decomposition in order to map methods to the activities. For the decomposition of the requirements engineering process, we chose the RGM as the basis. This model (RGM), in its basic form, includes three activities and attempts to decompose only the

capturing phase of the requirements generation process. However, the proposed x-RGM, which builds on top of the RGM, consists of sixteen activities and addresses the entire requirements engineering process. The decomposition of the requirements generation process into activities of the x-RGM is illustrated below:

Phase name	# of activities	Activity name
Requirements Capturing	6	• Customer/requirements engineer indoctrination • Requirements elicitation meeting • Rationalization and justification • Prioritization • Verifying quality attributes • Stakeholder validation
Global Analysis	5	• Risk analysis • Cost/schedule estimation • Price analysis • Feasibility analysis • Conflict resolution
Organization and Compilation	1	• Organization and compilation
Confirmational Analysis	4	• Quality adherence • Traceability analysis • Customer validation meeting • Requirements reformulation

Table 5.1 Activities identified in the x-RGM

- **Identification of activity objectives**: For each of the sixteen activities identified in the x-RGM, the objectives are determined and explicitly stated, unlike in the other models where the objectives are often implied. The identification of objectives is imperative because methods are mapped to the requirements engineering process activities based on the achievement of their objectives. Thus, the x-RGM is better defined and more comprehensive than the other requirement generation models not only because of a refined level of abstraction, but also due to the explicit specification of objectives.
- **Synchronization of methods and activities**: A drawback of the current requirements engineering literature is that it focuses on identifying methods for the high level activities in the requirements generation process, but the techniques for the sub-activities are often ignored. As a consequence, the requirements engineer lacks guidance in choosing methods for the various requirement engineering activities. This research addresses this void in requirements engineering by identifying methods from various disciplines, and suggests their application for achieving the defined objectives of the x-RGM activities. In this thesis, for each activity in the x-RGM, we identify the principal techniques which are most accepted in the industry. Table 5.2 depicts the number of techniques identified for the various activities in the x-RGM.

Activity Name	Number of Methods identified
Customer/requirements engineer indoctrination	2
Requirements elicitation meeting	9
Rationalization and justification	4
Prioritization	5
Verifying quality attributes	3
Stakeholder validation	6
Risk analysis	6

Activity Name	Number of Methods identified
Cost/schedule estimation	8
Price analysis	7
Feasibility analysis	6
Conflict resolution	5
Organization and compilation	2
Quality adherence	3
Traceability analysis	4
Customer validation meeting	6
Requirements reformulation	1

Table 5.2 Number of methods identified for activities in the x-RGM

- **Selection of methods to optimize common criteria**: In the industry, often techniques for various activities are chosen based on certain selection criteria. However, the current requirements engineering literature fails to incorporate such criteria into the process of identifying techniques for performing activities of the requirements generation process. In this research, we attempt to overcome this shortcoming by identifying four commonly used criteria for the selection of methods – cost, time, personnel and completeness. For each of these criteria, we identify a set of methods for the entire requirements generation process, such that the chosen criterion is optimized and at the same time the objectives of the activities are achieved. Thus, this list of techniques provides the necessary guidance to the requirements engineer in the selection of methods for the various activities in the requirements generation process (x-RGM). The following table shows the number of methods selected for the x-RGM based on the four selection criteria.

Selection Criteria	Number of methods (Total : 77 methods)
Time	32
Cost	37
Personnel	49
Completeness	44

Table 5.3 Number of methods identified based on selection criteria

5.3 Future Work

This research presents a well-defined requirements generation model (x-RGM) and describes the synchronization of methods to activities in this model. The research work conducted for this thesis can be extended in several ways, and are discussed below.

Empirical evaluation of the expanded Requirements Generation Model (x-RGM) in a real world setting.

Although we conjecture that the adherence of the x-RGM results in a more complete and correct set of requirements, a detailed empirical evaluation will provide a deeper insight into the implementation aspect of the model. In addition, the empirical study will highlight the troublesome aspects of the model and will provide suggestions for further improvement. Such a study can provide results which could be used to prove the effectiveness of the x-RGM. In conducting the study, it is necessary to select a project of the right size and complexity so that the results are valid and can be generalized.

Development of a management tool for the x-RGM and the prescribed techniques.

The requirements generation process is an elaborate procedure consisting of several activities and method application. To help simplify this task, it is desirable to have a tool which provides guidance to the requirements engineer in the selection of activities and methods. It is imperative that this tool is tuned for efficiency by employing it in some real world projects, and guided by user feedback. Furthermore, development of a management tool requires addressing the issues of synchronization among the various tools and usability of the tool developed.

Adapting the model to other software development paradigms

The x-RGM has been developed assuming that all the requirements are generated upfront before the commencement of the design phase. Hence, this model is more suitable in an environment which follows the waterfall development paradigm. A possible extension to this model is to adapt it to suit other development paradigms, such as the evolutionary and spiral approaches. This would require considering the requirements engineering process not as an isolated phase, but as one which overlaps with the rest of the software development phases – design, coding, and testing.

Determining the content and format of information generated by the activities

The current requirements engineering literature focuses on specifying the content and format of the software requirements specification (SRS) and neglects the presentation of the intermediate requirement forms generated during the requirements engineering process. The identification of the content and format of the intermediate documents and its synchronization with the x-RGM can result in a more comprehensive and complete requirements generation model. The major issue that this research needs to address is the identification of the different representations of the intermediate requirements so that there is minimal / no loss of information as the requirements evolve during the requirements generation process.

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Appendix A: Organization Templates for Requirements

A.1 Template for requirements list organized by mode

- Specific requirements
    - External interface requirements
        - User interfaces
        - Hardware interfaces
        - Software interfaces
        - Communication interfaces
- Functional requirements
    - Mode 1
        - Functional requirement 1
        - .
        - .
        - Functional requirement n
        -
        -
        -
    - Mode m
        - Functional requirement 1
        - .
        - .
        - Functional requirement n
- Performance requirements
- Design constraints
- Software system attributes
- Other requirements

A.2 Template for requirements list organized by user class

- Specific requirements
    - External interface requirements
        - User interfaces
        - Hardware interfaces
        - Software interfaces
        - Communication interfaces
- Functional requirements
    - User class 1
        - Functional requirement 1
        - .
        - .
        - Functional requirement n
        -
        -
        -
    - User class m
        - Functional requirement 1
        - .
        - .
        - Functional requirement n
- Performance requirements
- Design constraints
- Software system attributes
- Other requirements

A.3 Template for requirements list organized by stimulus

- Specific requirements
    - External interface requirements
        - User interfaces
        - Hardware interfaces
        - Software interfaces
        - Communication interfaces
- Functional requirements
    - Stimulus 1
        - Functional requirement 1
        - .
        - .
        - Functional requirement n
        -
        -
        -
    - Stimulus m
        - Functional requirement 1
        - .
        - .
        - Functional requirement n
- Performance requirements
- Design constraints
- Software system attributes
- Other requirements

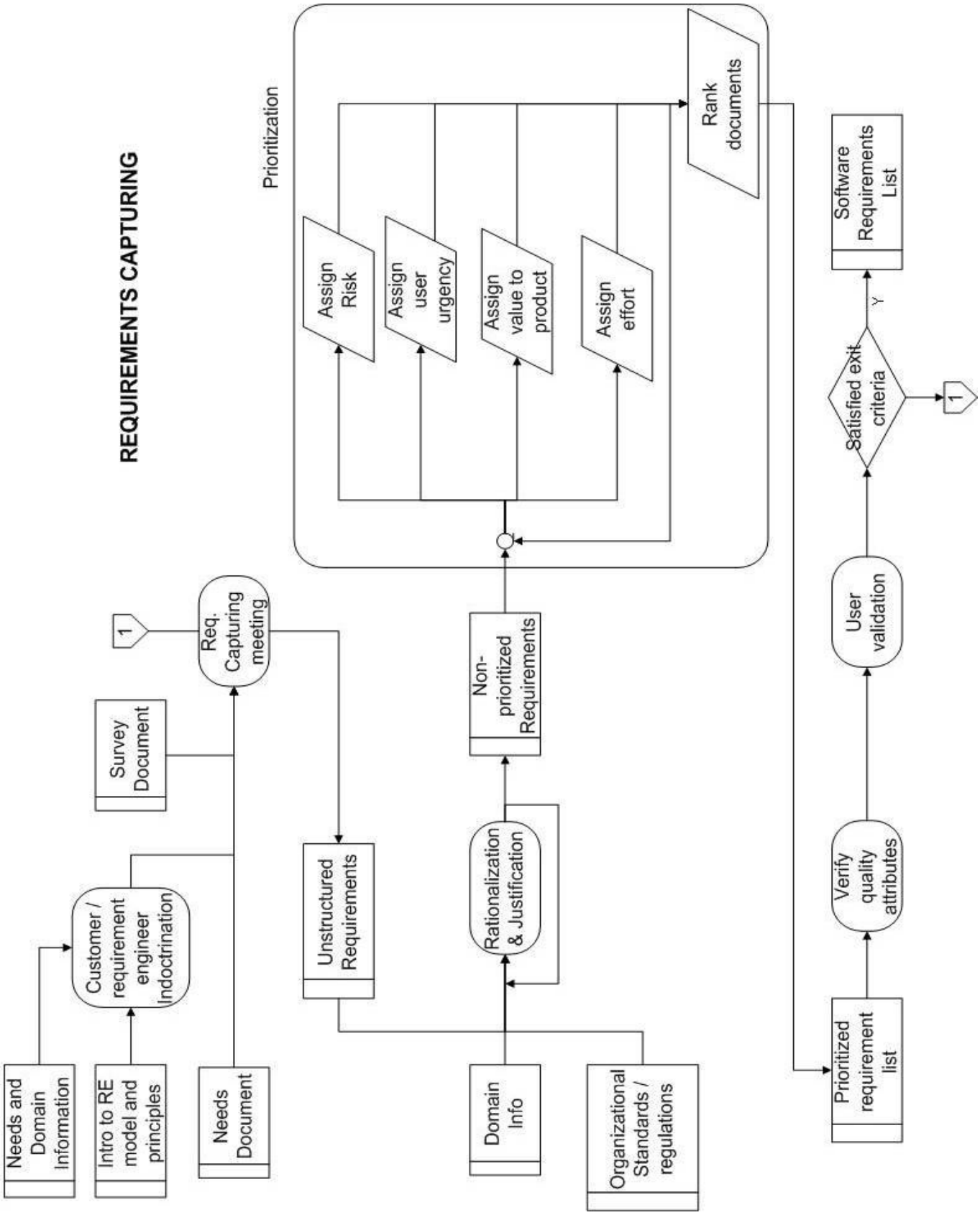
A.4 Template for requirements list organized by response

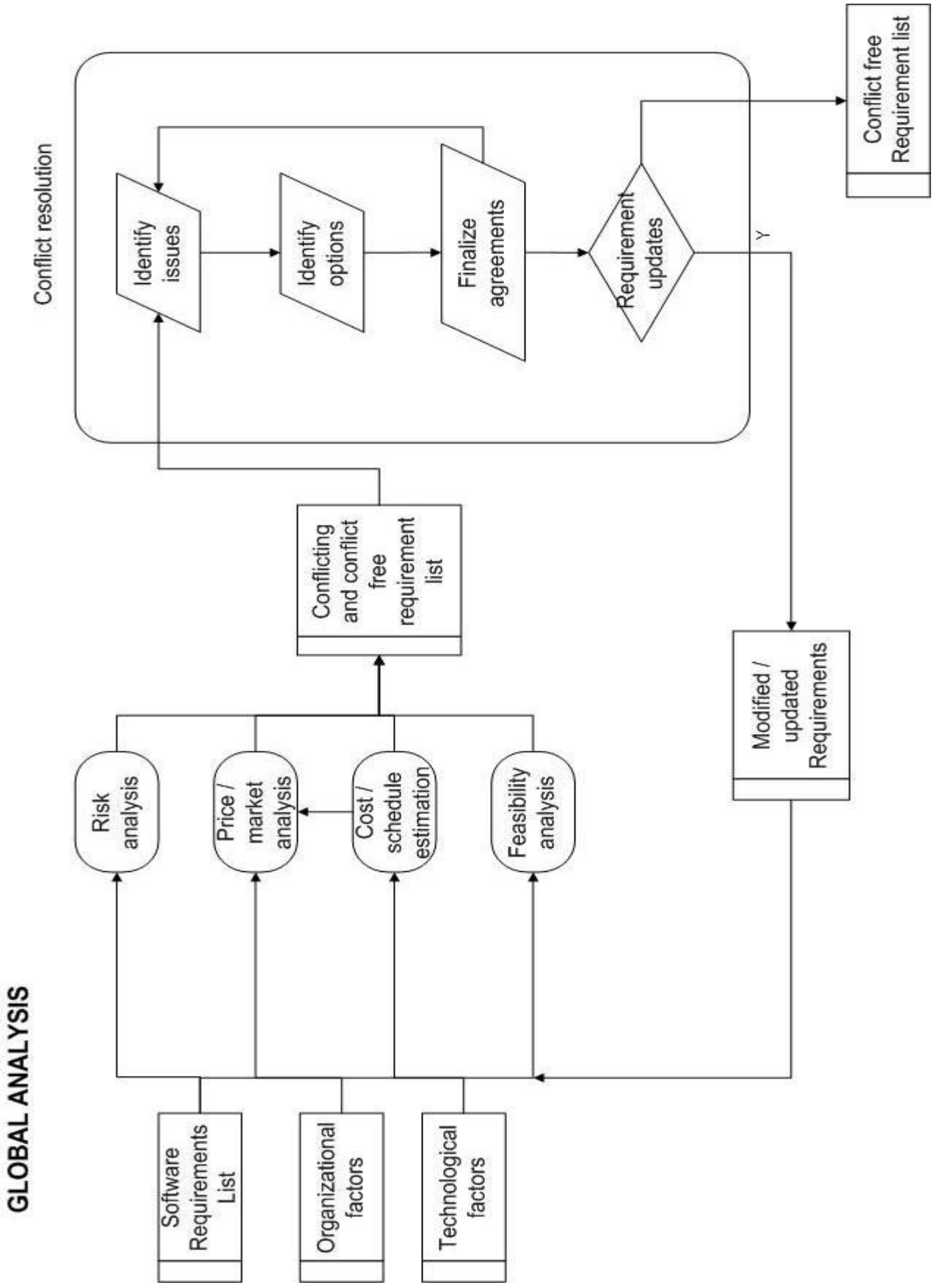
- Specific requirements
    - External interface requirements
        - User interfaces
        - Hardware interfaces
        - Software interfaces
        - Communication interfaces
- Functional requirements
    - Response 1
        - Functional requirement 1
        - .
        - .
        - Functional requirement n
        -
        -
        -
    - Response m
        - Functional requirement 1
        - .
        - .
        - Functional requirement n
- Performance requirements
- Design constraints
- Software system attributes
- Other requirements

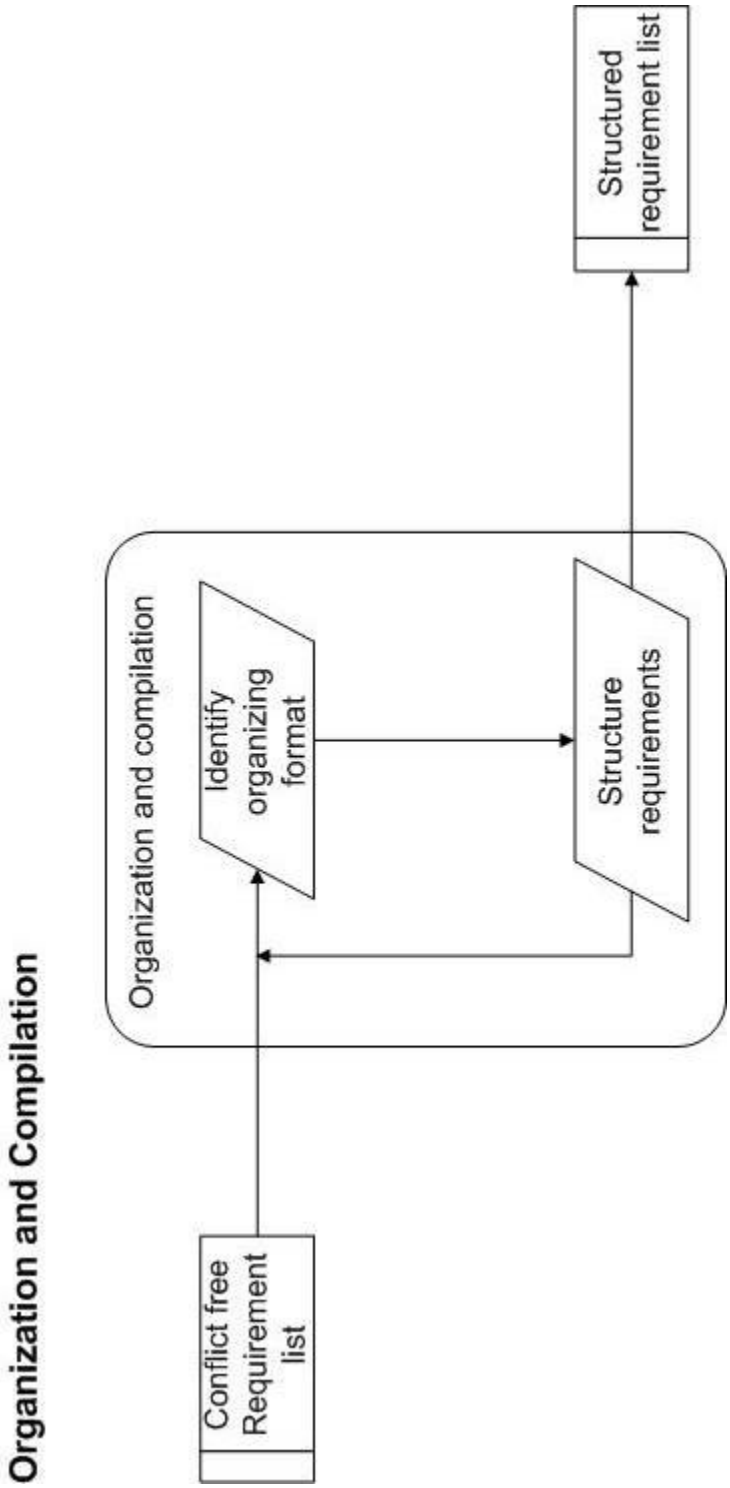
A.5 Template for requirements list organized by functional hierarchy

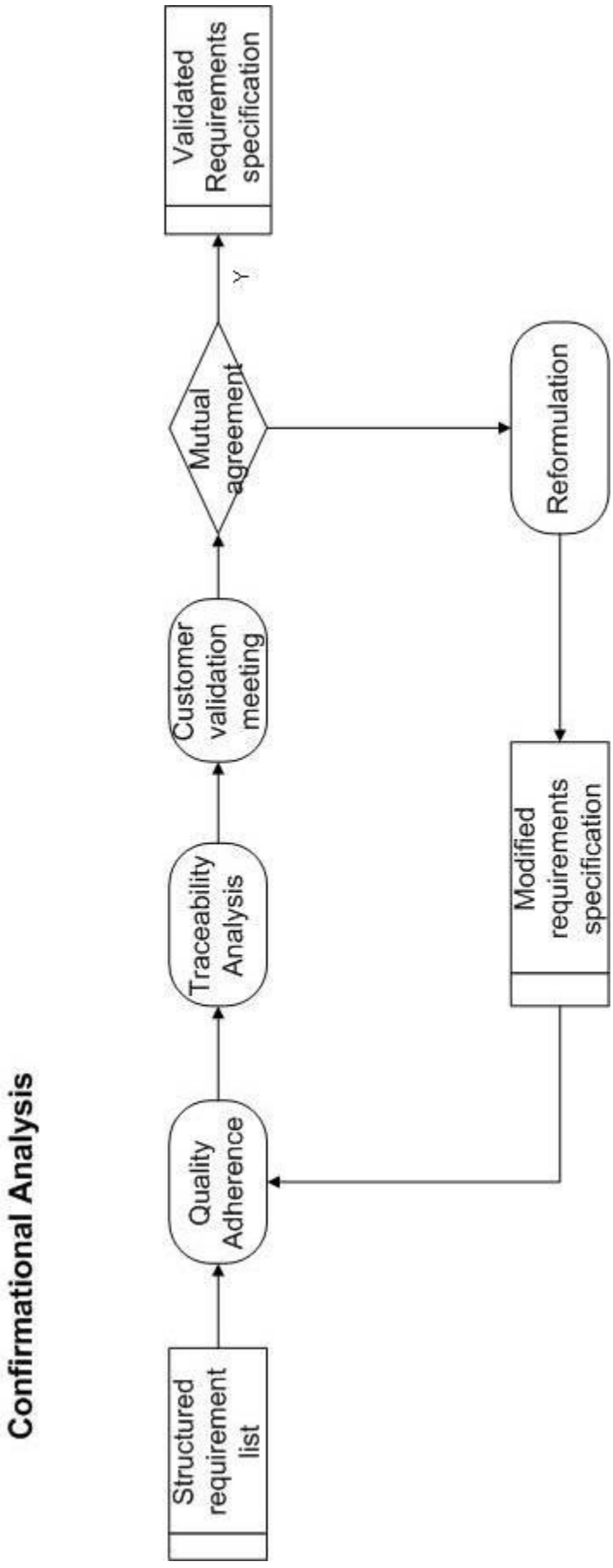
- Specific requirements
    - External interface requirements
        - User interfaces
        - Hardware interfaces
        - Software interfaces
        - Communication interfaces
- Functional requirements
    - Functionality 1
        - Functional requirement 1
        - .
        - .
        - Functional requirement n
        -
        -
        -
    - Functionality m
        - Functional requirement 1
        - .
        - .
        - Functional requirement n
- Performance requirements
- Design constraints
- Software system attributes
- Other requirements

Appendix B: The Expanded Requirements Generation Model (x-RGM)




GLOBAL ANALYSIS
Software Requirements List
Organizational factors
Technological factors
Risk analysis
Price / market analysis
Cost / schedule estimation
Feasibility analysis
Conflicting and conflict free requirement list
Conflict resolution
Identify issues
Identify options
Finalize agreements
Requirement updates
Y
Modified / updated Requirements
Conflict free Requirement list


Organization and Compilation
Conflict free Requirement list
Organization and compilation
Identify organizing format
Structure requirements
Structured requirement list


Confirmational Analysis
Structured requirement list
Quality Adherence
Traceability Analysis
Customer validation meeting
Mutual agreement
Y
Validated Requirements specification
Reformulation
Modified requirements specification

Appendix C: Description of Activities in x-RGM

Activity Name	**Customer / requirements engineer indoctrination**
Objective	Familiarizing the user to the RE process Educating the requirements engineer about the customer's domain Emphasis on the importance of the role of the participant
Action Points	• A brief introduction about RE, the importance of requirements, and what represent a requirement • An overview of the Requirements Generation Model • The importance of the role of participants in the RE process • The preparation involved when participants are requested to attend elicitation meetings • Introduction to the problem, user needs and problem domain
Pre-condition	Needs generation phase is completed
Doer	Requirements Engineer
Participants	Customer (other stakeholders are optional)
Resource/Input docs	Requirements engineering model and process principles, needs and domain information
Effect/Output docs	None

Activity Name	**Requirements elicitation meeting**
Objective	Identify and capture requirements from stakeholders
Action Points	• Identify primary stakeholders • Capture stakeholders requirements • Record the meeting proceedings • Identify system constraints
Pre-condition	Needs generation phase is completed
Doer	Requirements Engineer
Participant	Customer, user, developer
Input docs	Document, Market Survey document
Effect/Output docs	Unstructured list of requirements

Activity Name	**Rationalization & Justification**
Objective	Find rationale, justify, refine and decompose requirements
Action Points	• Identify classification of requirements • addressing the question "why" underlying the requirements • Identify requirements which are high level or unspecific • Justify the requirements • Refine and decompose the high level requirements
Pre-condition	Elicitation activity completed
Doer	Requirements Engineer
Participant	User, customer, developer
Resource/Input docs	Unstructured requirements, Domain Info, Organizational standards and regulations
Effect/Output docs	Non-prioritized requirement list

Activity Name	**Prioritization**
Objective	Rank requirements based on requirement attributes
Action Points	• Identify requirement attributes (risk factors, value to product, user urgency …..) • Estimate attribute values • Rank requirements based on stakeholder priorities.
Pre-condition	Rationalization and justification completed
Doer	Requirements Engineer
Participant	User, customer, developer
Resource/Input docs	Non-prioritized requirement list
Effect/Output docs	Prioritized requirement list

Activity Name	**Verifying quality attributes**
Objective	Check quality attributes of **local set** of requirements
Action Points	• Determine quality attributes to be examined • Arrange for QA experts • Verify and establish the adherence of quality attributes
Pre-condition	Prioritization completed
Doer	QA experts
Participants	Requirements engineer
Resource/Input docs	Prioritized requirement list
Effect/Output docs	Quality assessed requirements list

Activity Name	**Stakeholder validation**
Objective	Check if the individual requirements reflect the right product
Action Points	• Determine whether requirements capture stakeholders needs and intent • Record proceedings
Pre-condition	Verifying quality attributes completed and quality control satisfactory
Doer	Requirements Engineer
Participants	Customer, user, developer
Resource/Input docs	Quality assessed requirements list
Effect/Output docs	Software requirements list

Activity Name	**Risk analysis**
Objective	Determine the risk for requirements from the global perspective
Action Points	• Arrange for risk analysts • Assess risks for requirements from global outlook • Determine requirements which are controversial (high risk)
Pre-condition	Requirements capturing phase completed
Doer	Risk analyst
Participants	Requirements engineer (optional)
Resource/Input docs	Software requirements list, Organizational factors, Technological factors
Effect/Output docs	Risk assessment document

Activity Name	**Cost and schedule estimation**
Objective	Determine cost and time estimate for requirements
Action Points	• Perform cost analysis on individual functionality/components • Estimate time schedule for individual functionality /components • Determine if total cost and schedule meet customer's needs
Pre-condition	Requirements capturing phase completed
Doer	Requirements Engineer
Participant	Developers
Resource/Input docs	Software requirements list, Organizational factors, Technological factors
Effect/Output docs	Cost and schedule document

Activity Name	**Price analysis**
Objective	Examining and evaluating proposed price and demand (balance of functionality and desirability)
Action Points	• Assess market demand • Compare prices of similar products • Determine if price is reasonable
Pre-condition	Requirements capturing phase completed
Doer	Price analyst
Participants	Requirements Engineer, developer
Resource/Input docs	Software requirements list, Organizational factors, Technological factors, cost and schedule document (optional), market demand info.
Effect/Output docs	price analysis document

Activity Name	**Feasibility analysis**
Objective	Determine if product is feasible (Business/technology/cost)
Action Points	• Assess market demand • Determine if the product is profitable enough • Determine if risks are accounted for • Decide whether to continue with the software cycle
Pre-condition	Requirements capturing phase completed
Doer	Requirements Engineer
Participants	Developer, Manager
Resource/Input docs	Software requirements list, Organizational factors, Technological factors, market demand info., risk assessment document, price analysis document, cost and schedule document,
Effect/Output docs	feasibility analysis document (go/no-go decision), conflicting requirements list

Activity Name	**Conflict resolution**
Objective	Negotiate requirement conflicts
Action Points	• Identify stakeholder win conditions • Identify issues • Identify options • Finalize agreements
Pre-condition	Feasibility analysis completed
Doer	Requirements Engineer
Participants	customer, developer, user, manager
Resource/Input docs	Conflicting requirements l ist
Effect/Output docs	Conflict free requirements document/updated requirements list

Activity Name	**Organization and Compilation**
Objective	Structure requirements for better comprehension
Action Points	• Identify organization mode of requirements • Grouping of requirements according to the identified categorization • Document the requirements
Pre-condition	Analysis Phase completed
Doer	Requirements Engineer
Participants	-
Resource/Input docs	Conflict free requirements document
Effect/Output docs	Structured requirements list

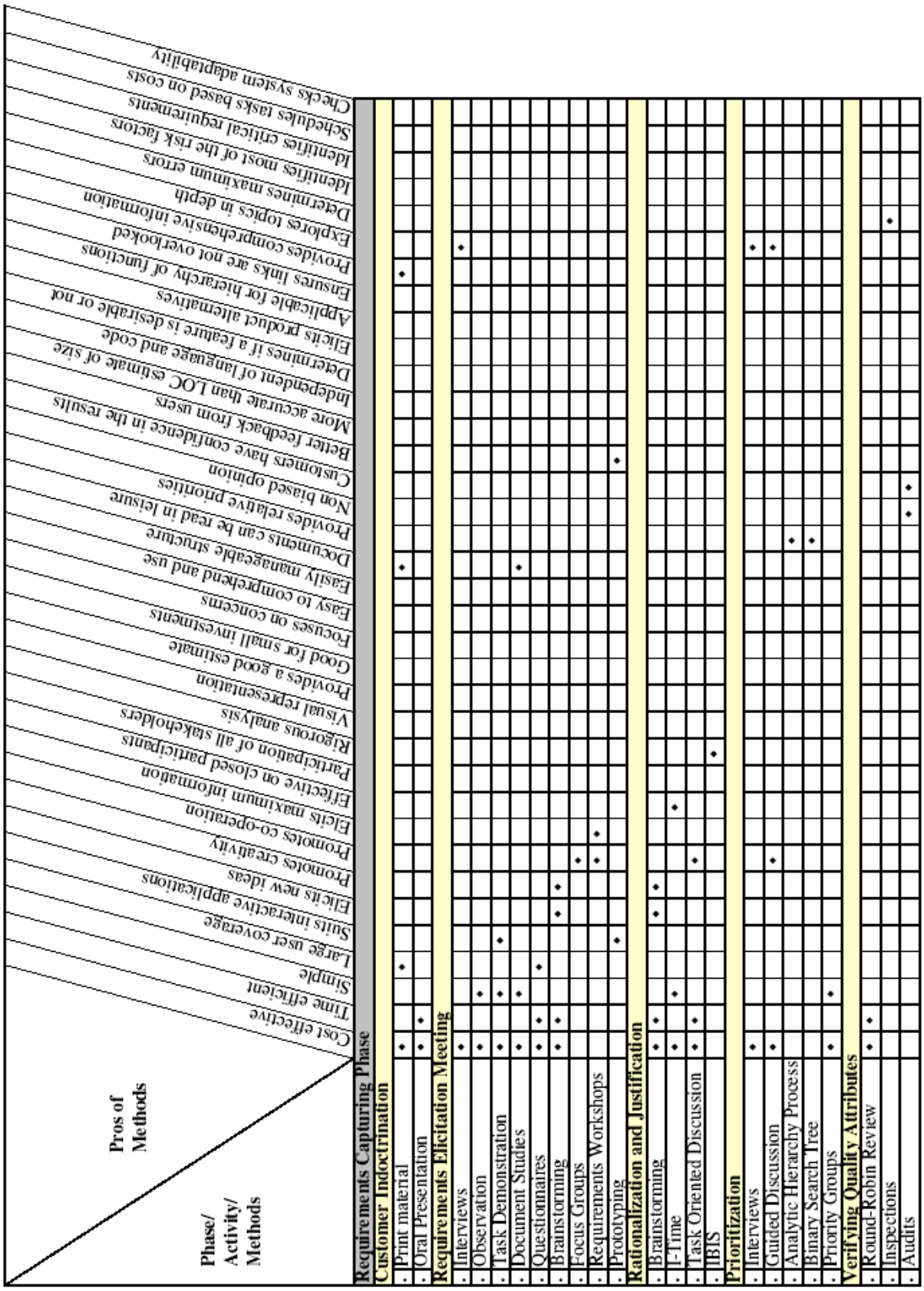
Activity Name	**Quality adherence**
Objective	Quality control for requirements from **global** perspective
Action Points	• Verify that quality control performed in local analysis phase • Determine quality attributes to be tested • Verify quality adherence of requirements
Pre-condition	Specification phase complete
Doer	QA experts
Participants	Requirements Engineer
Resource/Input docs	Structured requirements list
Effect/Output docs	Quality assessed requirements specification

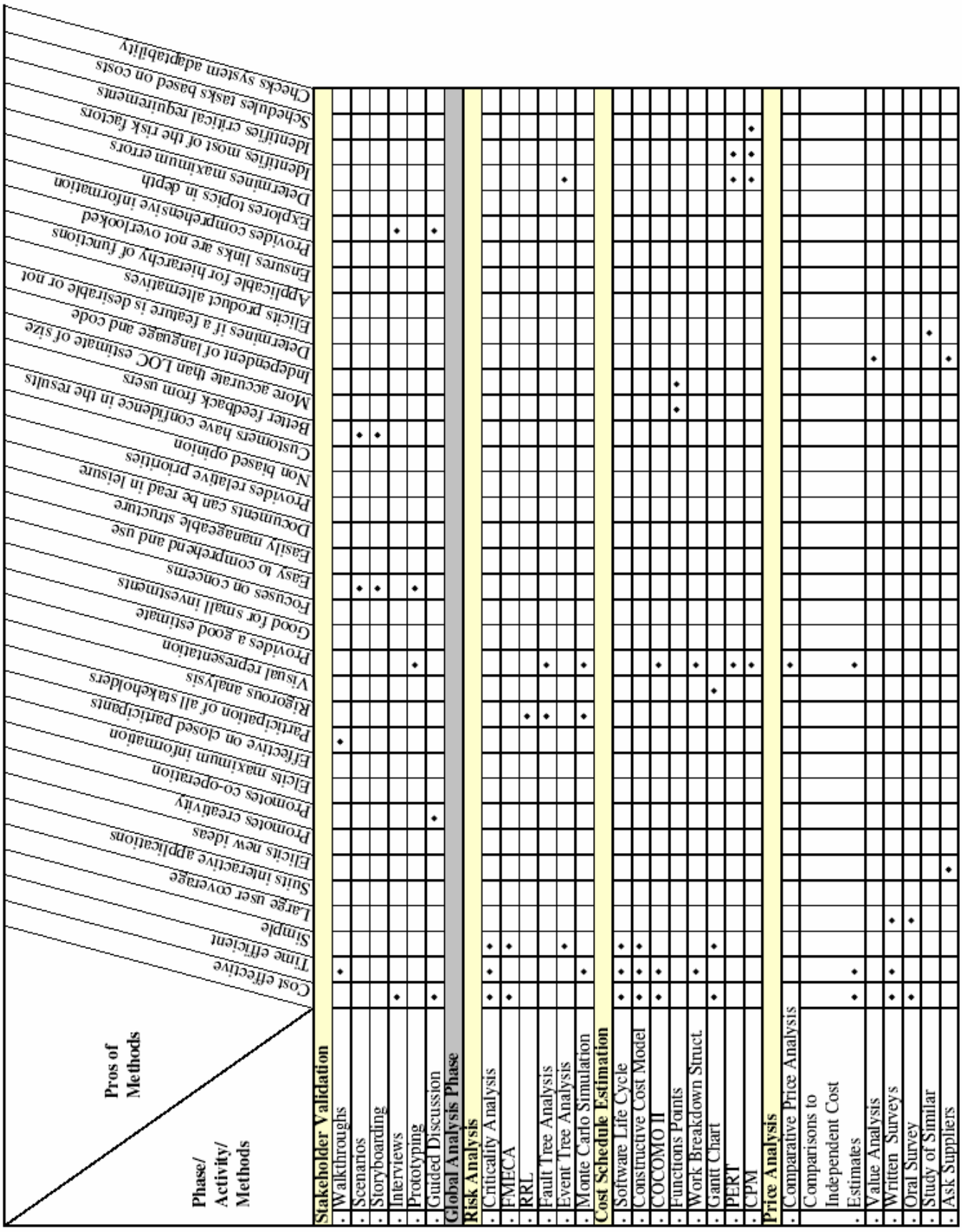
Activity Name	**Traceability analysis**
Objective	Linking requirements and verifying the matrix
Action Points	• Map the requirements to needs • Determine the dependency of requirements (resulting in a traceable diagram) • Verify the Traceability diagram
Pre-condition	Quality adherence activity completed
Doer	Requirements Engineer
Participants	-
Resource/Input docs	Software requirements list
Effect/Output docs	Traceability document/matrix, conflict free requirements list

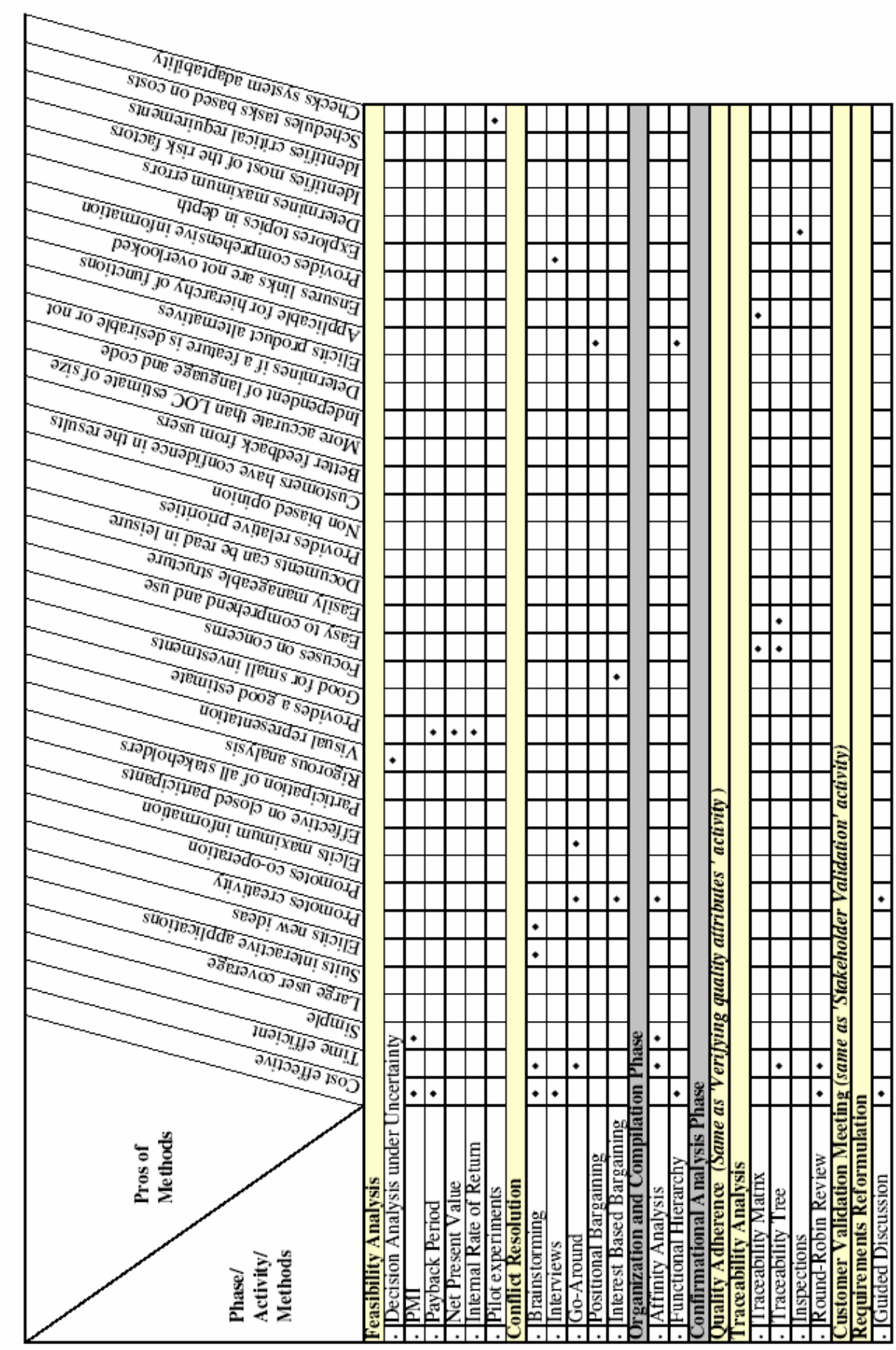
Activity Name	**Customer validation meeting**
Objective	Check if the requirements list captures customers needs right
Action Points	• Determine whether requirements capture customer intent • Determine requirements to be changed, if necessary
Pre-condition	Specification phase complete
Doer	RE engineer
Participants	Customer
Resource/Input docs	Quality assessed requirements specification
Effect/Output docs	validated requirements specification / list of modifications to requirements

Activity Name	**Reformulation**
Objective	Overcoming customer disagreement with requirements
Action Points	• Identify options • Finalize reformulation of requirements
Pre-condition	user validation complete and customer specifies certain modifications to the requirements
Doer	RE engineer
Participants	Customer, QA experts
Resource/Input docs	Customer disagreement with requirements specification
Effect/Output docs	modified requirements specification

Appendix D: Methods for Activities in the x-RGM




Phase/ Activity/ Methods
Pros of Methods
Cost effective
Time efficient
Simple
Large user coverage
Suits interactive applications
Elicits new ideas
Promotes creativity
Promotes co-operation
Elicits maximum information
Effective on closed participants
Participation of all stakeholders
Rigorous analysis
Visual representation
Provides a good estimate
Good for small investments
Focuses on concerns
Easy to comprehend and use
Easily manageable structure
Documents can be read in leisure
Provides relative priorities
Non biased opinion
Customers have confidence in the results
Better feedback from users
More accurate than LOC estimate of size
Independent of language and code
Determines if a feature is desirable or not
Elicits product alternatives
Applicable for hierarchy of functions
Ensures links are not overlooked
Provides comprehensive information
Explores topics in depth
Determines maximum errors
Identifies most of the risk factors
Identifies critical requirements
Schedules tasks based on costs
Checks system adaptability
Stakeholder Validation
. Walkthroughs
. Scenarios
. Storyboarding
. Interviews
. Prototyping
. Guided Discussion
Global Analysis Phase
Risk Analysis
. Criticality Analysis
. FMECA
. RRL
. Fault Tree Analysis
. Event Tree Analysis
. Monte Carlo Simulation
Cost Schedule Estimation
. Software Life Cycle
. Constructive Cost Model
. COCOMO II
. Functions Points
. Work Breakdown Struct.
. Gantt Chart
. PERT
. CPM
Price Analysis
. Comparative Price Analysis
. Comparisons to Independent Cost Estimates
. Value Analysis
. Written Surveys
. Oral Survey
. Study of Similar
. Ask Suppliers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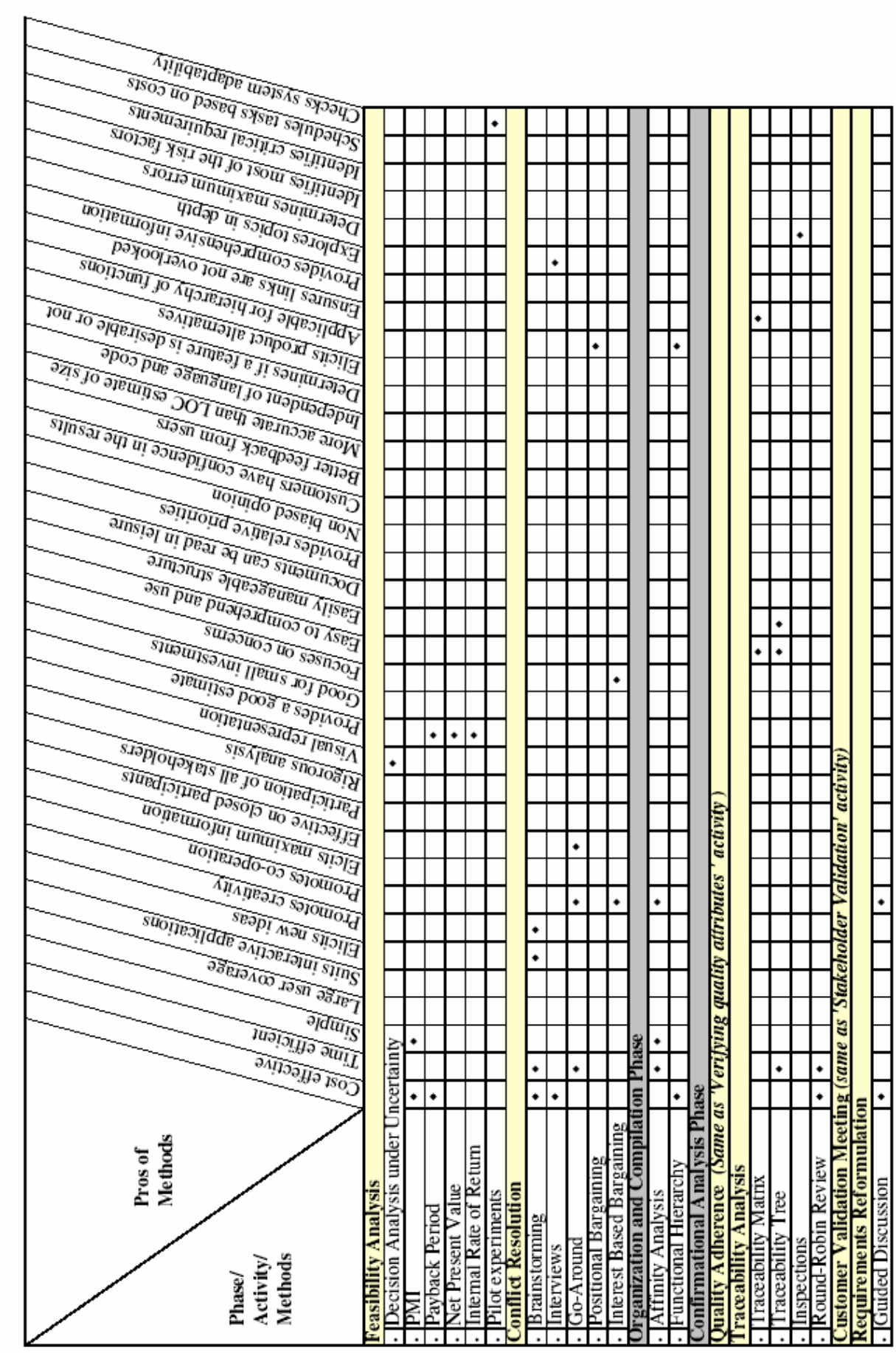
Identifies most of the risk factors
Identifies critical requirements
Schedules tasks based on costs
Checks system adaptability
Feasibility Analysis
· Decision Analysis under Uncertainty
· PMI
· Payback Period
· Net Present Value
· Internal Rate of Return
· Pilot experiments
Conflict Resolution
· Brainstorming
· Interviews
· Go-Around
· Positional Bargaining
· Interest Based Bargaining
Organization and Compilation Phase
· Affinity Analysis
· Functional Hierarchy
Confirmational Analysis Phase
Quality Adherence (Same as 'Verifying quality attributes' activity)
Traceability Analysis
· Traceability Matrix
· Traceability Tree
· Inspections
· Round-Robin Review
Customer Validation Meeting (same as 'Stakeholder Validation' activity)
Requirements Reformulation
· Guided Discussion


Phase/ Activity/ Methods
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Promotes creativity
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· PMI
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· Net Present Value
· Internal Rate of Return
· Pilot experiments
Conflict Resolution
· Brainstorming
· Interviews
· Go-Around
· Positional Bargaining
· Interest Based Bargaining
Organization and Compilation Phase
· Affinity Analysis
· Functional Hierarchy
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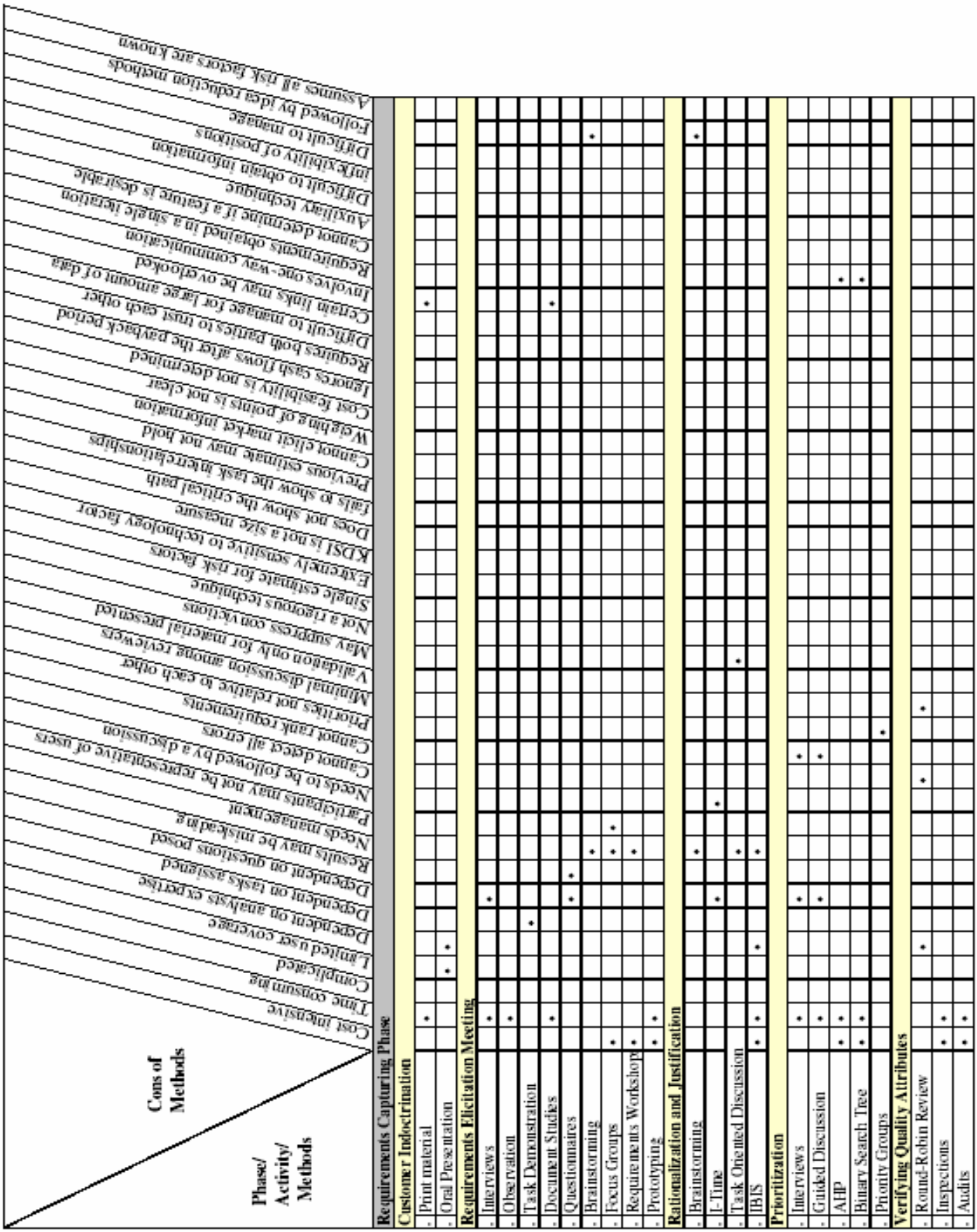
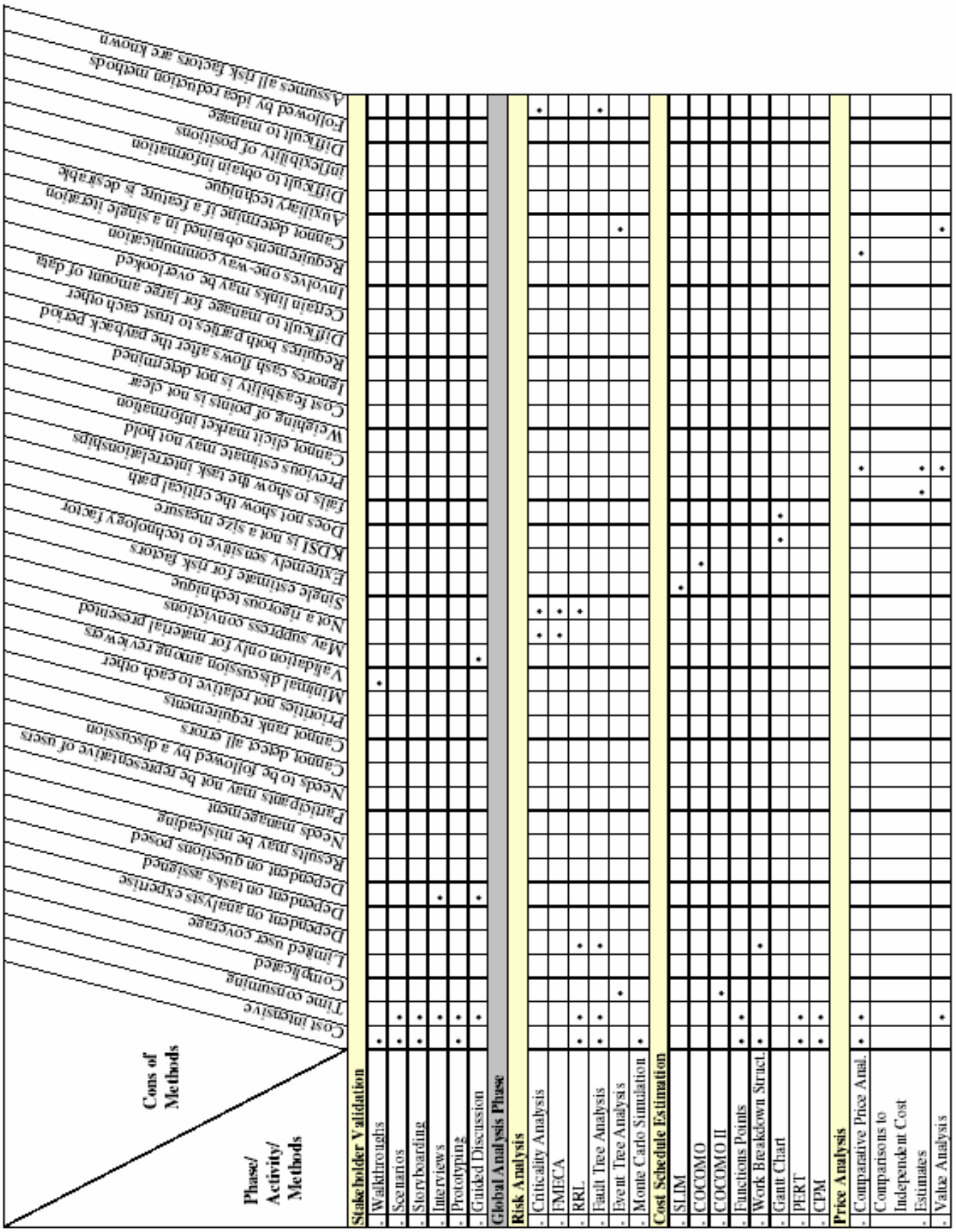
Quality Adherence (Same as 'Verifying quality attributes' activity)
Traceability Analysis
· Traceability Matrix
· Traceability Tree
· Inspections
· Round-Robin Review
Customer Validation Meeting (same as 'Stakeholder Validation' activity)
Requirements Reformulation
· Guided Discussion


Phase/ Activity/ Methods
Cons of Methods
Cost intensive
Time consuming
Complicated
Limited user coverage
Dependent on analysts expertise
Dependent on tasks assigned
Dependent on questions posed
Results may be misread
Needs management support
Participants may not be representative of users
Needs to be followed by a discussion
Cannot detect all errors
Cannot rank requirements
Priorities not relative to each other
Minimal discussion among reviewers
Validation only for material presented
May suppress controversial issues
Not a rigorous technique
Stable estimate for risk factors
Extremely sensitive to technology factor
KDSI is not a size measure
Does not show the critical path
Fails to show the task interrelationships
Previous estimate may not hold
Cannot elicit market information
Weighing of points is not clear
Ignores cash flows after the payback period
Requires both parties to trust each other
Difficult to manage for large amount of data
Certain links may be overlooked
Involves one-way communication
Requires objects obtained in a subtle iteration
Cannot determine if a feature is desirable
Auxiliary technique
Difficult to obtain information
Inflexibility of positions
Difficult to manage
Followed by idea reduction methods
Assumes all risk factors are known
Requirements Capturing Phase
Customer Indoctrination
- Print material
- Oral Presentation
Requirements Elicitation Meeting
- Interviews
- Observation
- Task Demonstration
- Document Studies
- Questionnaires
- Brainstorming
- Focus Groups
- Requirements Workshop
- Prototyping
Rationalization and Justification
- Brainstorming
- I-Time
- Task Oriented Discussion
- IBIS
Prioritization
- Interviews
- Guided Discussion
- AHP
- Binary Search Tree
- Priority Groups
Verifying Quality Attributes
- Round-Robin Review
- Inspections
- Audits


Phase/ Activity/ Methods
Cons of Methods
Cost intensive
Time consuming
Complicated
Limited user coverage
Depends on analysis expertise
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Results may be misleading
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Fails to show the critical path
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Cost feasibility is not determined
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Difficult to manage for large amount of data
Certain links may be overlooked
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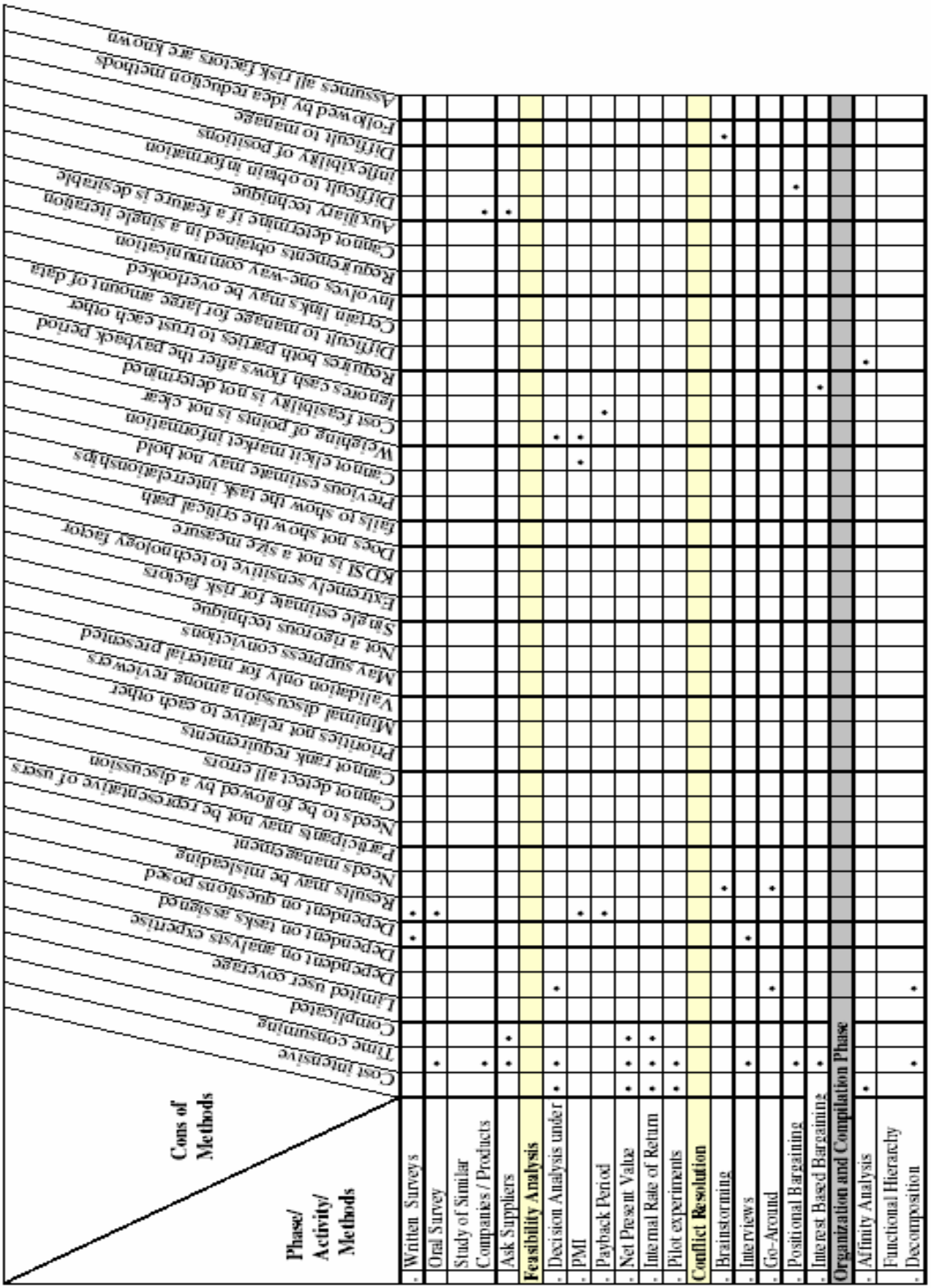
Requirements obtained in a single ingration
Cannot decompose if a feature is desirable
Auxiliary technique
Difficult to obtain information
Inflexibility of positions
Difficult to manage
Followed by idea reduction methods
Assumes all risk factors are known
Stakeholder Validation
- Walkthroughs
- Scenarios
- Storyboarding
- Interviews
- Prototyping
- Guided Discussion
Global Analysis Phase
Risk Analysis
- Criticality Analysis
- FMECA
- RRL
- Fault Tree Analysis
- Event Tree Analysis
- Monte Carlo Simulation
Cost Schedule Estimation
- SLIM
- COCOMO
- COCOMO II
- Functions Points
- Work Breakdown Struct.
- Gantt Chart
- PERT
- CPM
Price Analysis
- Comparative Price Anal.
- Comparisons to Independent Cost Estimates
- Value Analysis


Phase/ Activity/ Methods
Cons of Methods
Written Surveys
Oral Survey
Study of Similar Companies / Products
Ask Suppliers
Feasibility Analysis
Decision Analysis under
PMI
Payback Period
Net Present Value
Internal Rate of Return
Pilot experiments
Conflict Resolution
Brainstorming
Interviews
Co-Around
Positional Bargaining
Interest Based Bargaining
Organization and Compilation Phase
Affinity Analysis
Functional Hierarchy Decomposition
Cost intensive
Time consuming
Complicated
Limited user coverage
Dependent on analysts expertise
Dependent on tasks assigned
Results may be misleading
Needs manage ment
Participants may not be representative of users
Needs to be followed by a discussion
Can ot detect all errors
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Priorities not relative to each other
Minimal discussion among reviewers
Validation only for material presented
May suppress conviction s
Not a rigorous technique
Sh ple estimate for risk factors
Extremely sensitive to tech nology factor
KD SI is not a size measure
Does not show the critical path
fails to show the task interrelationships
Previous estimate may not hold
Can ot elicit market information
Weighing of points is not clear
Cost feasibility is not determined
Ignores cash flows after the payback period
Requires both parties to trust each other
Difficult to manage for large amount of data
Certain links may be overlooked
Involves one-way communication
Requirements obtained in a single iteration
Can ot determine if a feature is desirable
Auxiliary technique
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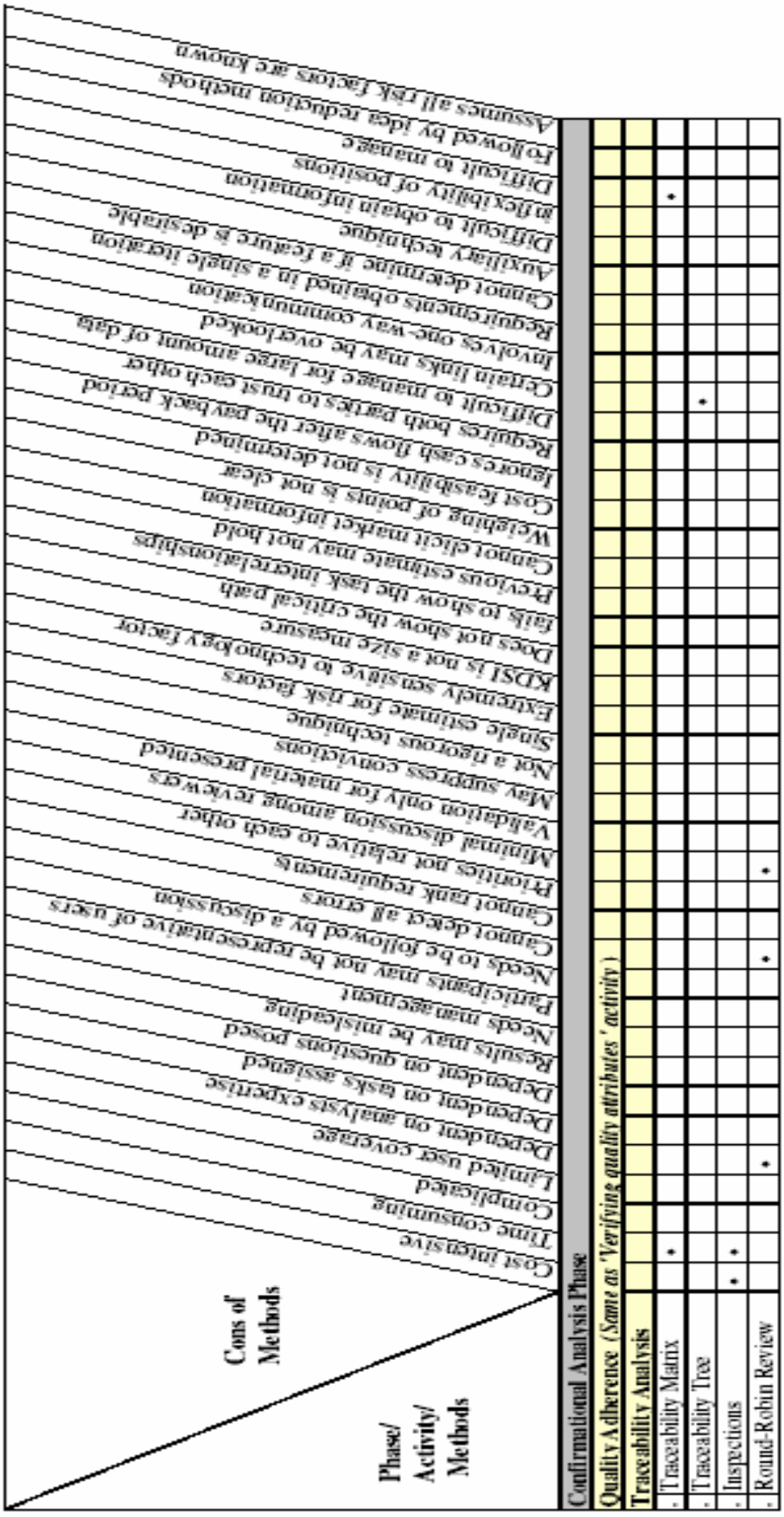
Inflexibility of positions
Difficult to manage
Followed by idea reduction methods
Assumes all risk factors are known


Phase/
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Cons of
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